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**Collaborative CoRe Design for Year 10 Electricity and
Magnetism: Professional Development for Enhancing
Practising Science Teachers' PCK**

A thesis

submitted in fulfilment

of the requirements for the degree

of

Doctor of Philosophy

at

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by

Jared Alan Carpendale



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Abstract

This study investigated the effectiveness of collaborative content representation (CoRe) design as a professional learning and development (PLD) intervention for enhancing practising science teachers' pedagogical content knowledge (PCK) for teaching Year 10 (14-15-year olds) *Electricity and Magnetism* in New Zealand. There were three case study teachers in this study, each of whom were practising science teachers with a limited physics background. These teachers collaborated with six other experienced science teachers; three of whom also had a limited physics background, while the others were physics specialist teachers. All nine teachers were from the same school.

PCK is a highly specific form of professional knowledge that teachers have, which enables them to teach particular content to a particular group of students. Since its inception, many approaches have been suggested for exploring science teachers' PCK, but the exact nature of PCK and how to measure it has been problematic. To address these issues, two international PCK Summits have been held to advance the agenda of PCK research. The first Summit was in 2012, where a key output was a Consensus Model of PCK. The second Summit was in 2016, where researchers critiqued the use of that model, and discussed future PCK research. Outcomes of the second Summit are being published in the book *Repositioning PCK in Teachers' Professional Knowledge* (due out in late 2018). This book introduces the Refined Consensus Model of PCK (RCM of PCK), which was used as conceptual framework to guide this study.

Data was collected in three phases. In Phase One, case study teachers were interviewed about teaching Year 10 *Electricity and Magnetism* and then observed teaching this topic. Phase Two involved all participants in two CoRe design workshops, where they shared and debated ideas, and discussed pedagogical considerations with respect to teaching different concepts. The first workshop was a pilot exercise, while the second focused on Year 10 *Electricity and Magnetism*. All discussions were recorded and field notes were taken in workshops. In Phase Three, case study teachers were observed teaching the same topic to a different Year 10 class, then interviewed about changes to their practice. All participants were also asked about their overall experiences with collaborative CoRe design.

Findings show collaborative CoRe design enhanced the case study teachers' PCK for Year 10 *Electricity and Magnetism*. Development was seen in their subject matter knowledge, knowledge of instructional strategies, and knowledge of students' understanding and learning. Furthermore, all participants saw value in CoRe design as it allows topics to be unpacked and teacher's PCK to be shared. The teachers felt it was a worthwhile PLD intervention, they were interested in taking part in CoRe design in the future, and they offered suggestions to make it sustainable within their school.

Thus, this study showed collaborative CoRe design is a worthwhile and effective PLD intervention for practising teachers. Not only did teachers explicitly identify their own PCK developments, enhancements were also seen in lesson observations. Schools could adopt this model of PLD to encourage collaboration amongst their staff and to allow for knowledge transfers between teachers with differing content backgrounds and pedagogical strengths.

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My parents, Ian and Jann, have always encouraged me to do great things, and have been very supportive of my entire university journey. While they may not have fully understood what my PhD was about, they were always very supportive and urged

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My sincerest thank you,

A handwritten signature in black ink, appearing to read 'J. Carpendale', written in a cursive style.

Jared Carpendale

Presentations and Publications from this Thesis

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Acronyms

Acronyms that are frequently used in this thesis:

CoRe – Content Representation

cPCK – Collective Pedagogical Content Knowledge

ePCK – Enacted Pedagogical Content Knowledge

ERO – Education Review Office

NCEA – National Certificate of Educational Achievement

NRC – National Research Council

NZC – New Zealand Curriculum

NZQA – New Zealand Qualification Authority

OECD – Organisation for Economic Co-operation and Development

PaP-eRs – Professional and Pedagogical Experience Repertoires

PCK – Pedagogical Content Knowledge

PCK&S – Pedagogical Content Knowledge and Skills

PhET – Physics Education Technology

PLD – Professional Learning and Development

pPCK – Personal Pedagogical Content Knowledge

RCM of PCK – Refined Consensus Model of Pedagogical Content Knowledge

SLO – Specific Learning Outcome

TPK&S – Teacher Professional Knowledge and Skills

TPKB – Teacher Professional Knowledge Bases

TSPK – Topic Specific Professional Knowledge

Chapter One

Introduction

1.1 Overview

This chapter presents information about the background and the rationale for this doctoral thesis. Section 1.2 offers a brief outline of my background and interest in science and physics education at a secondary school level in New Zealand. Section 1.3 details key contextual information about physics education in New Zealand and the participants involved. Section 1.4 discusses the rationale behind the study, and Section 1.5 explains why it is significant. Section 1.6 details the research objectives and questions, which guided this investigation. Lastly, there is a guiding overview to the structure of this thesis.

1.2 Researcher's Background

1.2.1 Developments as a Teacher and Researcher

As a student, I was always interested in science, particularly chemical and physical phenomena. This interest directed me to begin a Bachelor of Science, with a chemistry and physics focus. I also started a Bachelor of Teaching at the same time with the goal of becoming a secondary school teacher. After four years of study, I graduated with my two degrees ready for the next challenge.

While becoming a teacher was my goal, and I was now qualified for this role, I still wanted to continue my education at university as I felt there was so much more to learn about science education. With this hunger for more knowledge, I enrolled in a Postgraduate Diploma of Education majoring in science education. I completed assignments about different aspects of science education, such as its purpose and educational research paradigms that are employed when carrying out research. The knowledge I gained provided a strong foundation in science education and allowed me to move forward towards my first research project, which was investigating the experiences of Saudi Arabian students as they studied bridging science courses to prepare them for university-level study in New Zealand.

After completing my Postgraduate Diploma, I began my Master of Education research degree. There were two areas that I was interested in and wanted to research further: the nature of science and informal learning environments. Teaching students about the nature of science aims to develop their understanding

about scientific knowledge, and how it is generated, for example, scientific knowledge construction and its tentative nature, and how scientists work and develop theories. This type of learning is driven by the need for students to become scientifically literate citizens in society. Informal learning environments, such as museums, zoos, and interactive science centres, advocate for alternative settings for students to develop their scientific knowledge, rather than a formal classroom environment where most science education is centred. Thus, I was excited when approached to undertake sponsored research to investigate how students may learn about the nature of science at a local interactive science centre. I completed this project part-time as I was teaching full-time at a local secondary school. I concluded that aspects of the nature of science were not always apparent within interactive science exhibits, but with careful preparation around visits and effective questioning techniques, students could enhance their nature of science knowledge. I successfully submitted my thesis and I had now completed my Master of Education degree with Honours (see Carpendale, 2012).

I took a break from study to focus on my career as a teacher and was promoted to into a middle management position where my key role was to mentor students. I then changed to a different role where I oversaw the delivery of the senior curriculum, and ensured students were placed in appropriate courses. During this break from study, I also developed my pedagogy and skills as a science, physics, and chemistry teacher.

However, as a senior physics teacher, I often became confused and then frustrated when students had misunderstandings around physical concepts that, in my view, should be covered and mastered during junior science courses. It appeared that some of this issue could be attributed to whomever their previous science teacher was. For instance, it seemed that if their science teacher did not have a well-development conceptual framework around some of these concepts and did not utilise appropriate teaching strategies, students misunderstood key concepts. It appeared fitting then, that research to develop an understanding of a teachers' pedagogical content knowledge (PCK) for teaching physics concepts in junior science, and how this PCK could be enhanced, would be useful. It was this idea that developed into my Doctor of Philosophy degree, which I enrolled in while also teaching full-time.

1.2.2 Reflecting on My Professional Learning

In New Zealand, teachers are required to be registered with the Education Council of New Zealand. This council requires teachers to be ‘provisionally registered’ for their first two years of service and teachers must take part in an in-house mentoring programme before attaining full registration (Education Council, 2017a). During this phase of my career I met regularly with mentor teachers from my school. These meetings were invaluable for me and I developed my professional knowledge for teaching greatly. My mentor teacher for physics would sit with me weekly while we explored upcoming topics and concepts. He used his expertise and experience to highlight important parts of the curriculum, concepts that students find difficult, misconceptions that students have, how to best approach these concepts, practical experiments and demonstrations that lead to better conceptual understanding, how to ensure the students would be adequately prepared for the following years if they took physics, and then how these concepts would be assessed. I was routinely asked difficult questions and I had to ponder the answers and explain my thinking. It was by exploring these questions and sharing ideas that my professional knowledge improved. This type of collaboration between experienced and inexperienced teachers reminded me of my initial teacher training, and it made me think about how these types of knowledge exchanges that I experienced could be developed into an effective professional learning and development (PLD) intervention to promote professional learning within a school.

These meetings reminded me of being involved in content representation (CoRe) design as a pre-service teacher, which later grew into valuable educational research (e.g., Hume, 2010; Hume & Berry, 2011). However, reflecting on this experience, I remember the challenging endeavour of trying to use our inexperienced minds to decide which concepts to teach and how to teach them. In their research, Hume and Berry (2011) and Donnelly and Hume (2015) also noted that their pre-service participants’ experienced this same challenge, highlighting the importance of considering experienced teachers’ input. As pre-service teachers, we sought experienced teacher input by consulting our mentor teachers when completing teaching placements. This entire CoRe design experience showed me, and instilled in me, a crucial aspect of becoming a teacher – the need for collaboration between those that may need development and those who are experienced.

In preparation for my doctoral study, I was reflecting on these two career changing experiences – being mentored by an experienced teacher, and being involved in CoRe design. This collaboration with senior teachers while I was still developing as a teacher, combined with my personal experiences with CoRe design, developed into this study – investigating the use of collaborative CoRe design for Year 10 *Electricity and Magnetism* as a professional development intervention for enhancing practising science teacher’s PCK.

1.3 Context of this Study

1.3.1 Physics Education in New Zealand

In New Zealand, students are required to be enrolled at school between the ages six and 16 (Ministry of Education, 2017). Students start their schooling in Year 1 and begin secondary school in Year 9, continuing until the end of secondary school in Year 13. (Students who leave when they are 16 would normally have finished Year 11.) This study focused on Year 10 students, who were students in their second year of secondary school, aged 14 or 15.

For the first 10 years of schooling (i.e., Year 1 to Year 10), what students learn about is governed by the New Zealand Curriculum (NZC) document (Ministry of Education, 2007), which serves as a policy to guide teachers and schools. This document identifies eight learning areas, which are: English; the arts; health and physical education; learning languages; mathematics and statistics; science; social sciences; and, technology. Up to, and including Year 10, schools are required to effectively teach all learning areas except for learning languages (Ministry of Education, 2007). As well as these eight learning areas, the NZC also identifies eight Curriculum Levels where students may be achieving. For example, when students first start school most are working towards achievement at Level 1 of the NZC, while Year 13 students work towards achievement at Level 8. Figure 1.1 shows the relationship between year levels and Curriculum Levels.

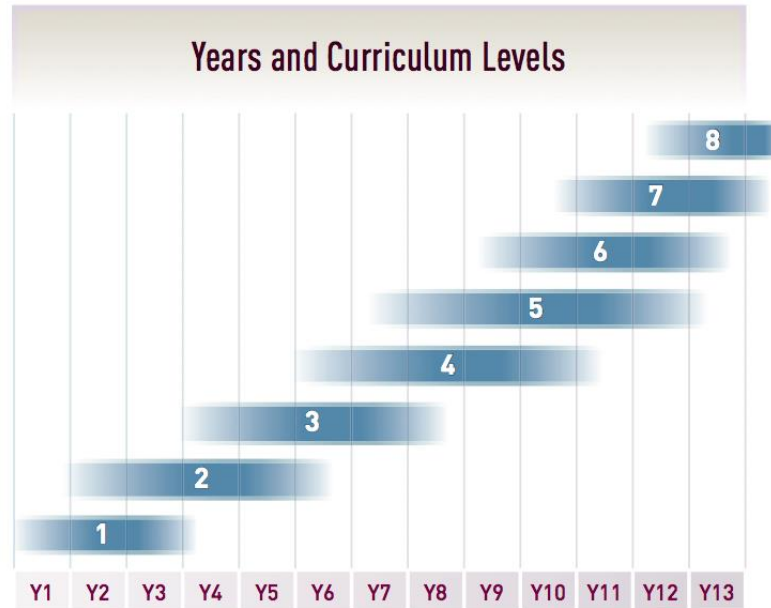


Figure 1.1: Relationship between the curriculum levels and years of schooling as indicated by the NZC document. Note that Year 10 students should be working at Level 5 (Reprinted with permission, Creative Commons [CC BY 3.0 NZ], Ministry of Education, 2014b).

As a subject, physics is located within the science learning area of the NZC, and is referred to as the Physical World (along with biology, the Living World; Earth sciences, Planet Earth and Beyond; and chemistry, the Material World) (Ministry of Education, 2007). Each of these four sub-learning areas or strands have associated Achievement Aims that are overarching across all eight Curriculum Levels and the expectation is that all should be covered throughout the course of the students' schooling. For physics, there are three Achievement Aims, which are:

Physical inquiry and physics concepts

Students will explore and investigate physical phenomena in everyday situations.

Physical concepts

Students will gain an understanding of the interactions that take place between different parts of the Physical World and the ways in which these interactions can be represented.

Using physics

Students will apply their understanding of physics to various applications.

(Ministry of Education, 2014b)

These Achievement Aims are made more specific at each Curriculum Level, in the form of Achievement Objectives. As identified earlier, the focus of this study is at Level 5 of the NZC. At this Curriculum Level, there are two Achievement Objectives for physics, which are:

Physical World

Students will:

Physical inquiry and physics concepts

Identify and describe the patterns associated with physical phenomena found in simple everyday situations involving movement, forces, electricity and magnetism, light, sound, waves, and heat. For example, identify and describe energy changes and conservation of energy, simple electrical circuits, and the effect of contact and non-contact on the motion of objects.

Using physics

Explore a technological or biological application of physics.

(Ministry of Education, 2014b)

The NZC also specifies that students should learn about the nature of science as an “overarching unifying strand” (Ministry of Education, 2007, p. 28), while using the

other strands as contexts for learning. Like the contextual strands, the nature of science strand has Achievement Aims and Achievement Objectives, relevant to different Curriculum Levels. Further information about the nature of science in the NZC is discussed in Chapter Two, Section 2.2.4.

While the NZC covers education through Years 1-13, schools are only required to ensure they are effectively covering the Achievement Objectives until Year 10 (Ministry of Education, 2007). However, in Years 11-13, while the taught curricula should also be derived from the NZC in the first instance, high stakes assessments such as the national qualification actually influence key decisions about what to teach (Hume & Coll, 2010). The National Certificate of Educational Achievement (NCEA) is the primary qualification in New Zealand national qualification, and it is governed by the New Zealand Qualifications Authority (NZQA) (NZQA, 2014b). At these levels of schooling, science may also become an optional subject area for students, although many schools do make it a compulsory subject (NZQA, 2014a).

1.3.2 Participants

This study centred on practising science teachers in a New Zealand secondary school who do not have a physics background but were teaching physics concepts as part of a junior science programme. Teachers in New Zealand are required to have completed a university qualification in education, however, a specific subject degree is not mentioned as a requirement (Education Council, 2017b). For example, it could be expected that to teach physics a Bachelor of Science degree with a component of physics and a teaching qualification would be required; however, this requirement is not mandatory. This non-requirement can lead to a problem in some schools with teachers instructing in a subject area that they are not be entirely familiar with or may be limited in. This issue is of particular significance for science, technology, engineering, and mathematics (STEM) education, where Toulmin and Groome (2007) report that a large number of teachers in America teach outside of their particular field of expertise due to there not being enough STEM teachers. Such an example was the focus of this study. It could be argued that these teachers have PCK in physics education that needs developing to ensure students are offered opportunities that allow them to construct scientifically

accurate conceptual frameworks in basic physics. A similar issue was identified in a study by Naano, Hume, and Coll (2012) who investigated the practice and effectiveness of science teachers with limited content and pedagogy knowledge in developing countries. Naano et al. (2012) documented that this lack of expertise affected the way the teachers taught, and the style of instruction was rather teacher directed – students became passive learners rather than engaging in the lesson. Naano et al. (2012) express the need for PCK enhancement of such teachers to ensure that students acquire more complex, higher level cognitive skills and concepts.

1.4 Rationale for this Study

The initial idea behind this study was driven by my frustration and confusion when teaching senior physics at secondary school. Many students appeared to have misunderstandings around certain physical phenomena that I did not anticipate, since they were part of the junior science curriculum at our school (e.g., symbols, circuit diagrams, basic understandings of what was meant by current, resistance and voltage, and series and parallel circuits). While it may be seen that it is the role of a teacher to help students learn and understand what they have missed or not mastered previously, it is an issue from a pragmatic and logistical point of view. As a teacher, I feel under pressure to cover all the required concepts within a school year, which is made more challenging by the added pressures from senior management to constantly improve grades in qualifications. These tensions present a dilemma for me as a teacher, as well as many of my colleagues – do we focus on ensuring students re-develop concepts, so they are more closely aligned to scientific understandings, or focus on higher-order concepts to promote higher grades, which may leave some students unsure about some concepts?

Research has shown that there is an important link between quality teaching, such as appropriate use of strategies in a context and teacher clarity, and student achievement (Hattie, 2012). For example, in a report commissioned by the Ministry of Education in New Zealand about investigating ways to improve education outcomes, Alton-Lee (2003) highlighted the relationship that exists between quality teachers and student achievement. The report points out that there are common

aspects of quality teaching across various curricula, but to be effective these aspects often need to be combined with curriculum-specific pedagogy, citing the example that quality teaching for languages is different to that for mathematics. The emphasis that Alton-Lee (2003) placed on the role of pedagogical and subject-specific pedagogical knowledge of teachers in quality teaching is consistent with the work done by Shulman (1986, 1987) on PCK.

PCK is one of the seven categories of professional knowledge that Shulman (1986, 1987) conceptualised as being important when studying and critiquing teacher knowledge. He defined it as being “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). Teachers who have a rich and developed PCK will have sufficient content knowledge, effective pedagogy, and awareness and understanding of how preconceptions and misconceptions may affect student learning (Shulman, 1986). He suggested that PCK is the key difference between skilled and experienced specialists teaching a particular topic and others who may have little experience with teaching that topic. Further discussion about PCK can be found in Chapter Two, Section 2.4.

There is a shortage of specialist physics teachers world-wide, which results in teachers having to teach out-of-field (Hobbs, 2012). In New Zealand, this problem of insufficient physics teachers was highlighted in a 2016 online news article, where schools were reported to utilise either retired or untrained teachers in physics (Shuttleworth, 2016). As this shortage of specialist teachers is an ongoing issue, a survey was conducted in 2017 by the Post-Primary Teachers’ Association, which showed that the gap of specialist teachers for science and mathematics in New Zealand is worsening. Principals stated that science and mathematics teachers are often the hardest to appoint. The result of this shortage is that schools are forced to drop courses outright, or transfer them to outside providers (Dooney, 2017).

As there is a shortage of specialist teachers, it is likely that those specialist teachers who are available may have more senior classes than junior science classes. Thus, some teachers who are teaching junior science may not have a strong physics background, meaning they have an underdeveloped PCK for physics topics. Since strong PCK is important for teaching difficult concepts, it follows that such teachers’ PCK in various physics topics needs further development.

Two studies by Hume and Berry (2013) and Hume, Eames, Williams, and Lockley (2013) explored the effectiveness of using CoRe design process to enhance topic-specific PCK for teachers in a New Zealand context. The Hume and Berry (2013) study focused on pre-service teachers as they developed foundational PCK throughout their teacher training, first by involvement in the CoRe design process and then developing and, using their own CoRes to inform their practicum teaching. The other study (Hume et al., 2013), focused on early career teachers who were in their second year of teaching. These teachers were invited to take part in professional learning sessions with content and pedagogical experts outside of their schools to create CoRes for PCK development.

Both studies showed that collaboration between novice teachers and experts can be useful in helping to develop early career teachers' and pre-service teachers' PCK for particular topics. However, while these studies showed that the CoRe design process was effective at helping these novice teachers to enhance their PCK, the logistics and time involved could sometimes make the process somewhat difficult to implement. For example, involving a variety of people (who were not in the same location) and organising external workshops could be an unrealistic and time consuming professional development avenue for schools to try and replicate to help teachers enhance their PCK. This limitation was also apparent in the study by Bertram and Loughran (2012) who investigated six practising teachers' views on CoRe design, who were from different schools. These authors concluded that teachers valued the CoRe design process and saw it as a worthwhile activity, but felt too much time needed to be invested into the process.

The study presented in this thesis is unique from other CoRe design studies in that it focused on using collaborative CoRe design as a professional development intervention within one school with a group of practising science teachers. It investigated the collaboration between experienced physics teachers and teachers with little background knowledge in physics who are teaching in the same school, rather than inviting other people from outside of the school structure to take part. This approach will draw on the existing knowledge and pedagogical expertise from teachers within the school for the collaborative exercise of CoRe design.

1.5 Significance of this Study

The New Zealand government highlights the importance of science education for its future growth. For example, in their Statement of Intent 2013-2018, the Ministry of Education emphasise the need for developing science education (Ministry of Education, 2013). This document references the importance of science education several times, for example referring to science as a high value area that is required for servicing the demand for skilled engineers. It also points out that to achieve this intent there would need to be investment from the government into fostering student interest in science, by not only educating individuals but also supporting research to develop innovative practice.

However, recent statistical information from international surveys comparing students' achievements across different countries show that New Zealand students are falling behind those of other countries in their understanding of science. As physics is a significant component of science it could be implied that this trend may also be applicable to physics, which supports my concerns about our students' learning. The Programme of International Student Assessment (PISA) is a large scale international survey that is run by the Organisation for Economic Cooperation and Development (OECD) every three years. It focuses on the level of understanding for reading, mathematics, and science of 15-year olds. The most recent data is from 2015 where approximately 540,000 students completed the assessments, which represented about 29 million 15-year old students, from 72 different countries and economies (OECD, 2016). Since New Zealand's initial involvement in this programme in 2006, the survey results show a steady decline of New Zealand students' understanding of science (OECD, 2014, 2016).

Figure 1.2 is used to visually represent the changes in student performance in science, particularly for New Zealand students. However, it is important to note that the comparison shows the trend for student performances in their own country, rather than a comparison of science performances across countries. For example, some countries show a large positive shift (e.g., Georgia) compared to New Zealand – this shift does not necessarily mean that their students performed better than New Zealand students, rather they performed better than they did in 2006.

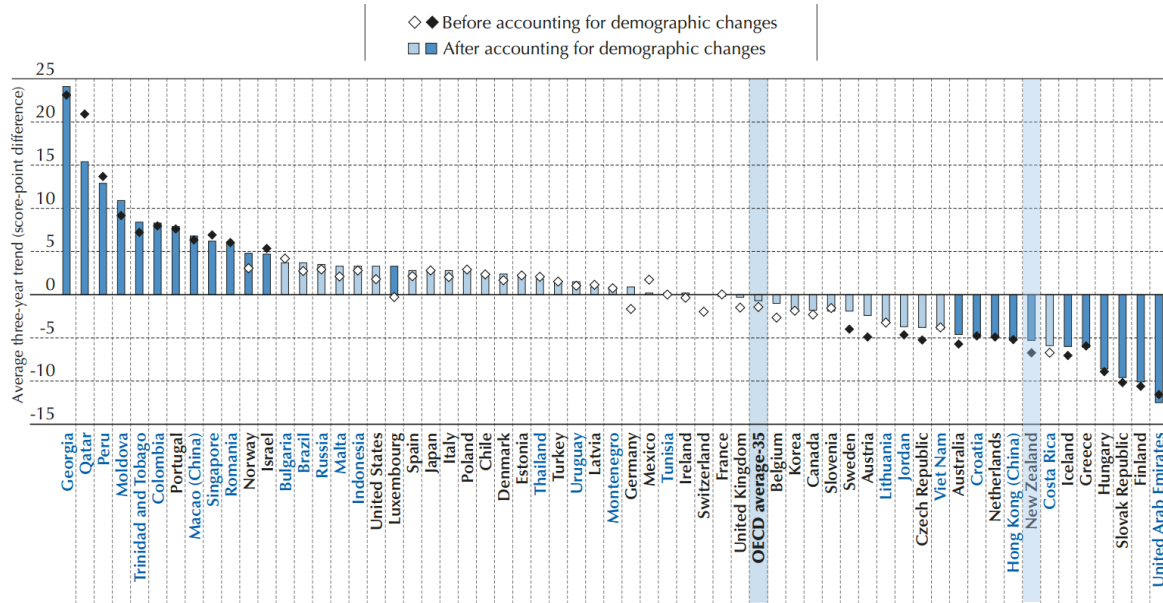


Figure 1.2: PISA results showing average three-year trends in science performance since 2006, after accounting for demographic changes (Adapted with permission, Creative Commons [CC BY-NC-SA 3.0 IGO], OECD, 2016, p. 86).

The Trends in International Mathematics and Science Study (TIMSS), is another international survey that measures and compares student understanding in science, focusing on fourth and eighth grades – which is Year 5 and 9 in New Zealand. TIMSS is completed every four years and started in 1995. Interestingly, at the time of first writing this chapter, only the 2011 results were available which showed an increase in science understanding from 1995 to 2003 but this gain decreased by 2011 (Martin, Mullis, Foy, & Stanco, 2012). However, new data from the 2015 TIMSS survey again shows an increase in science understanding (Martin, Mullis, Foy, & Hooper, 2016).

A professional development intervention to enhance teacher PCK for teaching the Year 10 *Electricity and Magnetism* topic is a worthwhile undertaking because it can enhance teachers' professional knowledge in a particular area of need. The completion of this study could provide useful insights into how CoRe design works as a professional development intervention within a school-based group of practising teachers. This process has the potential to provide an authentic and meaningful professional learning experience directly linked to solving problems

around student learning; as opposed to the traditional one-day generic professional development that some schools may offer (often run by outside experts).

As a practising teacher, there are various opportunities for professional development throughout the school year; however, time is often a limiting factor. For these opportunities to be useful to teachers they must be effective (Barber & Mourshed, 2007) and focused on improving student learning (Soine & Lumpe, 2014). However, many in-house run workshops are focused more on logistical matters related to school improvement (Desimone, 2009), such as learning how to navigate through student management software. Whilst this type of opportunity falls under the net of professional development, it is not focused on enhancing teachers' professional learning for teaching practice that improves student learning. Therefore, another possible outcome from the findings of this study is that CoRe design may be used as an effective professional development intervention for practising teachers.

The empirical evidence and discussions from this study will also be useful to the science education community for future research. For example, in their work about exploring PCK developments, Sickel and Friedrichsen (2017) point out the need for more studies to investigate PCK developments in different contexts. Also, conversations about this study with participants at the 2nd PCK Summit in December 2016 revealed the importance of such studies to shape conceptualisations of PCK for science education. Therefore, it is not only intended that this work will develop teachers' professional knowledge and aid the design of effective professional development interventions in schools, but also that it will provide useful insights for the science education research community.

1.6 Statement of Research

This study investigated the effectiveness and suitability of using CoRe design as a professional development intervention to enhance science teachers' PCK. This statement is addressed in Chapter Eight of this thesis after exploring the PCK development of science teachers in a subject area where they have a limited background, and from analysing their perceptions and experiences of CoRe design.

While the CoRe design process has been seen to be an effective tool for helping teachers develop their PCK, there have been some limitations outlined by other studies such as time requirements (Bertram & Loughran, 2012) and the need for support of people outside of the school environment (Hume et al., 2013). This research addressed these identified limitations by developing a study which investigated collaboration between teachers within one school where they all taught. The rationale behind this decision lies in the observation that when researchers brought in experts to help with the collaboration they saw an enhancement of teachers' PCK, but the time investment and manageability of that arrangement proved to be an issue. It is postulated that since schools already have specialist (and experienced) teachers amongst their staff, these teachers could be a useful source of pedagogical expertise as opposed to bringing in other external people.

1.6.1 Study Objectives

This study had two key objectives framing the entire research. Using a multiple-case study approach featuring CoRe design workshops facilitated by an experienced CoRe design researcher, semi-structured interviews, focus group discussions, and classroom observations, this study aimed to:

1. Explore and establish the nature of personal and enacted pedagogical content knowledge (pPCK and ePCK¹), for the Year 10 topic *Electricity and Magnetism*, of teachers with a limited physics background.
2. Investigate the effectiveness and suitability of a professional learning and development (PLD) intervention, known as collaborative content representation (CoRe) design, when used for enhancing the pPCK and ePCK, for the Year 10 topic *Electricity and Magnetism*, of teachers with a limited physics background.

¹ pPCK and ePCK are new terms which are introduced and discussed in Chapter Two, Section 2.4.5.

1.6.2 Research Questions

The research objectives were developed into the following three research questions:

1. In the New Zealand context, what does the personal and enacted pedagogical content knowledge (pPCK and ePCK) of junior science teachers with a limited physics background look like for the Year 10 topic *Electricity and Magnetism*?
2. What impact does collaborative CoRe design have on the pPCK and ePCK development of junior science teachers with a limited physics background for the New Zealand Year 10 topic *Electricity and Magnetism*, when working collaboratively with experienced physics and junior science teachers?
3. What are teachers' experiences and perceptions of collaborative CoRe design as a professional learning and development (PLD) intervention for enhancing pPCK and ePCK?

1.7 Structure of the Thesis

An overview of the structure of the next seven chapters of this thesis is as follows:

Chapter Two provides a comprehensive and in-depth discussion of the literature which contextualises and positions this study. The literature review is divided into five key focus areas: science education as a whole; views on student learning and understanding in science; the nature and conceptualisation of PCK for science education; the process of CoRe design and the link between CoRe design and PCK; and, professional development and learning for teachers. This detailed literature review highlights and discusses both historical and current research in these fields, which in turn strengthens the rationale behind the importance of this research. There is also a section in this chapter about my involvement in the 2nd PCK Research Summit, and its influence on this study.

Chapter Three outlines and discusses the methodology that guided the study. Theoretical perspectives that underpin educational research such as ontological and

epistemological considerations and their influence on research are discussed briefly, along with the nature of educational research and current paradigms that are employed in educational research. These ideas form the basis upon which decisions were made to use the interpretive paradigm to guide the scope and parameters of this research. The multiple case study approach used to explore teacher's PCK developments and experiences is discussed, along with the specific data collection techniques and tools that were used to generate data. Key aspects of the study's trustworthiness and ethical considerations are also discussed here. Within this chapter, an account of how the data was analysed is also provided.

Chapters Four, Five, and Six present and analyse the data that was collected. To make the large amount of variable-rich qualitative data logical and understandable, a chapter has been devoted to each of the three research phases. Throughout these chapters, direct excerpts from interviews, documents, and classroom observations are used to illustrate themes and trends emerging from analysis of the data.

Chapter Seven discusses and interprets the emergent themes and trends presented in the previous three chapters in light of the relevant literature to identify key findings for each research question.

Chapter Eight presents implications and conclusions from this study. Included in this chapter is how this study may influence science education in schools and the use of professional development interventions within schools. How collaborative CoRe design could be used as a framework for an effective professional development intervention is also included. Limitations throughout the research process are highlighted here. Suggestions for future research extending beyond the scope of this study are also outlined here, and a final conclusion is offered.

Chapter Two
Literature Review

2.1 Overview

This research investigated the nature of practising science teachers' pedagogical content knowledge (PCK) and PCK development for teaching Year 10 *Electricity and Magnetism* before, during, and after the use of collaborative CoRe design as a professional learning development (PLD) intervention. For this investigation, a comprehensive literature review was required to examine existing research in fields related to the focus of this study. This literature review informed the approach taken in this study, notably the conceptual framework and research design.

The literature around developing teachers' PCK for science education is vast. However, reviewing the literature in conjunction with the research objective in this study, five significant aspects were revealed, which are briefly outlined below and then subsequently discussed in depth.

1. Curriculum goals of science education. This aspect relates to views on learning science that are prevalent in the science education research community. For example, students learning about the nature of science and scientific inquiry to become scientifically literate;
2. Student learning theories and pedagogies in science education. This section investigates and discusses how views on learning for science have developed. It also deals with the use of mental and expressed models to explore learning, and the nature and role of misconceptions in learning, and identifies some common student misconceptions in electricity and magnetism;
3. Pedagogical content knowledge (PCK). An account of the conceptualisation of PCK and its refinement is provided and discussed. Also included here is the application of PCK to teaching science, how a teacher's PCK may be represented, and capturing teacher's PCK. Finally, a summary of the two PCK Summits and their influence on this study is provided.
4. Content representation (CoRe) design. The development of CoRe design and its use as a professional development intervention is outlined, including advantages and limitations for developing teachers' PCK; and,
5. Professional learning and development (PLD). This part characterises professional development and professional learning, and identifies key features of effective PLD interventions.

2.2 Science Education

This section focuses on the curriculum goals for science education, student qualities to achieve those goals, and how the New Zealand Curriculum (NZC) promotes learning these qualities.

2.2.1 Curriculum Goals of Science Education

Curriculum goals for science education have developed over time to ensure that what students are learning is relevant to the modern society in which they live in (Gluckman, 2011). Gluckman (2011) notes that historically, science was a method for yielding certainty and exactitude. However, a modern view is that science is a process of complex systems and scientific knowledge is expressed as a probability with uncertainty, but never as an absolute. Appropriate goals for science education needed development to reflect this shift in conceptualising science. These goals should reflect the true nature of science – how scientists work to solve problems and generate science knowledge.

To initiate and support reform-based future orientation curriculum development internationally, researchers working within the science education domain have identified some key curriculum goals for educators. For example, in 2012, in the United States of America, the ‘Committee on a Conceptual Framework for New K-12 Science Education Standards’ was formed by the National Research Council (NRC²), which built on previous science education research. This Committee was challenged to review information about science curriculum goals, including current limitations, with the goal of developing a framework for the American K-12 education system that would express and communicate goals and expectations for students learning science. They reported that the fundamental goal for science education was to develop students into scientifically literate citizens who have: an appreciation for science as an enterprise; appropriate content knowledge; the ability to make informed decisions about scientific information; the capability to learn

² The NRC is a council that works alongside another national body known as ‘The National Academies of Sciences, Engineering, and Medicine’ to provide governments and other organisations information for improving public policy and education about science, technology, and health (National Academies, 2007).

about science outside of school; and the capabilities to pursue science-based careers, if they choose to (NRC, 2012). These points are concisely summed by the NRC (2012) who state the primary goal of science education is to “cultivate students’ scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context” (p. 41).

Similar curriculum goals related to scientific literacy are being adopted and developed in many different curricula from various countries, including that of New Zealand where it is a strong focus (Bull, Joyce, & Hipkins, 2014). Education in New Zealand is guided by New Zealand Curriculum (NZC) policy document (Ministry of Education, 2007), where “in science, students explore how both the natural physical world and science itself work so that they can participate as critical, informed, and responsible citizens in a society in which science plays a significant role” (p. 17). In the NZC, emphasis is placed on students learning about the nature of science and scientific inquiry to become scientifically literate.

Becoming scientifically literate involves students learning about the skills, processes, and knowledge associated with science using various disciplines of the science domain as contexts. For example, the NRC (2012) separates science into four core disciplines: Physical Science; Life Sciences; Earth and Space Sciences; and, Engineering, Technology and Applications of Science. In comparison, the NZC separates the domain of science into four disciplines, referred to as strands, which are: the Living World; Planet Earth and Beyond; Material World; and Physical World (Ministry of Education, 2007).

The primary focus of this study is physics, which is located within the Physical World of the NZC. The key concepts that have been identified for students to learn within this content area are: forces, motion, energy, and waves (Ministry of Education, 2007; NRC, 2012).

The key curriculum goal of science education in New Zealand is to promote the development of scientifically literate students, but some questions around developing scientifically literate students remain. For example, what specific qualities do scientifically literate citizens have, how do teachers teach students to become scientifically literate, and how does the NZC promote this curriculum goal?

2.2.2 The Qualities of Scientifically Literate Students

Scientific literacy is a well-documented term in science education, with many science education researchers adopting it as a fundamental goal and exploring what it entails (Laugksch, 2000). Over the last six decades of discussion and debate by researchers about what scientific literacy means, common aspects have been identified (e.g., DeBoer, 2000; Fives, Huebner, Birnbaum, & Nicolich, 2014; Laugksch, 2000; Lederman, Antink, & Bartos, 2014; NRC, 2012). For example, N. G. Lederman et al. (2014) indicates that while the specificity of being scientifically literate was under scrutiny, it was primarily about a person's "ability to make informed decisions about scientifically-based personal and societal issues" (p. 286). To identify specific qualities of a scientifically literate person, Fives et al. (2014) conducted a systematic review of literature which defined 'scientific literacy'. This review identified five components of being scientifically literate and associated student skills for each component. A summary of these five components is:

1. Role of Science

Understand the nature of science and recognise that science is a process for answering questions.

2. Scientific Thinking and Doing

Observe, record, and analyse information to draw conclusions.

3. Science and Society

Apply scientific thinking to occurrences in everyday life (e.g., question the accuracy, validity, and reliability of sources of information).

4. Mathematics in Science

Recognise the relationship between mathematics and science.

5. Science Motivation and Beliefs

Value science as a process and develop their self-efficacy for scientific thinking.

From the work of the NRC (2012), Fives et al. (2014), and N. G. Lederman et al. (2014), the qualities of a scientifically literate person emerge. Such a person can make informed decisions in their everyday lives about science-related issues (NRC,

2012), because they have an understanding of: key science concepts (NRC, 2012); the epistemological underpinnings of science (Fives et al., 2014; N. G. Lederman et al., 2014); and, the inquiry processes in science (Fives et al., 2014; N. G. Lederman et al., 2014). To represent the relationship between these qualities and being scientifically literate, Figure 2.1 was created by the author of this thesis.

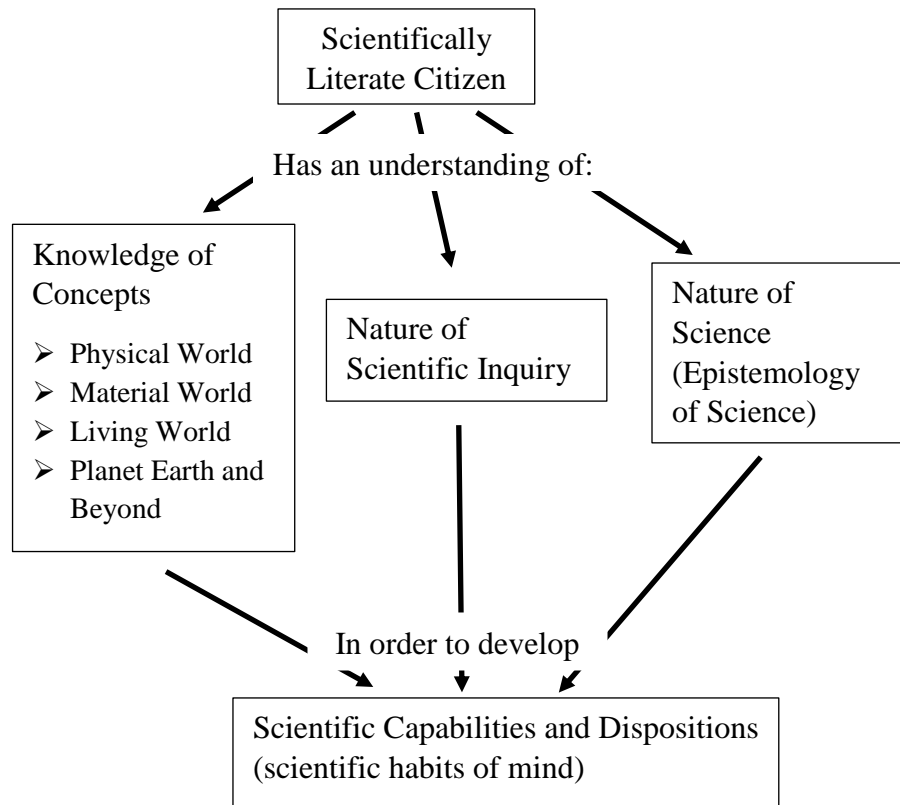


Figure 2.1: The qualities of scientifically literate citizens, created by combining the work of: Fives et al. (2014), N. G. Lederman et al. (2014), and the NRC (2012). Note, the structure of the Knowledge of Concepts used here is from the NZC (Ministry of Education, 2007).

Thus, to become scientifically literate, students require an understanding of key science concepts, along with capabilities in science. Consequently, those policy makers behind curriculum design and teachers enacting that curriculum need to ensure that these key features of scientific literacy are being developed in students.

2.2.3 Concepts, the Nature of Science, and Scientific Inquiry

The physics concepts thought to be key to scientific literacy have not changed significantly over the last few decades, and the physics key concepts informing this study are those derived from the NZC (Ministry of Education, 2007). However, within the science education community, views about what the nature of science and scientific inquiry meant have undergone change. For example, refining and defining what was meant by the term ‘nature of science’ was a goal for many academics and philosophers working within the science education community over the last century (e.g., Abd-El-Khalick & Lederman, 2000; Hipkins, 2002; Hipkins, Barker, & Bolstad, 2005). During this period, there was much debate leading to a number of reviews which attempted to identify similarities and differences between authors (e.g., Abd-El-Khalick & Lederman, 2000). Today, there is growing consensus amongst this community that defining the nature of science should centre on “the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge” (Abd-El-Khalick & Lederman, 2000, p. 666). Lederman and Lederman (2012) add that the “nature of science refers to the characteristics of scientific knowledge that are directly derived from the process/method used to develop the knowledge” (p. 336). The NRC (2012) recognises this consensus and outline eight key points that students should understand to appreciate the nature of science. A summary of these points is:

1. There is no single ‘scientific method’;
2. Scientists seek patterns, classify objects, and make generalizations from empirical data;
3. Reviewing and critiquing ideas is an integral process for developing scientific knowledge;
4. Scientific knowledge is tentative. Ideas are thoroughly scrutinised before being widely accepted;
5. Models are used to represent scientific information;
6. Science encompasses not only content knowledge but also procedural and epistemic knowledge;

7. New ideas in science seek to explain the unexplained, or explain phenomenon in a more elegant manner; and
8. Science is a coherent body of knowledge rather than an assortment of facts that serves as a powerful tool.

(NRC, 2012, p. 78)

These key features of the nature of science from the NRC (2012) show similarities to a conceptualisation or view of the nature of science held by N. G. Lederman et al. (2014). These authors maintain that to understand the nature of science, students should:

- Be able to differentiate between observation and inference;
- Have the ability to identify differences between theories and laws;
- Appreciate the input of imagination and creativity on the development of scientific knowledge;
- Appreciate the subjective nature of scientific knowledge and the influences that a scientist's ontology has on developing scientific knowledge;
- Comprehend that science is a human enterprise – it is practised within a context and will have influence over that context;
- Understand the tentative nature of scientific knowledge; and,
- Differentiate between the epistemological underpinnings of science and scientific processes.

The last understanding to do with differentiating between the epistemology of science and the processes of science that produce this form of knowledge is of special interest because N. G. Lederman et al. (2014) are pointing out the need to have knowledge of scientific inquiry in addition to knowledge of the nature of science.

Scientific inquiry refers to a process that scientists use to generate scientific knowledge. The term originated over six decades ago where science educator Paul Hurd questioned the effectiveness of science education for future generations (Hurd, 1958; Meltzer & Otero, 2015). His concern was that children may not be “receiving an education that will enable them to cope with a society of expanding

scientific and technological developments” (Hurd, 1958, p. 14). To combat this concern, Hurd (1958) identified the importance of allowing students the opportunity to understand science by taking part in the scientific processes, allowing students the “feeling that he has, in some small way, been a scientist for the day” (p. 16).

N. G. Lederman et al. (2014) argue scientific inquiry, as a pedagogical framework, is about developing scientific knowledge by combining science procedures traditionally taught (e.g., observation, collecting data, and analysing) with scientific knowledge, and using critical and scientific reasoning. If teachers promote and subscribe to this way of introducing, scaffolding, and supporting students’ development of concepts, it can be said that students are engaged in authentic scientific inquiry when they are encouraged to “engage in and reflect on authentic science activities” (Jadrich & Bruxvoort, 2011, p. 3). In a classroom setting, this type of pedagogical approach requires teachers to develop lessons that allow their students to act as scientists by approaching an issue, problem, or question from a scientist’s point of view (Jadrich & Bruxvoort, 2011; Lederman & Lederman, 2012). For example, in early school years, students may categorise information or collect data for graphing. As students develop and transition through secondary school, scientific investigations become more complex and students should be encouraged to start developing relationships from the information that they have collected.

However, when trying to use this pedagogical approach, there is a danger of teachers and students adopting a distorted and naïve view of the scientific inquiry process – often referred to as ‘the scientific method’ (e.g., Hume & Coll, 2008; N. G. Lederman et al., 2014). This ‘scientific method’ that some teachers promote due to their own perceptions of carrying investigations, portrays the inquiry process as a linear algorithmic procedure whereby students remember and follow a set sequence of steps that will give them success when investigating scientific questions (N. G. Lederman et al., 2014). The more progressive view of a scientific inquiry process advocates that “the [scientific] questions guide the approach and the approaches vary widely within and across scientific disciplines and fields” (N. G. Lederman et al., 2014, p. 290).

Thus, while students should be encouraged to engage in authentic scientific inquiry (Jadrich & Bruxvoort, 2011; Lederman & Lederman, 2012), some teachers find it

to be a challenging pedagogical approach to actually implement. The result is that authentic scientific inquiry and practical work may be overlooked. Most notably, these challenges stem from contextual restraints within the school and classroom. For example: time allowances for teaching science at their school; the guiding curriculum and what assessments students need to complete; and, student aptitude and behaviour (Cheung, 2008; Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010; Staer, Goodrum, & Hackling, 1998; Windschitl, 2003).

Students becoming scientifically literate has been recognised as the overarching goal of science education, and the qualities that students need have been identified. It is important to consider how the NZC promotes teachers to achieve this goal.

2.2.4 Developing Scientific Literacy: The New Zealand Curriculum

In 2007, the NZC was revisited and revised; placing a larger emphasis on students learning about the nature of science and the importance of learning science to make informed decisions and understanding the implications that science may have in their lives (Ministry of Education, 1993, 2007). While this document does not state it explicitly, some of these aspects are like those outlined earlier about scientific literacy. Previous to this refinement, the Ministry of Education (1993) indicated the purpose of science education was about understanding the world that we live in, asking questions, clarifying ideas, and establishing validity of ideas. However, the revised version produced by the Ministry of Education (2007) identified a purpose that is more aligned with the information detailed earlier in this literature review about becoming scientifically literate.

The Ministry of Education (2007) indicates that science education is important as “many of the major challenges and opportunities that confront our world need to be approached from a scientific perspective, taking into account social and ethical considerations” (p. 28). This document also attempts to address two of the key elements of developing scientific literacy, which is, understanding the nature of science and scientific inquiry. However, as N. G. Lederman et al. (2014) caution, there is a tendency for the conflation of these two separate concepts in science curricula, which is the case in the NZC (Ministry of Education, 2007). The specific view of the nature of science expressed in the NZC is:

The nature of science strand is the overarching, unifying strand. Through it, students learn what science is and how scientists work. They develop the skills, attitudes, and values to build a foundation for understanding the world. They come to appreciate that while scientific knowledge is durable, it is also constantly re-evaluated in the light of new evidence. They learn how scientists carry out investigations, and they come to see science as a socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions.

(Ministry of Education, 2007, p. 28)

Like the previous curriculum, the revised NZC encourages teachers to incorporate nature of science aspects into their lessons, along with content knowledge from the four contextual strands. To aid teachers, the conceptualisation of the nature of science above is separated into four Achievement Aims which can be integrated with the Achievement Aims from the disciplines (e.g., Physical World) setting the context. The four Achievement Aims for the nature of science are:

Understanding about science

Learn about science as a knowledge system: the features of scientific knowledge and the processes by which it is developed; and learn about the ways in which the work of scientists interacts with society.

Investigating in science

Carry out science investigations using a variety of approaches: classifying and identifying, pattern seeking, exploring, investigating models, fair testing, making things, or developing systems.

Communicating in science

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.

Participating and contributing

Bring a scientific perspective to decisions and actions as appropriate.

(Ministry of Education, 2014b)

Another key aspect of the NZC revision was the development of five key competencies (Ministry of Education, 2007; Rutherford, 2005). Brewerton (2004) explains competencies can be viewed as “capabilities needed to undertake a task or meet a demand” (p. 3) and that key competencies would be “those competencies needed by everyone across a variety of different life contexts to meet important demands and challenges” (p. 4). Research commissioned by the New Zealand Ministry of Education led to the development and adoption of five key competencies into the NZC framework to promote students developing skills such as being able to contribute effectively, reflect on their learning, or show innovative thinking in our forward-moving and changing environment (Brewerton, 2004).

The actual key competencies adopted in the 2007 NZC were developed from the work done by the Organisation for Economic Co-operation and Development (OECD) who investigated the definition and selection of key competencies in their project ‘definition and selection of competencies: theoretical and conceptual foundations’ (DeSeCo) (OECD, 2001, 2005). The result of this investigation revealed three broad categories of key competencies which are detailed in Figure 2.2 on the following page.

These three broad categories can be summarised as:

- The ability to use tools interactively is concerned with individuals using physical and socio-cultural tools to engage with the environment that they are immersed in.
- The nature of interaction between people is becoming more interdependent. As such, individuals are required to develop the ability to interact with others, especially people from a range of difference backgrounds.
- As individuals move forward with their development, they need to act autonomously, take responsibility and manage their own behaviours.

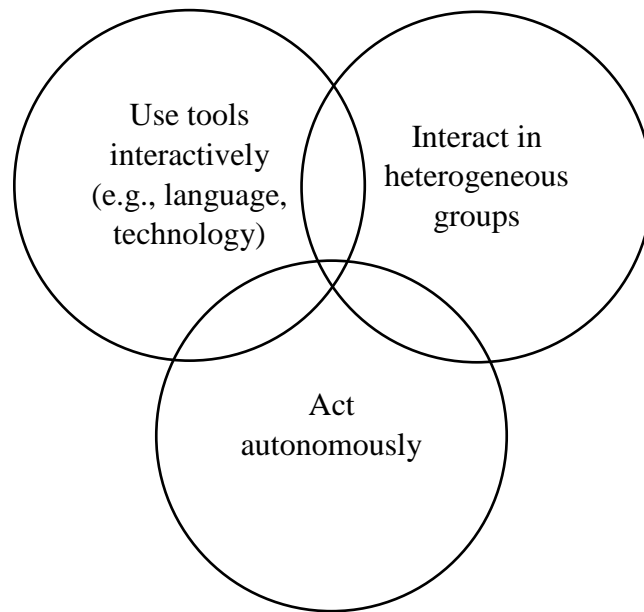


Figure 2.2: The three broad categories of key competencies as identified by DeSeCo (Reprinted with permission, Creative Commons [CC BY-NC-SA 3.0 IGO], OECD, 2005, p. 5).

While these broad categories have their own emphasis, they are somewhat interrelated. The central idea that unifies these three categories is being reflective – that is, adapting to change, learning from experience and having a critical stance (OECD, 2005).

As the OECD comprises of 34 countries (OECD, 2015), it is not surprising that identifying specific attributes from each of the three categories is rather contextually bound (Brewerton, 2004; OECD, 2005). In the New Zealand context, the adopted framework consisted of five key competencies. Each of the five key competencies and their descriptions, as adopted by the NZC, are summarised in Table 2.1 on the following page.

Table 2.1: A summary of the five key competences from the NZC document (Reprinted with permission, Creative Commons [CC BY 3.0 NZ], Ministry of Education, 2007, p. 12).

Key Competency	New Zealand Curriculum Description
Thinking	Make sense of information using critical and metacognitive processes. Students will be able to seek, use, and create knowledge to problem solve, ask questions, and challenge assumptions.
Using language, symbols, and texts	Work with and make sense of the language and codes used to represent knowledge. This is of particular importance in science where technical phrases, symbols, and diagrams are used frequently. Students will be able to make interpretations in range of contexts.
Managing self	Develop a sense of self-motivation with an ambitious attitude. Students will be able to be reliable and resourceful, and will set high standards and establish goals.
Relating to others	Effectively interact with a diverse group of people in various contexts. Students will be able to listen well, share ideas, and recognise the importance of cooperation.
Participating and contributing	Effectively and actively become involved with communities around common areas of interests. Students will be able to develop a sense of belonging and will have an understanding about the quality and sustainability of milieus.

In their review of these essential skills and their implications on science education, Barker, Hipkins, and Bartholomew (2004) argue the importance of relating these key competencies to a science context. In their concluding remarks, Barker et al. (2004) indicate the need for developing a set of science-specific competencies that “reflect a view of science and science education that is appropriately expansive, socially integrated and future-focussed” (p. 10). The notion of developing a set of key science-specific competencies can be seen in the information produced for educators by the New Zealand Council for Educational Research (NZCER). NZCER suggest that it is not enough for students to simply learn and develop knowledge and skills, they must be able to use what they know, that is, they need to engage with science. This need for engagement in science, and the need for developing key competencies in a scientific context, led to the development of the “five science capabilities” (Bull et al., 2014, p. 10). Succinctly, these capabilities were developed to create explicit links between information from the science curriculum document such as: learning about the nature of science; learning

scientific concepts; rationale about why students should learn science; key competencies; and information from existing resources that available for teachers and science educators (Bull et al., 2014; Hipkins, 2014).

The capabilities are:

1. Gather and interpret information
2. Use evidence to support ideas
3. Critique evidence
4. Making meaning of scientific representations
5. Engage with science

(Bull et al., 2014, p. 10)

More information about these science capabilities and resources to support teachers when developing their lessons is available on the Te Kete Ipurangi (TKI) website. TKI is an online educational portal that is an initiative by the Ministry of Education that supports teachers, parents, and students with regards to the curriculum and NCEA. For example, TKI offers the following supplementary information about the science capabilities:

- Gather and interpret data.
Learners make careful observations and differentiate between observation and inference.
- Use evidence.
Learners support their ideas with evidence and look for evidence supporting others' explanations.
- Critique evidence.
Not all questions can be answered by science.
- Interpret representations.
Scientists represent their ideas in a variety of ways, including models, graphs, charts, diagrams and written texts.

➤ Engage with science.

This capability requires students to use the other capabilities to engage with science in “real life” contexts.

(Ministry of Education, 2014a)

Interestingly, there appears to be an important omission from these five science capabilities that have been developed, which is questioning. Questioning is not mentioned either directly as a capability or in the supplementary information, which is significant given asking critical scientific questions has been identified as being an important attribute of a scientific literate person (e.g., Fives et al., 2014; NRC, 2012).

The first section of this literature review has focused primarily on the evolution of curriculum goals for science education in the NZC that meet the need for developing scientifically literate citizens. The next section investigates how students may learn some of the key elements of becoming scientifically literate identified in this section.

2.3 Student Learning Theories and Pedagogies in Science Education

This section focuses on student learning theories in science, and how students develop their conceptual understanding. To achieve this conceptual understanding, pedagogies in science education are also outlined along with a discussion about how students may develop misconceptions.

2.3.1 Views on Learning in Science

Education research over the last century has informed the way that educators and researchers understand and view learning in science and associated pedagogies. The views on learning over these years were consistent with the current and leading psychology theories of the day. For example, throughout the first half of the 1900s research in science education was underpinned by behaviourism (Duit & Treagust, 1998). This view of learning was consistent with the work that was introduced by

psychologist John Watson in the early 1900s where the focus was on investigating behaviour, and identifying what was happening, without focusing on why (O'Donohue & Kitchener, 1999).

During the second half of the 1900s, changes to how researchers viewed learning occurred as educational researchers began directing their attention to intellectual development rather than behaviour, which was consistent with the ideas in cognitive psychology that Jean Piaget was working on at the time (Başer & Geban, 2007; Duit & Treagust, 1998). These advances in cognitive psychology led to the development of the theory of 'constructivism' in the 1970s (Duit & Treagust, 1998).

This movement from behaviourism to constructivism in psychology, and subsequently education, meant that many science education researchers began to adopt and subscribe to this cognitive constructivist view of learning (Dole & Sinatra, 1998). Adherents of constructivism advocated that developing knowledge is not something attainable by simple teacher and student interactions (Dole & Sinatra, 1998). Rather, knowledge was something that was created over time by the learner (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Knowledge construction occurs when the learner is involved in various learning activities which are designed to challenge their existing conceptual framework (Al khawaldeh, 2013; Driver, Asoko, et al., 1994). Constructing knowledge in this way to alter an existing framework around phenomena in science became known as a process of 'conceptual change' (Al khawaldeh, 2013; Dega, Kriek, & Mogese, 2013; Dole & Sinatra, 1998; Driver, Asoko, et al., 1994; Duit & Treagust, 2003; Posner, Strike, Hewson, & Gertzog, 1982).

Conceptual change, as a means of explaining how students learn in science, was introduced by Posner et al. (1982) and it has been a focus for science educational researchers ever since (Hovardas & Korfiatis, 2006). Not only did Posner et al. (1982) propose conceptual change, they also explained how it may occur. The first step must involve challenging the learner's original conception, thus setting up a situation where there is a sense of dissatisfaction in the learner because the new ideas/knowledge do not agree with his/her original conceptual framework (Dega et al., 2013; González-Espada, Birriel, & Birriel, 2010; Palmer, 2003; Posner et al., 1982). In the second phase, the learner needs to consider the new conception that

has been offered to be intelligible (Posner et al., 1982), meaning that they are able to understand this new concept (Palmer, 2003). It needs to offer an improved explanation, that is, “the capacity to solve the problems generated by its predecessors. Otherwise it will not appear a plausible choice” (Posner et al., 1982, p. 214). This last part of the conceptual change process sees the learner considering the new concept as fruitful (Dega et al., 2013; Posner et al., 1982), whereby the new adopted conception can solve new problems that the original one failed to (Palmer, 2003; Posner et al., 1982).

Stepans (1994) offered a useful and simplistic model for conceptual change that teachers could implement in their classrooms to allow students to go through the process. Using his information, Table 2.2 was constructed to show the stages and what each stage represents.

Table 2.2: A summary of the six stages for conceptual change offered by Stepans (1994, p. 7).

Stage	Explanation
Committing to an outcome	Students become aware of their own preconceptions about a concept by thinking about it and making predictions before an activity begins.
Exposing beliefs	Students share their beliefs in small group situations, and then with the class.
Confront beliefs	Students test their ideas and discuss them with peers.
Accommodate the concept	Students work towards resolving conflicts between their preconceptions, class discussions, and observations.
Extend the concept	Students make connections between the concept learned and other situations, including their daily lives.
Go beyond	Students are encouraged to pursue additional questions and problems of their choice related to the concept.

Constructivism was further developed by researchers who were not only interested in investigating the cognitive processes of students as individuals, but also in examining how students function in social contexts (Leach & Scott, 2003). This

viewpoint on learning was consistent with Vygotskian psychology and focused on “social interactions between individuals, or as individuals interact with cultural products that are made available to them in books or other sources” (Leach & Scott, 2003, p. 93). This development was useful for researchers, as interactions within classrooms between the teacher and students became important considerations, allowing for the investigation into the relationship between students’ learning and how they were taught (Leach & Scott, 2003). Leach and Scott (2003) indicate that one of the key implications of this perspective is that it “opens up all kinds of possibilities for teacher education and professional development work, with a view to improving students’ learning” (p. 104). This view of learning became known as the sociocultural view of learning.

When discussing how students learn in science, an important consideration is misconceptions, that is misalignments between students’ beliefs/constructs and the scientific conceptions (Palmer, 2003). Research about student misunderstandings dates back to Piaget’s work in the 1920s (Driver & Easley, 1978). Since then, extensive research has occurred and various authors have used different terms to characterise student misunderstanding, such as: preconceptions (e.g., Clement, 1982), alternative frameworks (e.g., Driver, 1981), alternate conceptions (e.g., Hewson & Hewson, 1984), naïve beliefs (Caramazza, McCloskey, & Green, 1981), and misconceptions (e.g., Gilbert & Watts, 1983; Helm, 1980). There are some differences between these labels which “reflects differences in how researchers have characterized the cognitive properties of student ideas and their relation to expert concepts” (Smith, Disessa, & Roschelle, 1994, p. 119). This study has chosen to follow current trends in science education literature by using the term ‘misconception’ as a useful catch-all term to explore all the labels that others have used (Kind, 2014; Larkin, 2012; Wendt & Rockinson-Szapkiw, 2014).

Adherents of constructivism and conceptual change advocate for identifying potential student misunderstandings and using pedagogical techniques to develop student’s mental frameworks to align with accepted theories. However, from a socio-cultural view on learning, Leach and Scott (2003) indicate that “misconceptions simply represent ways of communicating in everyday social language. This is the mode of communication that prevails in day-to-day living, and those ways of communicating are ‘viable’ in that they are widely understood”

(Leach & Scott, 2003, p. 101). These authors are suggesting that misconceptions may be a misalignment between terms used within a scientific and an everyday context, and that teachers need to be explicit about differentiating the use of terms when teaching science.

The points that have been made above are about the evolution of learning theories using science as a context. The following section focuses on learning issues and implications for pedagogy in physics education.

2.3.2 Views on Learning in Physics

Historically, physics education was seen as a teacher directed process whereby detailed information was transmitted about physical concepts and principles, along with their applications to students, primarily using text books for information (Nielsen & Thomsen, 1990; Whitaker, 1979). However, experiencing this highly teacher-directed process, students often do not gain the desired understanding (Dykstra, Boyle, & Monarch, 1992). This issue occurs as “simply presenting students with the logical arguments of scientific concepts during instruction does not encourage conceptual learning since such reasoning makes little sense in the context of students’ own beliefs” (Başer & Geban, 2007, p. 247).

Students may already have pre-existing ideas and rigid conceptual frameworks regarding many areas of the Physical World before starting a physics course. The existence of these strongly held ideas can prove to be a barrier to learning, if they are misconceptions, and it is a difficult task for teachers to develop their understanding further. Progressive physics educators advocate that students need to engage in a form of conceptual change to gain a meaningful understanding around physical phenomena (Dega et al., 2013; González-Espada et al., 2010).

Thus, teachers need to develop lessons and use instructional strategies that have the capacity to challenge firmly held conceptual frameworks (containing misconceptions), allowing for the generation of new knowledge by undergoing a conceptual change process (Dykstra et al., 1992). Taking students through this process can often require great skill and creativity on the teacher’s part. For example, in the context of electricity and magnetism, Dega et al. (2013) found that misconceptions can be complex and the abstract nature of some concepts makes it

difficult to get students to go through a conceptual change process. These authors investigated the use of computer simulations and saw that this particular strategy could promote conceptual change.

Many traditional teacher-centred pedagogical approaches within physics education have been examined and critiqued for their effectiveness (e.g., Bowe, 2007). The main agenda for these approaches is to communicate the correct information to the students, however, such approaches have limitations. For example, giving students information and then having them repetitively solve problems may not allow for sufficient conceptual development, which limits their capabilities for successfully applying knowledge to more complex situations (Bowe, 2007).

An investigation about science teachers' beliefs around teaching and learning science by Tsai (2002) highlighted a thought-provoking point in relation to these traditional teacher-centred approaches. He noted that a possible reason for many educators having these traditional views surrounding the teaching and learning of science (including the nature of science) may be due to their own science experiences at school. Furthermore, these views could also be further reinforced during teacher training (Tsai, 2002).

The extensive research that has been completed around the area of conceptual change within science education has led to an important development that physics educators must consider. Not only do they need to consider *what* is being taught, but *how* that information is going to be taught to ensure students develop a sound understanding (Bowe, 2007).

In summary, physics teachers need to employ a variety of pedagogical approaches that are focused more towards student-centred learning to allow for the process of conceptual change to take place (Başer & Geban, 2007; Bowe, 2007). These pedagogical approaches are required so that any student misconceptions can be challenged and they can develop new conceptual frameworks more aligned with the accepted scientific one (Başer & Geban, 2007).

A pedagogical approach to aid student understanding is the use of representations, analogies, or models, which can represent abstract ideas. This strategy is discussed in the following section.

2.3.3 Representations, Analogies, and Models

Models and analogies are useful pedagogical tools for teaching concepts to students as they represent complex information in a way that can help students develop their conceptual frameworks for understanding physics ideas (Coll, 2006; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Harrison & Treagust, 2006). For this research, analogies and models are interpreted as methods of representing complex information in an easy-to-understand way to communicate these concepts to students (Adúriz-Bravo, 2013; Harrison & Treagust, 2006; Jones, Ross, Lynam, Perez, & Leitch, 2011). A useful framework for discussing models and their influence on student understanding is offered by Chittleborough, Treagust, Mamiala, and Mocerino (2005). These authors identify four types of models that are involved with the learning process: scientific models, teaching models, mental models, and expressed models. Figure 2.3 depicts the relationship between these four models.

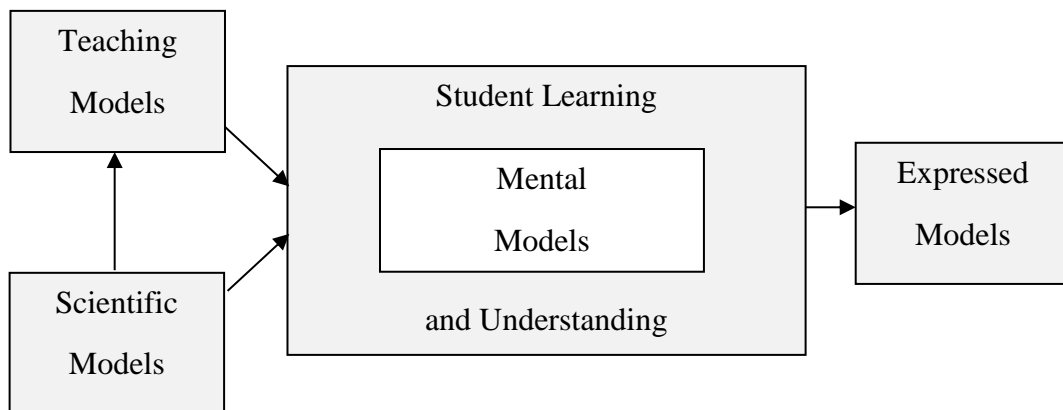


Figure 2.3: A theoretical framework of models in learning, relating the four types of models: scientific, teaching, mental and (Adapted with Publisher's permission, from Chittleborough et al., 2005, p. 197).

Within this framework, the scientific models are those models that have been developed by scientists to explain certain physical phenomena, and critiqued and scrutinised by the scientific community (Chittleborough et al., 2005; Gilbert, 1999). In contrast, a teaching model is a pedagogical device/tool developed by teachers and influenced by the scientific models to explain and portray certain science

concepts to students. Teaching models are often analogous representations of certain phenomena, typically designed to help students develop an understanding of abstract concepts through the use of metaphors, diagrams, simulations, pictures, and physical structures (Chittleborough et al., 2005). Examples of teaching models in science include Rutherford's solar system model of the atom (Coll, France, & Taylor, 2005), or the pressure and flow of liquids in pipes to represent voltage and current in electrical circuits (Stavy, 1991). As students engage with teaching and scientific models, they begin to develop links between the accepted scientific ideas and the analogies representation. As students form these links, they are developing their own 'mental models' about the concepts at hand.

The idea that people possess mental models dates back to 1943 where Kenneth Craik postulated each person's mind has a method of understanding the world (Craik, 1967). This study subscribes to the view that mental models are "cognitive representations of external reality" (Jones et al., 2011, p. 46). Essentially, a mental model is a means for thinking and allowing the development of a psychological or cognitive representation about certain pieces of information (Chittleborough et al., 2005; Johnson-Laird, Girotto, & Legrenzi, 1998; Jones et al., 2011; NRC, 2012). Such models are "used to describe and explain phenomena that cannot be experienced directly" (Coll et al., 2005, p. 184). As mental models are an abstract psychological construct within the learner's mind, it cannot be directly seen or measured. For others to understand the nature of their mental models, students must express information about them (Chittleborough et al., 2005; Coll et al., 2005). This expression of information by a student through writing, speech, or action is known as the expressed model.

Throughout the process of developing students' mental models from teaching and scientific models, misconceptions may arise. Misconceptions can occur whenever the student's developed conceptual mental model about a certain phenomenon contradicts or differs from that of the accepted scientific model (Chittleborough et al., 2005; Palmer, 2003). Chi (2008) argues that teachers' pedagogical approaches must acknowledge how students develop misconceptions during the learning process, which in turn influence their teaching practise. This awareness and pedagogical response from the teacher is an important aspect of a teacher's professional knowledge base (Gardner & Gess-Newsome, 2011).

2.3.4 Students Developing Misconceptions

While research around misconceptions dates back to the 1920s, the most significant research around this area was carried out throughout the 1970s and 1980s (Bell, 2005; Brown, 1992). Work in this era recognised that if students develop misconceptions careful instruction is needed to help students construct concepts closer to the scientific idea (Driver & Easley, 1978). Furthermore, the teacher needed to take misconceptions into account when designing lessons (Bell, 2005). This research signals the importance of designing appropriate pedagogies to achieve alignment of student ideas with scientific models, and that physics educators identify how misconceptions can develop within a student's mental framework.

Misconceptions can develop in different ways, such as the influence of a students' prior knowledge on their conceptual development or how students gather and interpret information (Zirbel, 2004). However, other influential factors on the development of student misconceptions stem from the teacher (e.g., Bayraktar, 2009; Halim & Meerah, 2002; Helm, 1980; Ivowi, 1984, 1986; Kose, 2008). For instance, if the teacher has insufficient content knowledge around various phenomena then they may have difficulty portraying and teaching certain concepts (Halim & Meerah, 2002). Likewise, a problem exists if teachers themselves have misconceptions (Bayraktar, 2009). On the other hand, if students have preconceived ideas and frameworks around physical concepts and teachers are unaware of these misconceptions, then rather than helping the students to develop the correct understanding, they may unintentionally compound the issue (Zirbel, 2004). For example, a study by Berg and Brouwer (1991) investigated how aware physics teachers were of students' misconceptions about rotational motion and gravity. They discovered that the teachers were relatively naïve about students' misconceptions and that a significant number of the teachers also held misconceptions about the topics they were teaching.

It is not surprising then that student misconceptions often arise when teachers are teaching subjects outside of their specialist area. Hashweh (1987) and Tobin, Tippins, and Gallard (1994) reported that non-specialist teachers tend not to have the appropriate knowledge needed to make analogies and represent information in ways that the students could comprehend. Such teachers could also hold

misconceptions, which they may then pass onto the students, thus reinforcing student misconceptions even further.

The following section addresses the issue of students' misconceptions in electricity and magnetism, including the identification of some common misconceptions.

2.3.5 Misconceptions in Electricity and Magnetism

When much research was being conducted into students' learning in science and the misconceptions they may have had, there was a significant focus on electricity (e.g., Pfundt & Duit, 1994). Data was gathered from students and teachers using surveys, interviews, and observations, and the findings from these studies highlighted the importance of teachers considering students' misconceptions and how they could be addressed. Specific examples of misunderstandings in electricity occurred around aspects such as closed circuits, voltage and potential difference, current flow, and the workings of batteries (Driver, Squires, et al., 1994). For example, in their interviews with students, Bauman and Adams (1990) noticed some confusion with the concepts of electrical energy and current flow. When questions were given to teachers about circuits, they also expressed misconceptions. Teacher misconceptions were also seen in a survey about electrical circuit understanding by R. Cohen, Eylon, and Ganiel (1983), who found that the average result of correct responses from the teachers who completed the survey was 51.5% (compared to all of the students who took part, whose average was 38.2%).

When reviewing research about student understanding in electricity, the following four student learning difficulties were identified:

- Distinguishing between key terms such as electricity and energy (e.g., Bauman & Adams, 1990);
- Identifying correct complete circuits (i.e., no open or short circuits) – both practically and when looking at diagrams (e.g., Johsua, 1984; Tasker & Osborne, 1985);
- Understanding conventional current in simple circuits and potential difference (e.g., R. Cohen et al., 1983; Osborne, 1983); and,
- Comprehending the concept of electrical resistance, voltage and power (e.g., Johnstone & Mughol, 1978).

Similarly, research was being conducted into student understanding about magnetism and electromagnetism, although not to the same extent as electricity or other areas of physical science (Driver, Squires, et al., 1994). One researcher who explored students' understanding of magnetism was Lloyd Barrow, who in 1987 what concepts should be covered for students when teaching magnetism (e.g., understanding magnetic poles, magnets can attract and repel, and magnets have a variety of sizes and uses). He also indicated that students he had worked with were aware of magnets from prior use at home or school, and identified some misconceptions that students may have. For example, students were unsure what a pole of a magnet represented and while students generally had an understanding about attraction forces, they did not fully understand the concept of repulsion. It was also noted that students had limited comprehension around electromagnetism (however, this gap in understanding may be linked to students not exploring and studying electrical circuits) (Barrow, 1987).

Barrow (1990) then analysed 10 textbooks that targeted elementary science to see how magnetism concepts were represented to investigate how they may influence misconceptions. After careful examination of these books, Barrow (1990) noted that: most of the concepts he identified in his earlier work had some coverage in the textbooks, but to varying degrees of representation; there was a lack of consistency of key definitions between different textbook series; and, most of the concepts were introduced as 'prose' (i.e., expressed to students in a matter of fact and dull way).

Almost three decades later, further research into educational materials to supplement the teaching of magnetism was completed by Barrow and Robinson (2007). During this study, trade books³ were analysed to explore their effectiveness of portraying the same concepts identified earlier (i.e., Barrow, 1987). Similar results were seen during this study to one about textbooks. Again, not all trade books had coverage of the concepts, and some even perpetuated misconceptions.

Also, in his book to support teachers with teaching physics concepts, Stepan (1994) identified some misconceptions in magnetism that students might have.

³ Trade books contain scientific information and are intended for the public and to introduce students to concepts, in contrast to textbooks which are intended for instructional purposes. Trade books can be seen as a useful resource to introduce scientific concepts outside of school, and supplement or replace textbooks in classrooms (Ford, 2006; Yacoubian et al., 2011).

However, upon critique, Barrow (2000) notes that there are no sources or evidence identified in the book by Stepan (1994) that qualify this list of misconceptions. However, this omission may be because the book is aimed at offering teachers useful and insightful activities to help them teach physical science concepts, rather than presenting empirical data and discussing research findings.

When reviewing the work of Barrow (1987, 1990), Barrow and Robinson (2007), and Stepan (1994), three major student difficulties become apparent, which are:

- Comprehending magnetic poles,
- Understanding attraction between magnets and other objects, and
- Identifying magnetic fields generated by current flow (electromagnets).

This information about student misconceptions was used by researchers to develop informed classroom pedagogies. This pedagogical development mainly focused on supporting science teachers by providing them with instructional strategies that they could practically employ with students. For example, the work of Osborne and Freyberg (1985) and their associates begins by outlining issues that science teachers may face in the classroom linked to students' conceptual frameworks. They then offer teachers useful pedagogical techniques they could use in the classroom. For example, in the context of electricity and magnetism, Cosgrove and Osborne (1985) propose teachers use a four phase sequenced approach for teaching a concept, the: preliminary, focus, challenge, and application phase. Table 2.3 below offers a summarised explanation of each of these phases.

Table 2.3: Four phase approach by Cosgrove and Osborne (1985) for teaching electricity and magnetism.

Phase	Explanation
Preliminary	This phase involves teachers developing an understanding of both a physicist's point of view and the students' point of view about a certain concept for phenomenon.
Focus	Here the teachers encourage the students to engage in a practical activity such as building circuits and then ask probing questions to focus on what the students are thinking about what is happening.

Table 2.3 Continued.

Phase	Explanation
Challenge	This phase is identified as the crucial piece of the sequence. During this phase, students can clarify and reconsider their own ideas by having their conceptual framework challenged by a new situation.
Application	This phase in the teaching sequence serves to reinforce the ideas that the students have developed during the challenge phase of the sequence. This reinforcement is achieved by encouraging the students to engage with a variety of different problems and situations whereby they require the knowledge that they have developed during the challenge phase to form explanations.

This sequence of pedagogical phases for developing students understanding in science is similar to current inquiry based models for science learning (e.g., Cross & Board, 2014; Harlen & Qualter, 2009; NRC, 2012) and supports the conceptual change process (e.g., Posner et al., 1982). To successfully navigate through these phases, Cosgrove and Osborne (1985) highlight the importance of skilled teaching, which requires specialised in-depth knowledge that combines topic specific content with key pedagogical strategies and recognition of the importance of students' prior knowledge. P. Scott, Asoko, and Leach (2007) agree, emphasising there is a need for teachers to have domain-specific knowledge to promote conceptual change.

These findings about teachers' required professional knowledge for effective learning in science align well with the notion of blending content and pedagogical knowledge, that is, the construct of pedagogical content knowledge (PCK).

2.4 Pedagogical Content Knowledge (PCK)

This section focuses on the development of the PCK construct and its conceptualisation for teaching science. Included within this section is an overview of how other researchers have tried to capture this form of teacher professional knowledge, and how two PCK Summits have been held to advance the agenda of PCK research.

2.4.1 The Development of the PCK Construct

During the 1980s, a paradigm shift to analysing and understanding teacher knowledge became an important consideration in research into teaching. This paradigm shift advocated moving away from viewing teaching as a generic and non-specific activity with the focus on teacher behaviour, to a focus on teacher knowledge as highly specialised and unique to each teacher (Hashweh, 2013; Shulman, 1986). Exploring this idea, Lee Shulman (1987, p. 8), conceptualised seven categories of a teacher's professional knowledge, including the new construct of PCK.

The seven categories were:

1. Content knowledge;
2. General pedagogical knowledge (such as classroom management and organisation);
3. Curriculum knowledge;
4. Pedagogical content knowledge (PCK);
5. Knowledge of learners and their characteristics;
6. Knowledge of educational contexts; and,
7. Knowledge of educational purposes and values.

Of these categories, PCK became an important influence on educational research (Shulman, 1986, 1987), particularly in mathematics and science. On reflection about the development of PCK three decades later, Shulman (2015) writes that the academic construct of PCK arose from the recognition that while there was an abundance of research into teachers' content knowledge, and their general pedagogical knowledge, there was a gap in domain specific pedagogies where the two forms of teacher knowledge merged. At the time of its initial development, Shulman (1986) conceptualised PCK as a special blend or amalgam of knowledge. This construct took two different, but important, aspects of professional knowledge for teaching and combined them together: knowledge of content, and knowledge of pedagogy (Shulman, 1986). With reference to teaching particular ideas in a given subject area, Shulman (1986) defined PCK as being:

The most useful form of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others. Since there are no single most powerful forms of representations, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice.

(p. 9).

His initial work on PCK highlighted the importance of teachers having sufficient content knowledge to be able to develop a rich understanding about certain concepts and then having the pedagogical knowledge and wisdom to be able to represent this information to students. He also acknowledged the need for teachers to identify and/or develop appropriate pedagogical strategies that recognised students' prior knowledge. He emphasised that the existing knowledge and preconceptions students have may include misconceptions, and careful considerations on the teacher's behalf is required to address them (Shulman, 1986).

These initial thoughts about PCK were then further refined by Shulman (1987):

It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.

(p. 8)

He uses this statement to indicate that PCK is the major difference between a person who is a skilled specialist at teaching a particular topic to particular groups of students, and a person who has little experience in teaching the topic. It follows that to be effective at teaching a certain topic, a rich PCK must be developed where a teacher can use a variety of examples and pedagogical strategies to illustrate particular concepts, make connections between topics, appreciate student

understanding, and identify big ideas (e.g., Gardner & Gess-Newsome, 2011; Lee, Brown, Luft, & Roehrig, 2007; Magnusson, Krajcik, & Borko, 1999; Yeo, 2008).

Like many new constructs in research, PCK would become the focus of major debate amongst academics over the coming years. Debates included how PCK is conceptualised, and its place within educational research, education reform, and the classroom. For example, Hashweh (2013) argued that Shulman did not examine “the interactions amongst the other categories, the hierarchies that might exist between them, or the different forms or types of knowledge within each category” (p. 117). Hashweh’s (2013) view was that this omission then placed the nature and conceptualisation of PCK under scrutiny and allowed for academics to critique it for the next three decades.

This scrutiny since the mid-1980s resulted in arguments in the literature that revealed the complexity of PCK. For example, van Driel, Verloop, and de Vos (1998) note a trend for various elements of PCK to be included and discussed in different ways by researchers, leading them to conclude that there is “no universally accepted conceptualization of PCK” (p. 677). Nevertheless, there are certain aspects of PCK that have been identified and commonly accepted amongst researchers, such as: it is a special type of personal knowledge that is unique to each individual teacher (e.g., Hume et al., 2013; van Driel et al., 1998); it develops over time as a teacher transitions from a novice to an experienced teacher (e.g., Kind, 2009; van Driel et al., 1998); it takes into account a teacher’s knowledge of three areas: content, pedagogy, and context (e.g., van Dijk & Kattmann, 2007); and, it recognises the importance of identifying areas and concepts that students may find difficult, or may have misconceptions in (e.g., van Driel et al., 1998). The general consensus amongst researchers was that PCK is derived from knowledge of subject, pedagogies, and context, as exemplified in a model of PCK sources proposed by Magnusson et al. (1999), which is shown on the following page as Figure 2.4.

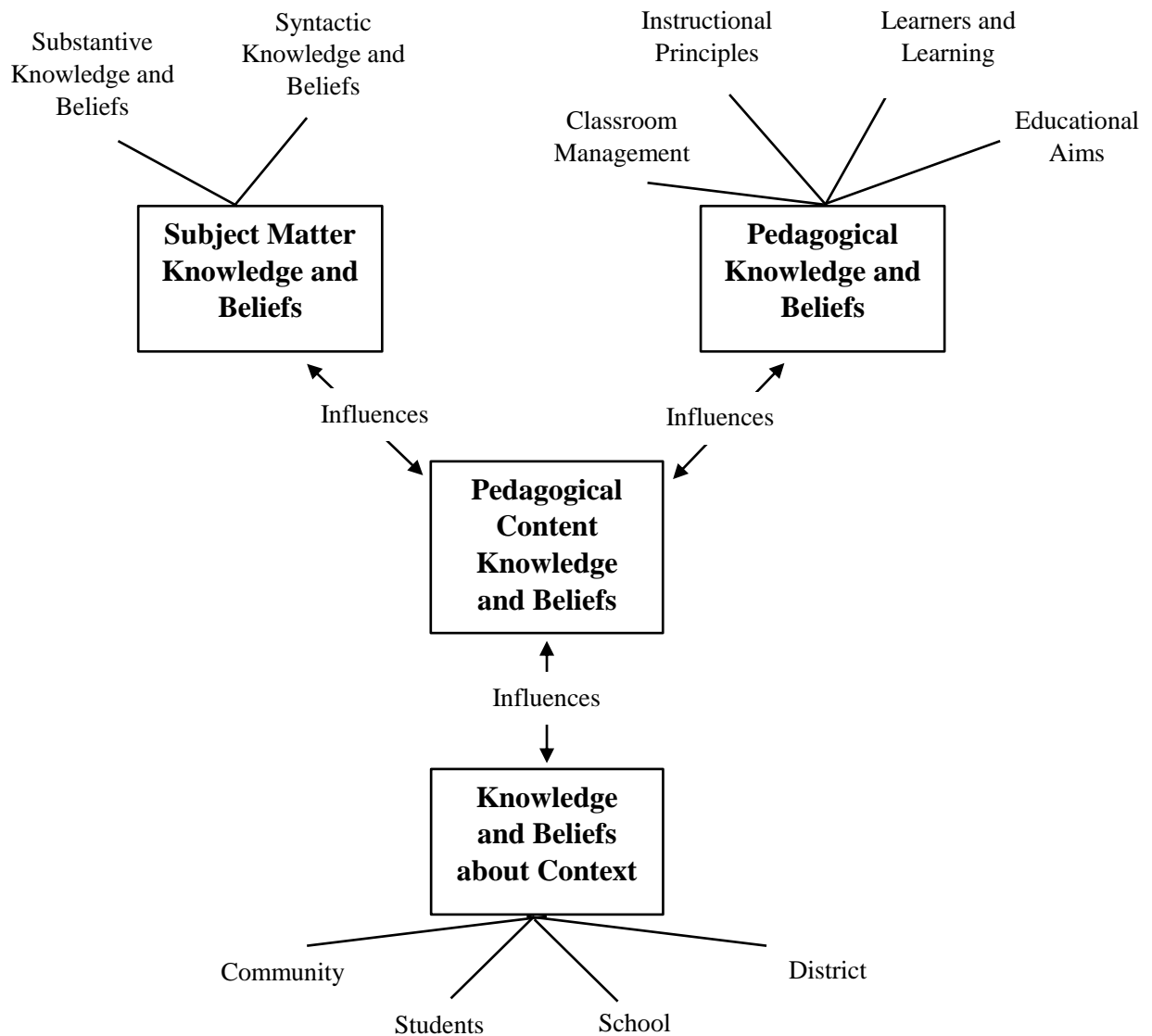


Figure 2.4: A model of teacher knowledge showing PCK as unique knowledge and the knowledge categories that it draws from (Reprinted with Publisher's permission from Magnusson et al., 1999, p. 98).

In Figure 2.4, subject matter knowledge represents both practical, and theoretical knowledge, as well as an understanding of rules and conventions associated with that knowledge area. Pedagogical knowledge includes knowledge about classroom management strategies, methods of delivery, learners and learning, and educational objectives and aims. Knowledge about context refers to considerations and information about the students and school, as well as the community and region of the school (Magnusson et al., 1999).

However, whilst the PCK construct was developed as a category of teacher knowledge, Shulman (2015) reflects that some important limitations need to be considered about the early conceptualisation and work around PCK. He identified four limitations, which are summarised below:

1. The first conceptualisation of PCK did not consider non-cognitive attributes such as emotion, feelings and motivation. He writes that these attributes should be an important consideration as they affect the relationship between the teacher and student, and how the teacher behaves and teaches.
2. The construct of PCK was highly intellectual leaving it inaccessible to some teachers. He believes that “the idea of PCK needs to place much-needed emphasis on teacher thought and emotion, but not by ignoring the role of action in teaching practice” (Shulman, 2015, p. 10).
3. PCK did not take attributes from a broader social and cultural context into consideration sufficiently. He writes that the contextual setting in which teachers and students are immersed have a great impact on the learning that takes place.
4. There was little emphasis placed on outcomes during the early work of PCK. He notes that behaviour processes were replaced by intellectual processes, but products and outcomes were ignored. This change meant that there was a gap in the relationship between how teachers taught and what students were learning.

While a general conceptualisation of PCK has been researched and outlined above, this next section introduces a conceptualisation that is specific to science education.

2.4.2 Conceptualising PCK for Science Education

As with any complex and multifaceted concept or construct, different researchers and academics make varied interpretations about what they consider to be important ideas, concepts, and considerations. One widely and accepted useful conceptualisation of PCK for science education was offered by Magnusson et al. (1999). Their model has since been the framework most often cited when discussing science teachers' PCK (Gess-Newsome, 2015).

In their PCK model, Magnusson et al. (1999) furthered earlier work on components of PCK by Tamir (1988) and Grossman (1990) to identify five components comprising PCK for teaching science:

1. Orientations towards science teaching;
2. Knowledge and beliefs about science curriculum;
3. Knowledge and beliefs about students' understanding of specific science topics;
4. Knowledge and beliefs about assessment in science; and,
5. Knowledge and beliefs about instructional strategies for teaching science.

(Magnusson et al., 1999, p. 97)

Figure 2.5 on the following page shows how Magnusson et al. (1999) perceived each of these five components of a teacher's PCK for teaching science to be intertwined within the academic construct of PCK.

Of these five components, the model implies that most influential component on a science teacher's teaching is their *orientation towards teaching science* because this component will ultimately influence how a teacher will plan and deliver a lesson (Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008; Talanquer, Novodvorsky, & Tomanek, 2010). In their work reviewing what orientations towards teaching science teachers may have from the literature, Magnusson et al. (1999) identified nine different orientations for teaching science. These nine orientations, along with the goals allied to that orientation and its characteristic of instruction, are detailed in Table 2.4 on Page 55. Kind (2015) noted that teachers are known to move between different orientations as they teach a unit of work depending on what they want the outcome of that lesson to be.

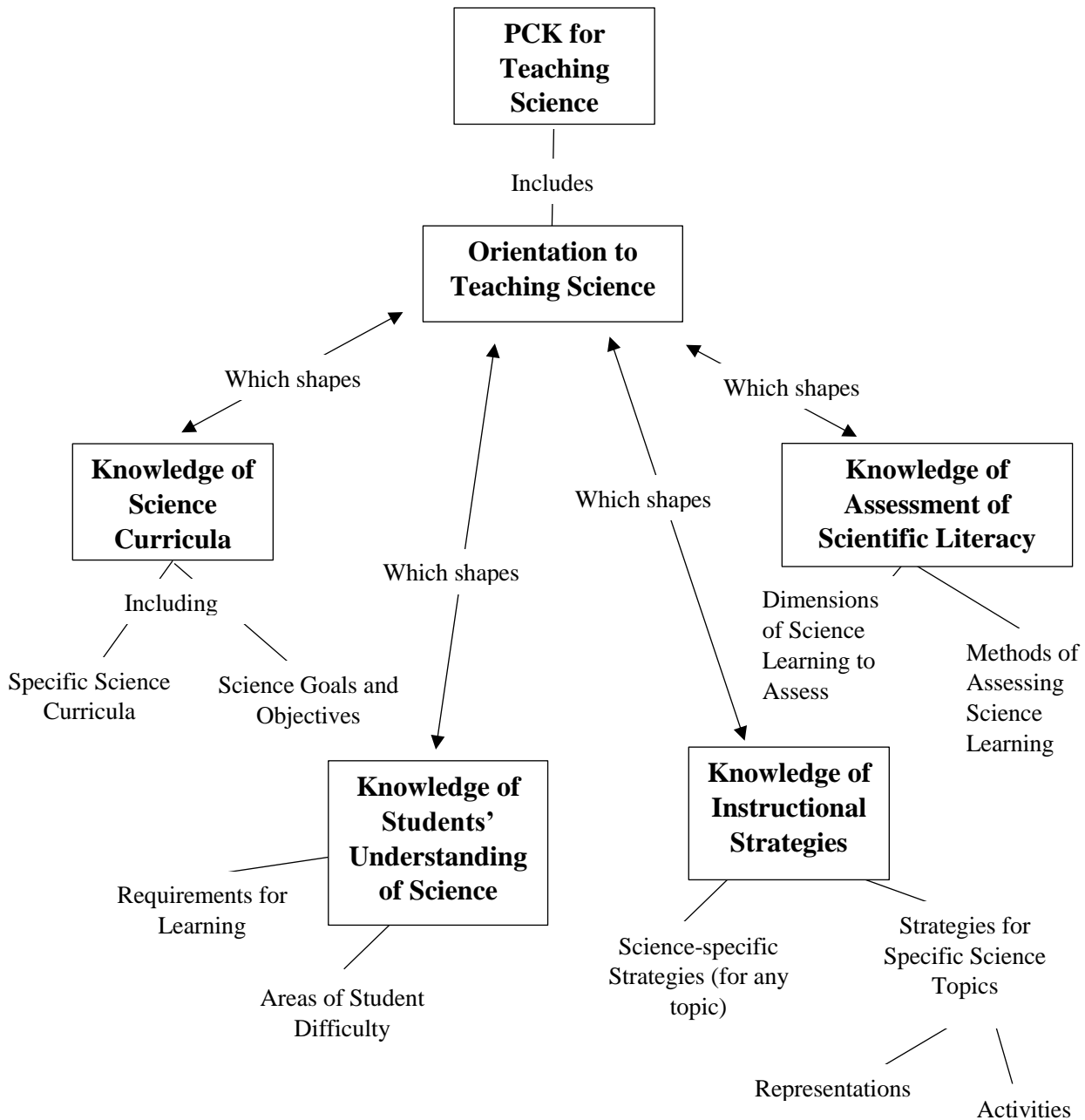


Figure 2.5: Key components of pedagogical content knowledge for teaching science (Reprinted with Publisher's permission from Magnusson et al., 1999, p. 99).

Table 2.4: The goals of different orientations to teaching science and their characteristics (Reprinted with Publisher's permission from Magnusson et al., 1999, p. 100 and 101).

Orientation	Goal	Characteristic
Process	Help students develop the "science process skills".	Teacher introduces students to the thinking process employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Represent a particular body of knowledge (e.g., chemistry).	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by revealing the relationship between particular concepts and phenomena.
Didactic	Transmit the facts of science.	The teacher presents information, generally through lecture or discussion, and questions are directed to students to hold them accountable for knowing the facts produced by science.
Conceptual Change	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions.	Students are pressed for their views about the world and to consider the adequacy of alternative explanations. The teacher facilitates discussion and the debate necessary to establish valid knowledge claims.
Activity-Driven	Have students be active with materials, "hands-on" experiences.	Students participate in "hands-on" activities used for verification or discovery. An issue with this orientation is that the chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	Provide opportunities for students on their own to discover targeted science concepts.	Student-centered where students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project-Based Science	Involve students in investigation solutions to authentic problems.	Project-centered where teacher and student activities centre on a "driving" question that organizes concepts and principles and steers activities within a topic of study. Through investigation, students develop a series of artefacts (products) that reflect their emerging understanding.
Inquiry	Represent science as inquiry.	Investigation-centered where the teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.

Table 2.4 Continued.

Orientation	Goal	Characteristic
Guided Inquiry	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science.	Learning is community-centered where 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 the adequacy of their conclusions. The teacher scaffolds students' efforts to use the material and intellectual tools of science, towards their independent use of them.

To aid with the reader's understanding about how different teachers' orientations influence their teaching, Magnusson et al. (1999) offer a useful example in the context of teaching students about electric circuits. They describe how a teacher with a 'discovery' orientation might give equipment (e.g., power supply, wires, bulbs) to students and let them follow their own ideas when exploring what is happening (e.g., getting the bulb to glow). Over time it is expected that these students discover different types of circuits. After this discovery process, the teacher can then put labels (scientific terms) to the circuits that they have made (i.e., open, closed, series, parallel). In contrast, a teacher with a 'conceptual change' orientation may encourage students to discuss their ideas about circuitry to develop an understanding of what existing ideas, including misconceptions, students possess. This teacher could then develop appropriate strategies to allow the students to build upon their existing ideas and perhaps experience some cognitive conflict that persuades them to adapt their ideas to a more scientific view. A teacher working with a 'guided inquiry' orientation develops a question, problem or situation to encourage students to explore aspects of circuitry. For example, challenging them to develop a model circuit to control lights in a house. This scenario enables students to discuss how they might achieve what they want (e.g., one light being on while another is off). These initial ideas could lead into discussions about circuit behaviour. Through this pedagogical approach, students are encouraged to converse with their peers to develop explanations about their observations that can then be compared to scientific views.

The Magnusson et al. (1999) model predicts a science teacher's orientation influences his/her knowledge of: science curricula, students' understanding,

assessment and scientific literacy, and instructional strategies, and this relationship is reciprocal (i.e., these knowledge forms also influence a teachers' orientation towards teaching science). This idea of reciprocity is represented in the Magnusson et al. (1999) model by the use of double headed arrows. While this model is a useful way to conceptualise PCK for science teaching, the complex relationships between all of the components suggest that teachers must make developments in each of the components to develop their overall PCK (Nilsson, 2014). Below is a summary of features for each of the other four knowledge components from the Magnusson et al. (1999) model of PCK for teaching science, that is: knowledge of science curricula; knowledge of students' understanding; knowledge of assessment of scientific literacy; and, knowledge of instructional strategies.

Knowledge of science curricula refers to a teacher's ability to identify important core ideas that are relevant the curriculum as a whole and ought to be learnt by students (Park & Oliver, 2008). Magnusson et al. (1999) indicate that there are two different knowledge categories for this component: the first relates to goals and objectives, and the second, specific curricular programmes. This knowledge of goals and objectives category refers to teachers understanding guiding policy documents and frameworks, and the implications for teaching. In New Zealand, goals and objectives are outlined in the NZC (Ministry of Education, 2007), but senior secondary school goals and objectives are influenced heavily by the NCEA qualification (Hume & Coll, 2008; NZQA, 2014b). The knowledge of the specific curricular programme category refers to teachers' understanding about "programmes and materials that are relevant to teaching a particular domain of science and specific topics within that domain" (Magnusson et al., 1999, p. 103). Geddis, Onslow, Beynon, and Oesch (1993) refer to knowledge of the curricula component as "curriculum saliency" (p. 588), which Mavhunga and Rollnick (2011) explain is having an understanding of the curriculum as a whole, including recognising which concepts are appropriate for students, and which ones are peripheral. Geddis et al. (1993) comment that the degree of a teacher's curriculum saliency can explain the differences between "covering the curriculum and teaching for understanding" (p. 589).

Knowledge of students' understanding refers to the need for teachers to be aware of what concepts the students may find difficult, what preconceptions they might

have, and their interests and learning styles (Park & Oliver, 2008). Again, Magnusson et al. (1999) developed this component further, including knowledge of requirements for learning and knowledge of areas of student difficulty. Knowledge of requirements for learning refers to teachers' understanding how students might learn certain concepts to ensure they are provided with adequate scaffolding of their learning and skills. For example, in a practical activity investigating how the resistance of a light bulb filament changes with heat, the teacher needs to be able to help students develop skills for gathering and interpreting data, such as using a multimeter and drawing graphs. Knowledge of areas of student difficulty refers to teachers having an understanding about the kinds of problems students may have when attempting to learn certain concepts and skills. Magnusson et al. (1999) identify three types of issues that teachers need to be aware of related to the difficulties students can experience learning certain concepts and skills. Firstly, many concepts in science are somewhat abstract making them difficult for some students to grasp. In these learning situations teachers will need to use pedagogical strategies that make the concept more accessible to the learners. Secondly, some situations may require students to think critically and employ problem solving skills which the students need to further develop. Lastly, some students may have misaligned or alternate views that conflict with the targeted scientific concept (i.e., misconceptions), which hinder learning.

Knowledge of assessment of scientific literacy is separated into two categories by Magnusson et al. (1999), that is "knowledge of the dimensions of science learning that are important to assess, and knowledge of the methods by which that learning can be assessed" (p. 108). The first category refers to teachers being knowledgeable about which aspects of scientific literacy could be assessed within a particular unit of work (i.e., *what* to assess). Teachers with a well-developed PCK will be able to identify which aspects can be assessed, and will plan and enact lessons accordingly to ensure appropriate assessments can be conducted. The second category refers to teachers' knowledge about how to carry out appropriate assessments (i.e., *how* to assess). Teachers with a rich PCK will be knowledgeable about different methods of assessments and their appropriate use. For example, if conceptual knowledge was being assessed, questions or written examinations could be used. However, if

students' skills in science were being targeted, it may be more appropriate for students to carry out a research project or investigation (Magnusson et al., 1999).

Knowledge of instructional strategies refers to a teacher's ability to use strategies that are both subject specific and topic specific (Magnusson et al., 1999; Park & Oliver, 2008). In essence, this component of PCK is about science teachers representing complex ideas to students in ways that are scientifically valid, but also accessible, in other words "the teacher needs to simplify sufficiently to suit the learners' present purposes, but not oversimplify to undermine their future needs" (Nilsson, 2014, p. 1803). Magnusson et al. (1999) identify subject specific strategies as those strategies teachers may use in science that are different to other domains. For example, subject specific strategies for science could include the use of the 'learning cycle' as outlined by Lawson, Abraha, and Renner (1989), which is a three phase process of exploration, term introduction and concept application. Similarly, teachers could employ the '5Es model' in science inquiry learning (e.g., Hume, 2013) which is a five phase process that encourages students to engage, explore, explain, elaborate, and evaluate. These science specific strategies are further outlined in Table 2.5 and Table 2.6 respectively.

Table 2.5: The three phases and focuses of the learning cycle. Constructed from the information discussed by Lawson et al. (1989).

Phase	Focus
Exploration	Students explore new phenomena with little guidance to raise questions that their preconceived conceptual frameworks cannot answer. Students are encouraged to develop a hypothesis to explain their observations.
Term Introduction	Terms are introduced by the teachers that provide students with scientifically accepted information to help them develop their hypothesis and explain patterns of observations.
Concept Application	Additional phenomena that are similar to those given in the exploration phase are given to the students that encourage them to apply their hypothesis to see if it still holds true.

Table 2.6: The 5Es Learning Model (Adapted with Publisher's permission, Hume, 2013).

Phase	Focus
Engage	Engage students and elicit prior knowledge.
Explore	Provide hands-on experiences of the phenomenon.
Explain	Develop science explanations and representations of developing understandings.
Elaborate	Extend understandings to a new context or make connections to additional concepts through student-planned investigations.
Evaluate	Re-represent understandings, reflect on learning journey, and collect evidence about achievement of conceptual outcomes.

These strategies above are specific to the domain of science, but Magnusson et al. (1999) also argue the need for science teachers to have an understanding of topic specific strategies, when referring to PCK for effective teaching.

Topic specific strategies refer to a teacher's ability to represent concepts from a topic in ways that facilitate students' learning and to use activities that promote student comprehension (Magnusson et al., 1999; Veal & MaKinster, 1999). Representations of concepts can be done in a variety of ways such as using models or analogies. For example, when teaching electric circuits teachers could use a water flow analogy (Duit, 1991) or an analogy of students crossing a combination of bridges to explain the relationship between resistors in series and parallel (de Almeida, Salvador, & Costa, 2014). However, effective teachers must clearly understand the link between the analogy and the scientific concept to ensure it does in fact aid the students understanding (Magnusson et al., 1999). For example, Duit (1991) cautioned that inappropriate use of a water analogy for circuits actually perpetuates misconceptions.

Activities that best promote student comprehension of concepts or relationships within a topic include the use of problems, investigations, simulations, experiments, and demonstrations (Magnusson et al., 1999). Again, Magnusson et al. (1999) indicate that effective teachers need to be aware of the strengths and weaknesses of using certain activities. These authors also make the point that knowing about which

subject specific strategies to use in different situations is often dependent on the teachers' subject matter knowledge and their own experiences learning that knowledge.

Some researchers have refined the model offered by Magnusson et al. (1999) to align more with their own perception of PCK. For example, in their work on PCK, Lee et al. (2007) and Lee and Luft (2008) build on the work by Magnusson et al. (1999) by identifying seven components of PCK:

1. Knowledge of science,
2. Knowledge of goals,
3. Knowledge of students,
4. Knowledge of science curriculum organization,
5. Knowledge of assessment strategies,
6. Knowledge of teaching strategies, and
7. Knowledge of resources.

(Lee & Luft, 2008, p. 1351)

Similarly, in their re-conceptualisation of PCK, Park and Oliver (2008) identified teacher self-efficacy, as an important consideration for PCK since teachers' perceptions of themselves influence their behaviour in the classroom. Their notion of teacher self-efficacy is developed from the concept of self-efficacy found in Bandura's (1986) work on social cognitive theory. In his work, Bandura (1986, p. 391) defines self-efficacy as:

People's judgements of their capabilities to organize and execute courses of action required to attain designated types of performances. It is concerned not with the skills one has but with the judgements of what one can do with whatever skills one possesses.

Park and Oliver (2008) see self-efficacy as an important consideration when researching teacher's PCK, as it is known, for example, that teachers' tendency to pursue or avoid certain learning activities and opportunities in the classrooms is reliant on their feelings of competence and/or confidence in performing these

pedagogies effectively. This addition of self-efficacy is consistent with the work on PCK for teaching science by Appleton (2006) who recognised the important influence of teacher confidence on the way science is taught. He noted that a low sense of confidence in their own knowledge and abilities is especially an issue for teachers who have an underdeveloped knowledge of science concepts and subject matter.

Despite the ongoing debate around the nature of PCK for science education, researchers in the field were attempting to capture the PCK of teachers and this research is still in its early stages within the science education community (Gardner & Gess-Newsome, 2011). The subjectivity, uniqueness and interpretive nature of PCK makes trying to capture a 'concrete' representation of teachers' special knowledge a difficult and daunting task (Bertram & Loughran, 2012; Cooper, Loughran, & Berry, 2015), and there is no agreed upon method in the science education community for achieving this research goal (Gardner & Gess-Newsome, 2011). Furthermore, it has been acknowledged that part of this difficulty stems from the lack of a consensus around the PCK construct (Kirschner, Taylor, Rollnick, Borowski, & Mavhunga, 2015). Nevertheless, there have been several attempts to capture PCK and the next section serves to highlight some examples.

2.4.3 The Complexity of Capturing PCK

As PCK is a specialised form of knowledge that a teacher develops over time with experience, beginning teachers are likely to have basic or limited PCK (Hume et al., 2013; Lee et al., 2007). To track its progression and developments over time it is important to be able to identify what a teacher's PCK may look like (Lee et al., 2007). When trying to capture PCK, Henze and van Driel (2015) assert that a single instrument cannot capture a teachers' PCK in a reliable way. This claim is based on some of their previous work (see Henze, van Driel, & Verloop, 2008) where semi-structured interviews were used to develop an understanding of the teachers' evolving PCK. While this method was useful at showing PCK developments of teachers over the duration of the research, because interpretations relied heavily on teacher responses, the study was somewhat limited as teacher behaviour in the classroom was not analysed (Henze & van Driel, 2015). To ensure the validity of

the data and to minimise limitations, Henze and van Driel (2015) discuss the significance of not only using interviews to investigate what the teacher may espouse, but to also investigate teacher behaviour and actions within the class – which they refer to as a triangulated approach.

This approach using different data sources has been employed by various PCK researchers who have developed rubrics⁴ for scoring different aspects of PCK. Examples of this style of PCK research are evident in the literature, with some researchers developing rubrics exploring different elements of PCK and appropriate quality indicators. For example, reviewing the work by Lee et al. (2007) and Gardner and Gess-Newsome (2011) shows useful insights to methods that have been used.

Lee et al. (2007) developed an interview protocol for interviewing their participating teachers and then observed them teaching. For the classroom observations, field notes were taken about the teachers' actions which were analysed using a rubric that the researchers had developed from the literature around PCK. This rubric targeted five components of PCK which were separated into two categories:

Category 1: Knowledge of Student Learning and Conceptions

1. Prior knowledge
2. Variations in students' approaches to learning
3. Students' difficulties with specific science concepts

Category 2: Knowledge of Instructional Strategies

4. Science specific strategies/scientific inquiry – this element of the rubric utilised the five essential features of classroom inquiry as identified by the NRC (2000, p. 25).
5. Representations.

(Lee et al., 2007, p. 54)

⁴ Rubrics provide a useful method for scoring specific pre-determined characteristics such as knowledge and behaviour. Scoring is achieved by comparing data (e.g., from interviews or observations) to quality indicators that have been developed (Mertler, 2001).

Teachers' knowledge and classroom practices were then scored against each of these PCK elements, and each had three levels that the teacher could be working at: *limited*, *basic*, or *proficient*. The crosscutting quality indicators through all five PCK elements with respect to these levels were:

- Limited
 - No acknowledgement or consideration of element,
 - No incorporation of element into the lesson, and
 - Teacher used strategies and approaches that were pedagogically ineffective.

- Basic
 - Teacher recognised or considered element,
 - Limited incorporation of element into the lesson, and
 - Teacher used strategies and approaches that were pedagogically limited or underdeveloped.

- Proficient
 - Element actively recognised and considered,
 - Recognition was incorporated effectively into the lesson, and
 - Teacher used well-developed strategies that were pedagogically effective.

The conclusions from this study indicate that their methods for understanding PCK, particularly the rubric, were useful. Furthermore, they suggest that the development of such a rubric lends itself to further discussion about the PCK construct and capturing PCK of teachers.

In another example, Gardner and Gess-Newsome (2011) gathered data in three different formats: written reflections, classroom observations, and interviews. For the written reflections, teachers were asked to write a detailed reflection on a topic-specific lesson they had taught including what they did, what the students did, and why they did it. Teachers were observed teaching (video recorded), and a topic-specific lesson of interest was chosen to be analysed. The interview phase of their data collection was used to improve the overall quality of the data, and the same prompts from the written reflections were used to probe teachers' responses to gain

insight into their understanding and knowledge. Analysis was done using a rubric that they had developed from previous published PCK work. Their rubric consisted of three categories, separated into eight elements:

Category One: PCK-Content Knowledge

1. Depth, breadth, and accuracy of content knowledge,
2. Connections within and between topics,
3. Connections with the nature of science, and
4. Fluency with multiple modes of representations or examples of a topic

Category Two: PCK-Pedagogical Knowledge

5. Rationale for linking teaching strategies to student learning,
6. Strategies for eliciting student prior understandings, and
7. Strategies to promote student examination of their own thinking

Category Three: PCK-Contextual Knowledge

8. Understanding how student variations, such as student prior conceptions, impact instructional decisions.

(Gardner & Gess-Newsome, 2011, p. 6)

From the written reflections, classroom observations, and interviews, teachers were then scored appropriately against four levels: *limited*, *basic*, *proficient*, or *advanced*. For each of the eight elements, the crosscutting quality indicators through all eight elements with respect to these levels were:

➤ Limited

- Inaccurate content knowledge,
- No connections made,
- No appropriate examples used,
- No recognition or consideration of students' prior knowledge,
- No suitable instructional strategies used, and
- No rationale or rationale not suitable for use of strategies.

- Basic
 - Some inaccuracies of content knowledge,
 - Few connections made,
 - Examples have potential, but lacking clear link to content,
 - Narrow understanding of students' prior knowledge,
 - Instructional strategies that have potential are used, and
 - Simplistic rationale for use of strategies offered.

- Proficient
 - Mostly accurate content knowledge,
 - Some connections made,
 - One example used that makes explicit content link,
 - Adequate understanding of student prior knowledge,
 - Appropriate instructional strategies used, and
 - Appropriate rationale of use of strategies offered.

- Advanced
 - Completely accurate content knowledge,
 - Many connections made,
 - More than one example used that makes explicit content link,
 - Sophisticated understanding of students' prior knowledge,
 - Highly effective instructional strategies used, and
 - Sophisticated rational of use of strategies offered.

Scores from each element were combined to allow for an overall score of the teacher's PCK. These authors note that researchers can interpret the result in different ways, depending on the approach (e.g., high score versus average) and conclude that while their methods provided useful insights for PCK assessment, further work on developing a model for assessing PCK is needed.

These two accounts of studies show examples of how PCK has been researched and there are many other examples from researchers utilising different analysis techniques. For example, in their study, Park and Oliver (2008) not only used semi-structured interviews to gain an understanding of what a teacher's PCK looked like,

but also developed an observational protocol for carrying out lesson observations and identifying evidence of PCK (see Park & Oliver, 2008, p. 281). Similarly, Alonzo, Kobarg, and Seidel (2012) viewed videos of classroom teachers in action to make judgements about their PCK, although these authors do acknowledge that they cannot claim a full account of PCK by observations alone. For their analysis, they explored three broad categories of PCK:

Category One: Flexibility

Teachers' recognition of students' unconventionally worded contributions and rewording of their own questions when students exhibited confusion.

Category Two: Richness

Teachers' use of examples and connections among multiple representations (e.g., words, formulas, and drawings) to enhance students' understanding of the content.

Category Three: Learner Centered

Teachers' recognition of what piece(s) of content students need in order to grasp other pieces, as well as what content students find to be difficult and why.

(Alonzo et al., 2012, p. 1221)

These authors coded fragments of the observations to each of these broad categories identified whether they had a positive or negative effect on student knowledge or interest development. By correlating parts of the observations with student outcomes, they were able to make judgements about their participant teachers' PCK.

Using a different style of portraying PCK, Park and Chen (2012) mapped out components of PCK using biology teachers as participants. During this study, these researchers combined semi-structured interviews and classroom observations to

collect data. They recognised that these methodologies were effective at collecting data to develop their PCK maps, but there was a risk of oversimplifying the complex nature of PCK by using a simple map.

As shown in the previous two sections, different researchers advocate for divergent conceptualisations of PCK and methods to capture it. In the search for agreement between members of the science education community and ways forward in PCK research, ideas, beliefs, and opinions needed to be shared and critiqued. This bringing together of PCK philosophies was done via PCK Summits, where members from this community met to share and develop their own understanding.

2.4.4 First PCK Summit: Re-examining PCK in Science Education

To further re-examine and re-conceptualise PCK for science education, a PCK Summit was held in Colorado in 2012. This summit invited 22 active science education researchers, who utilised PCK in their research, to share their research, ideas, and opinions about PCK to guide and advance future science education research and the PCK construct (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015). It was recognised that these researchers had differing views on PCK and prior to the summit they were asked to synthesise their own research. This synthesising process encouraged participants to describe the nature of PCK, the model that they used as a conceptual framework, and how they collected and analysed data (Gess-Newsome, 2015). The week of intense discussion at this summit led to a comprehensive book that explored how various researchers conceptualised PCK for science teaching, their experiences with PCK, policy guidance, research developments, and future directions (Berry, Friedrichsen, & Loughran, 2015).

The book featured a consensus model for PCK – a model of PCK that represented all Summit participants' thinking about the PCK construct (Gess-Newsome, 2015; Kind, 2015). Whilst some researchers refer to this model as the 'consensus model of PCK', it was originally titled 'a model of teacher professional knowledge and skill including PCK and influences on classroom practice and student outcomes' or simply, TPK&S. This model is shown in Figure 2.6 on the following page and the elements are elaborated upon.

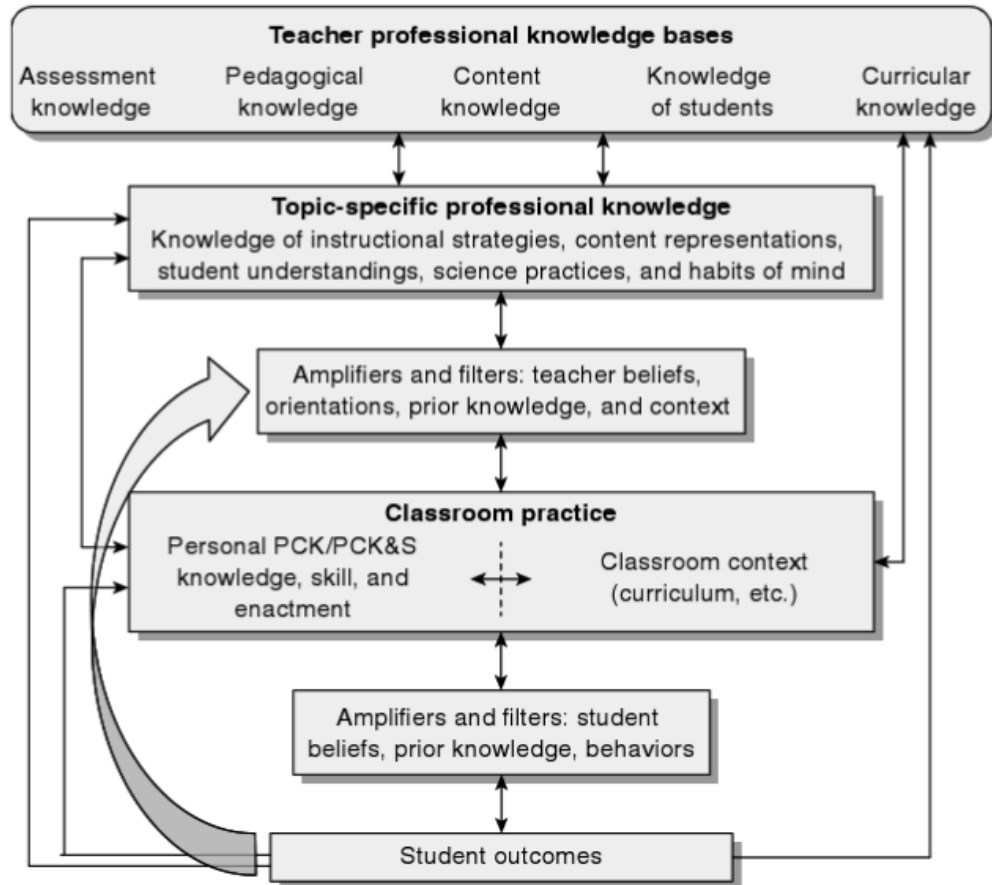


Figure 2.6: A model of teacher professional knowledge and skill including PCK and influences on classroom practice and student outcomes (Reprinted with Publisher's permission from Gess-Newsome, 2015, p. 31).

In this model, the Teacher Professional Knowledge Bases (TPKB) are seen as knowledge forms that are generated by research and experts, and they are formal bodies of knowledge which may extend beyond what a teacher requires. Teachers draw on this information when required (Gess-Newsome, 2015). These knowledge bases are general in terms of their applications to different learning areas, for example, having knowledge about formative and summative assessment ‘as a whole’, rather than within the specific application to a science context.

The application of these knowledge bases within contexts is acknowledged by the form of knowledge known as Topic-Specific Professional Knowledge (TSPK), where the focus has changed from teaching science in general terms, to a particular topic with a particular group of students. For example, one aspect utilised from the TPKB could be knowledge of a variety of different pedagogical strategies for

teaching students. Then, TSPK could refer to selecting those strategies based on which would be most appropriate for that particular topic and group of learners. Gess-Newsome (2015) explained that TSPK was where PCK was previously situated. However, TSPK is not considered private knowledge in the consensus model. It can be generated by research and best practice, it can be measured, it can be taught, and it could be used as a framework for professional development. Examples of TSPK may include having an appreciation and understanding for incoming student misconceptions, or how to include learning about the nature of science into a particular science context.

The classroom practice portion of the model recognises the input of TPKB and TSPK into a classroom teacher's PCK, and that it relies largely on the context of the situation. Whilst there is this 'knowledge' available to teachers, they choose which parts to accept and use and which parts to ignore. This decision making is where of amplifiers and filters come into play. For instance, a teacher's self-efficacy, personal philosophy for teaching science, or their willingness to take pedagogical risks will affect their application of TSPK into their classroom practice. The model shows that PCK is personal to a particular teacher, it is highly context specific, and it can be seen in teacher's planning for a lesson, or their enactment in the classroom, or it may be the teacher responding to an unexpected episode within the lesson. The classroom practice portion of the model reflects the thinking at the Summit, which lead to the development of two PCK constructs: Personal PCK and Personal PCK and skill (PCK&S) (Gess-Newsome, 2015). The definitions for these are as follows:

- Personal PCK is the *knowledge of, reasoning behind, and planning* for teacher a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes*.
- Personal PCK&S is the *act of teaching* a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes*.

(Gess-Newsome, 2015, p. 36)

Finally, student outcomes refer to what the students learn and experience in the classroom, and like teachers, there are amplifiers and filters that influence the entire learning process for students (e.g., student behaviour or engagement). These influences make it difficult to make judgements about the quality of teaching directly from test and examinations results. Not only do these amplifiers and filters affect student outcomes, but they also influence the classroom environment and the lesson (as well as influencing future lessons).

The intent behind developing this new consensus model was to create a model that all PCK researchers were comfortable with and could work with in their research. Rather than different researchers using different models, there could now be consensus within PCK research in the science education community that was being conducted internationally. Release of this model into the educational community led several years later to a second PCK Summit to critique its applicability. This second PCK Summit is covered in the next section.

2.4.5 Second PCK Summit: Analysing Science Teachers' PCK

The second PCK Summit was held in December 2016, in Leiden, the Netherlands. As the research information explored and discussed at this event is still being refined for publication and presentations, some of the references here are from personal communication with various Summit participants, including emails, conversations, and presentations. Like the first Summit, 26 active PCK researchers were invited to attend. Through the PCK work that my Chief Supervisor, Anne Hume, had carried out, we were invited to this Summit as an experienced and emerging researcher pair. Throughout the first part of the week of the Summit, various researchers from around the world shared in-depth details of their research to be critiqued by others within small groups. Ideas were summarised and information was reported back to the whole group. This information was collated by the Summit organising committee to guide the rest of the week's activities.

The second part of the week involved presentations from Julie Gess-Newsome (Oregon State University) about the evolution of the TPK&S model, and from Knut Neumann (Leibniz Institute for Science and Mathematics Education) about experiences using the model, interpreting the model, and refining what different

aspects of the model *actually* meant. Interestingly, during this phase of the Summit, a discrepancy in the book produced from the 2012 Summit was identified (i.e., Berry et al., 2015). There were two different versions of the model presented in the book; that depicted by Gess-Newsome (2015, p. 31) and the other version by Kind (2015, p. 192). This discrepancy raised interesting discussion points within the group. For example, when these models were presented side-by-side, an issue related to how different aspects influenced each other throughout the model was highlighted. For example, the TPK&S model (Gess-Newsome, 2015) can be driven from the bottom-up and from the top-down, compared to the Kind (2015) model, which only shows a top-down approach (J. Gess-Newsome, personal communication, December 8, 2016). The Kind (2015) model appeared to be an earlier version of the TPK&S model.

Following both presentations, and with input from the organising committee, three working groups were formed to tackle ideas for advancing the agenda of PCK research in science education. The three areas were tasked with: developing a ‘grand rubric’ to make judgements about various aspects of PCK and TSPK; identifying common issues that researchers face when working with PCK; and, re-exploring and revising the model, and making adaptations and changes where necessary.

The working group discussing quality indicators of PCK to inform a grand rubric was led by Kennedy Chan (University of Hong Kong) and Julie Gess-Newsome (Oregon State University). This discussion was initially based on a synthesis of rubrics that Chan had undertaken as part of his research. The rubrics that he used were those that other researchers had developed and used when working with PCK (see Alonzo et al., 2012; Gardner & Gess-Newsome, 2011; Heller, Daehler, Shinohara, & Kaskowitz, 2004; Kaya, 2009; Lee et al., 2007; Mavhunga & Rollnick, 2011; Park, Jang, Chen, & Jung, 2011). The initial discussion amongst this group of researchers identified eight qualities of PCK to be considered for inclusion in a grand rubric:

1. Accuracy of PCK (connection between content and strategy),
2. Richness of PCK,
3. Flexibility of the knowledge base, or coherence or integration of the knowledge,

4. Quality of integration,
5. Appropriateness of PCK (relevance and pedagogical effectiveness),
6. Alignment to key ideas,
7. Learner-centred, and
8. Sophistication of pedagogical reasoning

The main purpose of this exercise was to identify qualities that could be used across different data sources – although it was discussed that some may be omitted for different forms of data. For example, analysing the sophistication of pedagogical reasoning (i.e., *why* a teacher did a certain thing) can only be gathered from interviews about teaching, rather than observational data.

Discussion around these tentative qualities developed into five quality indicators that could be used for a PCK rubric, including:

1. Connection and selection of big ideas.
Coherence between big ideas (and smaller ideas). The ideas selected are relevant to the students and are pedagogically appropriate.
2. Selecting appropriate instructional strategies (including representations).
Appropriate instructional strategies and representations for the student, content, and context are used. Student-centred approaches that promote meaningful learning (a teacher led lesson can still be student-centred).
3. Recognising variation in student learning.
A positive classroom environment and climate is created to promote opportunities for students to reveal their thinking. Student interests, misconceptions, and prior knowledge are incorporated into the lesson.
4. Selecting next appropriate instructional strategy or step (based on student understanding).
Instructional strategies are adjusted based on student understanding and learning different concepts. Appropriate strategies are used to advance student thinking.

5. Teachers being able to articulate why they did what they did (pedagogical reasoning).

Being interactive about why they are using certain instructional strategies in the lesson. (It was thought that this component could have its own rubric also.)

A concurrent discussion taking place in a second working group led by Aaron Sickel (Western Sydney University) and Knut Neumann (Leibniz Institute for Science and Mathematics Education), focused on developing ‘agreed upon knowledge’ when working with PCK. Although, it was pointed out by John Loughran (Monash University) and Jan van Driel (The University of Melbourne) that the nature of research and academia means that sometimes alternative interpretations can be made about the same idea from different researchers and authors. The result is the use of the same term, but its meaning can be interpreted differently to the original, for example, the different interpretations of the TSPK phrase that were made by different authors and researchers present at the Summit.

Within the one-hour timeframe, the goal of this working group was to identify areas of contention with regards to PCK research. Areas that were identified were:

- Different interpretations and use of topic-specific and discipline specific professional knowledge.
- Differences between personal PCK, collective PCK, and canonical PCK.
- The roll of the amplifiers and filters within the model (this point was also being concurrently discussed by the group revising the model).
- Quality indicators for analysing PCK (this point was also being discussed by the group developing a grand rubric).

The third working group discussion centered on the reconceptualisation of the consensus model was led by Janet Carlson (Stanford University) and Kirsten Daehler (WestEd). Group members’ attention turned to the relationships between components of the model, and their positioning. The outcome of their discussions was a diagram sketched on a whiteboard where the group removed the TPKB from the top of the model and put these to the side – to ensure they were context free. The group also introduced collective PCK (cPCK) – a new term referring to what a

group of teachers may know about how to teach a certain topic or concept. TPKB and cPCK was then linked to teaching practice and student outcomes, which are contextually bound by amplifiers and filters, and dynamic pedagogical reasoning. Within the teaching practice components of this revision, a different type of PCK was proposed – enacted PCK (ePCK) where the teacher is engaged in a feedback loop of planning, enacting, and reflecting (K. Daehler, Personal Communication, December 9, 2016).

After the Summit, Carlson and Daehler used this sketch and knowledge of discussion leading to its creation (with the aid of a graphic designer) to produce a new model that captured the thinking of the group. This refined PCK model and accompanying explanatory information was sent to Summit participants as a working document for critique and refinement before being presented at the annual international conference hosted by the National Association for Research in Science Teaching (NARST), in San Antonio, April 2017. Carlson and Daehler used researchers' feedback from the presentation and working document to further refine the model. Again, the outcome was a working document that was sent to all participants from the second PCK Summit and other selected PCK researchers. This refined PCK model is shown as Figure 2.7 on the following page.

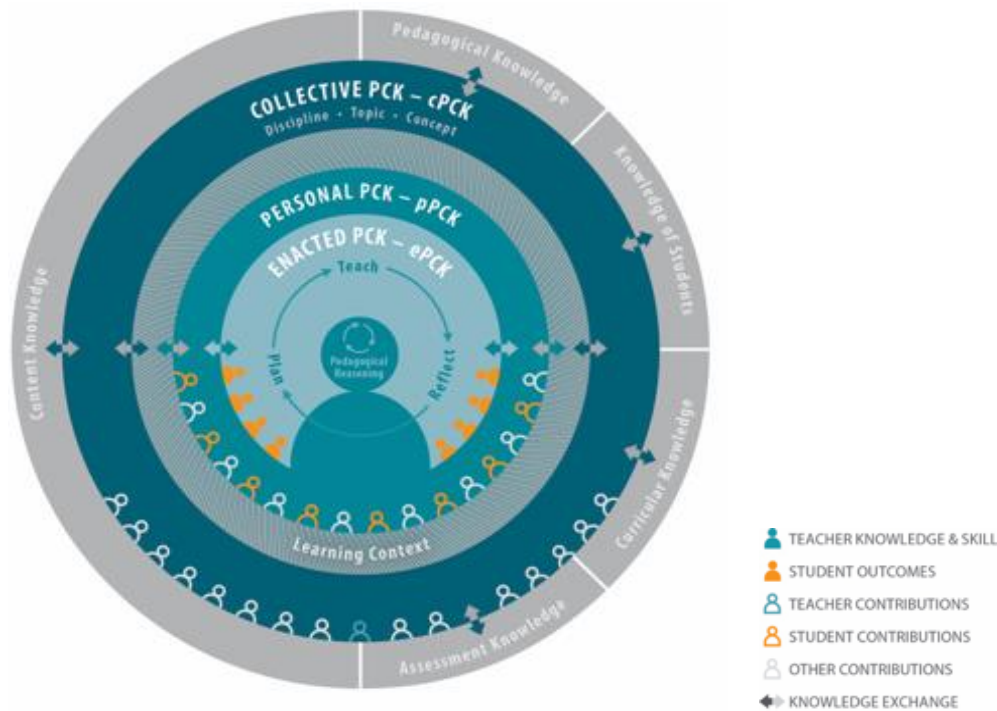


Figure 2.7: Refined Consensus Model of Pedagogical Content Knowledge (RCM of PCK) (Carlson & Daehler, 2018).

The unpacking of the Refined Consensus Model (RCM) of PCK above, which is used to inform this study, is based on the information provided in the working document. The model shows the influences on a teacher's unique PCK using concentric layers representing knowledge, experiences, and context. It is reasoned the concentric circles portray the complexity of PCK and the relationships between knowledge and experience better than using boxes and arrows (like the original consensus model).

To better understand this model, each concentric layer is explored, starting from the outside and moving inwards. The outer most layer represents teacher's professional knowledge bases, and is separated into two main groupings: subject matter knowledge (called content knowledge in the model), and general education knowledge. The general education bases represent knowledge that is often learnt through formal routes such as teacher education programmes. General education knowledge, as an overall base, is not explicit on the model, but it encompasses all those 'smaller' bases on the right-hand side: pedagogical knowledge, knowledge of

students, curricular knowledge, and assessment knowledge. Note, these knowledge bases are free from context and are not specific to a particular discipline.

The subject matter knowledge or content knowledge component refers to academic knowledge about a particular discipline (e.g., physics or chemistry), discipline-specific knowledge such as the nature of science, and the relationships between concepts and topics within domains (i.e., the interconnectedness of concepts, for example, current and resistance). Often this knowledge is learnt by the teacher via separate pathways from learning how to teach it (e.g., a Bachelor of Science). Teachers teaching out of field may have to learn this knowledge a different way.

The next layer inwards is referred to as collective pedagogical content knowledge (cPCK), which refers to a collection of contributions from professional knowledge sources and from various teachers about teaching a particular subject.

The grain size of specialised knowledge ranges from concept specific (e.g., teaching voltage in series circuits), to topic specific (e.g., teaching electricity and magnetism), to as broad as discipline specific (e.g., teaching physics). Examples of cPCK can be seen in journal articles or text books that are used to help with teacher instruction. One useful means for representing cPCK are content representations (CoRes) that have been developed by groups of educators (CoRes are discussed in the following section). For example, in their book about understanding and developing science teachers' PCK, Loughran, Berry, and Mulhall (2006) offer several CoRes which exemplify cPCK. Within the working document, Carlson and Daehler indicate that it is this particular layer of the RCM of PCK that has been a focus in PCK literature since its inception in the mid-1980s.

The RCM of PCK recognises that the context in which teaching and learning takes place in will affect a particular teacher's knowledge and practice. This recognition is represented in the Learning Context layer within the mode, which is shown as the layer that influences how shared and canonical knowledge is transformed into the teacher's own unique knowledge. The learning context refers to external influences on the teacher's knowledge and actual classroom teaching, such as national policy documents (e.g., NZC), qualifications (e.g., NCEA), and school priorities. These external influences drive many decisions within a school and classroom, and will influence what students are taught, and how. Student attributes are also included

within the Learning Context layer, as the teacher's understanding of student attributes will influence teacher knowledge and how they teach. Examples of student attributes include what curriculum level they are working at, their prior knowledge and misconceptions, their level of engagement and willingness, and their language proficiency.

Synthesis of a teacher's knowledge bases, cPCK, and the Learning Context develops into the teacher's personal pedagogical content knowledge (pPCK). This specialised pPCK is unique to a particular teacher and is influenced by teaching and learning experiences, input from collaboration with colleagues, and from engaging with different teaching resources and texts. Over time, pPCK develops and is further refined and it is the knowledge a teacher draws on when teaching particular topics or concepts in particular contexts.

When a teacher then accesses pPCK in an act of teaching, whether planning or teaching a lesson, they draw on and apply different parts of their pPCK that are applicable for a particular teaching episode. This application of pPCK is referred to as enacted pedagogical content knowledge (ePCK). Essentially, ePCK can be seen as a subset of pPCK, as the teacher may choose which aspects of their pPCK to utilise in the lesson, based upon prior experiences or the particular students they have at the time. The link between pPCK and ePCK, is pedagogical reasoning. Since ePCK is an application of pPCK based on the actual practice of teaching, it is fitting to view teaching and the pedagogical reasoning process as being dynamic, involving planning, enactment, and reflection, along with influence from colleagues.

While the diagram of the model denotes a somewhat static view, it is important to note the 'knowledge exchange' feature represented by the double-headed arrows between the layers. The purpose of this feature is to show that the entire model is dynamic, and that changes within one layer can affect another. Within this function of the model is the recognition of the amplifiers and filters on knowledge (from the first consensus model). For example, aspects such as teacher motivation and personal philosophy for teaching, or self-efficacy may act as amplifiers and filters, thus affecting knowledge exchanges between layers.

Like the first Summit, it is intended that another book will be published as a result of the second PCK Summit that will encapsulate all of the outcomes from the discussions of participants. It is hoped this book, including the RCM of PCK, will become a seminal reference point for those in the science education research community working with PCK.

During the early 2000s there was significant effort placed on developing, conceptualising, and understanding frameworks for portraying science teachers' PCK. At that same time, a particular development was being made which could represent this complex knowledge, which was called content representations (CoRes) (Loughran et al., 2006; Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000; Loughran, Mulhall, & Berry, 2004, 2008). The nature of CoRes and how they have been used to capture teacher knowledge and develop knowledge are discussed in the following section.

2.5 Content Representation (CoRe) Design

This section focuses on the development of CoRes to represent teachers' PCK, and how other researchers have used the process of developing CoRes (denoted as CoRe design) to enhance teacher's PCK.

2.5.1 Development and Process of CoRe Design

In 2000, John Loughran and his fellow researchers were exploring ways of representing the complexity of teachers' PCK (Loughran et al., 2000). The exploration led to the development of an approach that allowed teachers to work in a collaborative environment where they could think about and share how they might teach particular parts of a science topic to particular groups of students (Loughran et al., 2000). The tool they developed for depicting teachers' PCK in this collaborative approach became known as a content representation (CoRe) (Loughran et al., 2004). Accompanying each CoRe was a set of portrayals of teachers' classroom practice related to the teaching of specific scientific parts of the CoRe topic. These narratives became known as Professional and Pedagogical

experience Repertoires (PaP-eRs) (Loughran et al., 2006; Loughran et al., 2000; Loughran et al., 2004).

These two instruments for understanding and representing teachers' PCK were being developed concurrently. CoRes can be seen as "a holistic overview of teachers' pedagogical content knowledge related to the teaching of a given topic", while the PaP-eRs are "narrative accounts designed to purposefully offer insights into specific instances of that PCK" (Loughran et al., 2006, p. 25).

The CoRe itself takes the form of a spreadsheet-styled document with headings and prompts for teachers to address (see Appendix E2). The first step in developing a CoRe is to identify what key ideas are present within a science unit – called 'the big ideas'. Recognising what to actually teach students as a first step is an important consideration as it illuminates things that students may find difficult to understand, which can have an impact on developing misconceptions (Meyer & Land, 2006; Stokes, King, & Libarkin, 2007). This identification of big ideas represents the first step in pedagogical reasoning.

Once these big ideas have been identified, teachers use their professional knowledge to collaborate with others to develop responses to eight prompts. The eight prompts are designed to unpack pedagogical considerations related to teaching a specific big idea, and they are:

1. What do you intend students to learn about this idea?
2. Why is it important for students to know this?
3. What else you know about this idea (that you do not intend students to know yet)?
4. Difficulties and/or limitations connected with teaching this idea,
5. Knowledge about students' thinking which influences your teaching of this idea,
6. Other factors that influence your teaching of this idea,
7. Teaching procedures (and particular reasons for using these to engage with this idea), and
8. Specific ways of ascertaining students' understanding or confusion around this idea (include like range of responses).

(Loughran et al., 2006, p. 28)

Each of these prompts and their underlying themes and intentions are elaborated upon in Table 2.7 below.

Table 2.7: CoRe design pedagogical prompts and their underlying themes and intentions.

Pedagogical Prompt	Underlying Themes and Intentions
What do you intend students to learn about this idea?	This prompt is important for first identifying key and specific learning outcomes. Loughran et al. (2006) point out that experienced teachers find little difficulty with this first task. However, in contrast, teachers who are inexperienced in this area may be unsure and find it difficult to think of what the students are capable of achieving. After identifying key learning outcomes, the next question to think about is, why are these important?
Why is it important for students to know this?	Loughran et al., (2006) suggests that one of the key reasons for identifying various learning outcomes is linked to other curriculum aims. It is also suggested that effective teachers link what is being taught to students' lives and experiences to ensure students can relate to the content.
What else you know about this idea (that you do not intend students to know yet)?	The nature of scientific knowledge is complex and science teachers must ensure that they find an appropriate balance between not over simplifying a concept or making it too complex (Loughran et al., 2006). This part of the CoRe allows for teachers to then begin thinking about the notion of misconceptions and how they might affect student understanding. It also allows teachers to think about the next learning progression in the curriculum.
Difficulties and/or limitations connected with teaching this idea.	Identifying and addressing of student misconceptions is an important aspect of a rich and developed PCK (e.g., Shulman, 1986). The literature argues that experienced teachers recognize difficulties and limitations with ideas and use them to shape how they teach particular concepts, rather than simply focusing on giving the students information without considering what they may know (Loughran et al., 2006).
Knowledge about students' thinking which influences your teaching of this idea.	This prompt is similar to the previous one about difficulties and limitations when teaching a concept and the ability to address it relies vastly on the experience of teaching these concepts before. From past experience, teachers can analyse which learning activities are effective and how students respond to these different activities. Part of this prompt is also about ensuring activities are engaging for students so they can further their understanding (Loughran et al., 2006).

Table 2.7 Continued.

Pedagogical Prompt	Underlying Themes and Intentions
Other factors that influence your teaching of this idea.	The purpose of including this particular aspect in the CoRe design process is to allow for teachers to analyse their general pedagogical approach as well as their understanding of the context. Teachers can then examine how this might influence how a concept is taught (Loughran et al., 2006).
Teaching procedures (and particular reasons for using these to engage with this idea).	While it can be seen that the use of a particular teaching procedure will not guarantee that students will learn, it may promote student thinking and help them to further understand ideas (Loughran et al., 2006). Again, this is another area of CoRe design where experience is crucial as it relies on teacher experience to adapt to contextual and circumstantial changes (e.g., different cohorts of students with differing prior conceptions). Loughran (2006) sums this up succinctly: <p style="margin-left: 40px;">expertise is embedded in choosing teaching procedures that are appropriate to the intended learning outcomes and knowing not only how to use them, but why, under what changed circumstances and, being able to adjust and adapt them to meet the contextual needs of the time.</p> <p style="text-align: right;">(p. 49)</p>
Specific ways of ascertaining students' understanding or confusion around this idea (include like range of responses)	Teachers are continually carrying out formative and summative assessments on their students to gauge their level of understanding. This element of the CoRe design allows for teachers to identify specific ways in which they will assess student understanding of a particular concept. This step will allow for teachers to then reflect on the effectiveness of the teaching procedures that they have outlined earlier (Loughran et al., 2006).

A representation of a teacher's PCK for a particular topic begins to emerge when that teacher's responses to the prompts are analysed (Loughran et al., 2006). This PCK can then be analysed and compared to other teachers (e.g., the comparison of experienced teachers to novice teachers). Research on such comparisons has shown the importance of teacher experience for developing a rich PCK (Hume & Berry, 2011). Research has also been carried out where experienced and novice teachers work together to develop a CoRe, which saw novice teachers developing their PCK significantly (Hume et al., 2013).

2.5.2 Linking CoRe Design and PCK Development

Research using CoRe design as a tool for developing PCK is a recent development (Hume & Berry, 2013). This particular use of CoRe design has since been applied in new contexts by educational researchers, for example, in teacher education to investigate how the process may help student and novice teachers develop their PCK (e.g., Hume & Berry, 2011, 2013; Hume et al., 2013; Nilsson & Loughran, 2012).

The study by Hume and Berry (2011) involved a group of graduate student teachers working together in a collaborative workshop on two separate occasions. The science context was chemistry-related, with the first CoRe addressing atomic structure and bonding for Year 11 students and the second focusing on reduction and oxidation reactions for Year 12 students (both in the New Zealand context). The pre-service teachers working amongst themselves found the process of developing the CoRe to be a challenging task as they had little classroom experience. Nevertheless, these trainee teachers collaboratively persevered as they designed the CoRes in small group settings and discussed their CoRe design experiences in a whole-class forum/workshop environment. An important outcome of this research was that these participating pre-service teachers developed an awareness of the importance and complexity of PCK (Hume & Berry, 2011).

The outcomes and conclusions from this research indicate that the CoRe design process is difficult and challenging, especially when classroom teaching experience is lacking. However, with careful scaffolding throughout the CoRe design process, the pre-service teachers were able to develop their own tentative PCK, although the lack of classroom experience significantly hindered the development of their PCK (Hume & Berry, 2011). These conclusions were similar to the results discussed by Nilsson and Loughran (2012) who also investigated the impact of CoRe design on pre-service teachers in science.

These studies were followed up by further research. For example, the Hume and Berry (2013) study investigated PCK developments made by pre-service teachers as they first developed CoRes as a collaborative group, and then later as they each worked alongside respective mentor teachers on refinement of their CoRes whilst on teaching placement. The authors report that while this study had limitations such

as a short timeframe and a small number of participants (n=6), there were significant findings. For example, the pre-service teachers valued the professional discussions with their mentor teachers about developing a CoRe for a particular topic and appreciated their mentor teacher's input into developing their PCK. The findings also suggested that engaging in the CoRe design process is a useful opportunity for developing their professional knowledge as they transition to early career teachers.

The Hume et al. (2013) study focused on the PCK development of early career teachers as they worked as part of collaborative learning groups comprised of experts and novices. There were two focus groups, each with four participants comprising two pre-service teachers, one industry expert and one experienced teacher. One focus group was science-based, while the other was technology-based. In each group both experts were from the appropriate domains (Hume et al., 2013).

In their findings, Hume et al. (2013) documented how positive and productive the CoRe design process was as the focus groups worked collaboratively. This finding was centred on how the two (science and technology) groups approached the task of identifying the big ideas associated with the topic. The science group found these ideas easy to recognise, which researchers attributed to chemistry having a relatively established curriculum. In contrast, the technology group spent time discussing and debating technology as a knowledge domain (i.e., the nature of technology) before actually establishing what the key ideas were for their CoRe. However, the early career teachers found the process valuable and indicated in interviews that their PCK had been enhanced. For example, one participant discussed how the CoRe design process had shown her where to put specific emphasis during a topic. Another participant made reference to how she developed lessons to ensure the students could relate information and make meaning pertinent to their own lives (Hume et al., 2013).

The Hume et al. (2013) study also identified how this CoRe design process influenced unit planning and lesson delivery of the early career teachers. The process had a number of impacts, including:

- The increased confidence of the early career teachers when teaching some concepts that students found difficult to understand. They were now also

considering the idea of students developing links between concepts and fundamental big ideas.

- The ability for early career teachers to develop a thorough and complex unit plan that broke all the key ideas down into individual lessons. The teaching unit was flexible enough to allow for normal school disruptions.
- The capability of the early career teachers to alter the sequence of ideas that they were teaching.
- The knowledge about where to place emphasis during certain lessons to ensure enough importance was placed on critical concepts that students may find difficult to understand.
- The increased awareness of where and how to use assessments, and how to provide quality feedback to students.

However, using CoRe design to enhance teacher's PCK for teaching science is not without limitations. Teachers are known to be under time pressures caused by increased tasks without extra time allocation to get those tasks completed (Bailey & Colley, 2014), and conclusions from previous CoRe design research acknowledge that time is an issue when considering the impact on practice (e.g., Bertram & Loughran, 2012; Hume et al., 2013). For example, in their study, Bertram and Loughran (2012) saw that even though teachers valued the CoRe design process for enhancing their teaching skills, the time required for the task was a major negative factor affecting its use. The six practising teachers in this study, who came from three different schools (four, one and one respectively), were unsure of the sustainability of such a professional development tool within their own school. In similar vein, one of the conclusions drawn by the Hume et al. (2013) study was the logistical difficulty associated with having novice teachers, experienced teachers, and content experts collaborate together. That study suggested that a virtual professional development setting could be trialled in future studies.

Virtual workspaces, such as wikis, have since been explored as avenues for teachers to collaborate using CoRe design (e.g., Donnelly & Boniface, 2013; Donnelly & Hume, 2015). A wiki is "a system that allows one or more people to build up a corpus of knowledge in a set of interlinked web pages, using a process of creating

and editing pages” (Franklin & van Harmelen, 2007, p. 5). However, using this platform for CoRe design with teachers raised other issues. For example, Donnelly and Boniface (2013) found that by doing CoRe design online, important elements of CoRe design such as collaborative discussion and debates amongst teachers, were lost. Furthermore, these researchers acknowledged that the time issue was not necessarily resolved either, as some teachers found the mechanics of using the wiki platform difficult and time consuming. A similar conclusion was drawn by Donnelly and Hume (2015) who concluded that their participants were reluctant to engage in critiques of each other’s work whilst designing CoRe design using a wiki. Overall, these studies demonstrate that as teachers engage with the CoRe design process and collaborate with others, their PCK can be developed. Teachers developing their PCK using CoRe design can be seen a form of professional development, which addressed in the following section.

2.6 Teacher Education

This section focuses on what constitutes teacher education and how interventions can be developed to ensure they are effective. The link between teacher education and developing PCK is also explored.

2.6.1 Professional Learning and Development Interventions

Teacher education allows teachers to develop their professional knowledge and skills (Hill, 2007) to promote student learning (Jacob & McGovern, 2015). Initial teacher education for teachers occurs in their training programme and these courses have an obligation to prepare graduates for teaching students in schools. However, Dagen and Bean (2014) emphasise that early career teachers still have much to learn in their beginning years and will need ongoing support to succeed in the classroom. These authors argue experienced teachers will also need to understand the importance of ongoing learning to ensure they adapt their pedagogies appropriately to new research discoveries and contextual changes in schools and society. The process or means by which teachers take part in ongoing education for the purpose of updating and refining their professional knowledge and skills is termed

professional development (Reutzel & Clark, 2014). This form of teacher education encompasses a variety of activities such as: workshops, training sessions, conferences, university courses, and observational visits to other schools (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009).

However, a negative connotation has developed over time for the term of professional development amongst educators as it can be associated with activities with high cost, vague purpose, or lack of sustainability (Reutzel & Clark, 2014). Lieberman and Miller (2014) argue that the structure of the activities has also influenced teachers' attitudes as they are often "based on the assumption that teachers need direct instruction about how to improve their skills and master new strategies" (p. 7). Thus, professional development interventions tended to be prescribed activities where groups of teachers were typically presented with information, which may/may not have been applicable to contexts in which individual teachers worked. Lieberman and Miller (2014) maintain that these activities resulted in little change to classroom practice. They argue that a paradigm shift in the understanding of how professional development occurs was needed to transform the process and ensure the nature of teaching was the focus (Lieberman & Miller, 1999, 2014).

The re-conceptualising of professional development needed to shift the process from something that is done to teachers towards a process that works with teachers (Nilsson, 2014). Lieberman and Miller (1999) show how this change in focus should be manifested for different aspects of the professional development process for teachers in Table 2.8 on the following page.

These changes to the professional development process ensured teachers were encouraged to collaborate with one another and that the focus of teaching was on student learning (Darling-Hammond & McLaughlin, 1995, 2011). This focus of improving teachers' professional knowledge and skills for teaching became known as professional learning (Lieberman & Miller, 2014), which is seen by many in the educational community as a less-negative term than professional development (Reutzel & Clark, 2014).

Table 2.8: Changes required to professional development to ensure the nature of teaching becomes the focus (Reprinted with Publisher's permission, Lieberman & Miller, 1999, p. 24).

From		To
Individualism	→	Professional community
Teacher at centre	→	Learner at centre
Technical work	→	Inquiry into practice
Controlled work	→	Accountability
Managed work	→	Leadership
Classroom concerns	→	Whole-school concerns and beyond
A weak knowledge base	→	A broad knowledge base

After reviewing literature on the differences between professional learning and professional development for teachers, Lieberman and Miller (2014) offer five useful comparisons for different aspects, which are shown in Table 2.9.

Table 2.9: A comparison of different aspects of professional development to professional learning (Developed from Lieberman & Miller, 2014, p. 9).

Aspect	Professional Development	Professional Learning
Style	Primarily technical, skills-based work that promotes the application of prescribed skills and occurs in fragmented pieces.	Steady intellectual work that promotes meaningful engagement with ideas and with colleagues over time.
Delivery method	Involves teachers most often in knowledge consumption through the transfer of knowledge by way of direct instruction.	Involves teachers in knowledge creation through collaborative inquiry into practice.
Knowledge basis	Relies on outside expert knowledge.	Relies on both inside teacher knowledge and outside expert knowledge.
Focus	Focuses on general problems of implementation of new programs and policies and tends toward a "one size fits all" approach.	Focuses on specific problems of practice and takes into account the experience and knowledge of teachers.

Table 2.9 Continued.

Aspect	Professional Development	Professional Learning
Participation	Assumes that teachers will passively comply with the delivery of the content.	Assumes that teachers will actively engage in reflection, analysis, and critique.

These comparisons show that professional learning promotes a different way of thinking about teacher education than the more traditional professional development approach. The focus has shifted to improving student outcomes by using a collaborative approach to teacher education that encourages teachers to engage and reflect upon their own teaching practice (Lieberman & Miller, 2014).

In line with the terminology used by the New Zealand Ministry of Education (see Ministry of Education, 2018), this thesis utilises the term ‘professional learning and development’ (PLD). Within the construct of PLD, professional development is interpreted to represent the intervention that teachers engage in (Rohling & Spelman, 2014). Within these interventions, teachers may collaborate and share knowledge, which enhances their “knowledge about content and pedagogy and enable[s] them to use that knowledge to improve classroom and school practices that improve student learning” (Dagen & Bean, 2014, p. 44). Thus, PLD interventions will be used to describe the activity, while professional learning will describe the acquisition or development of knowledge, of skills, and attitudes as a result of the activity.

After exploring how PLD interventions are interpreted in this thesis, the next section outlines what makes these interventions effective for maximising the professional learning.

2.6.2 Effective Professional Learning and Development Interventions

As noted in the previous section, traditional professional development approaches may not have the desired long term effect on a teacher’s practice in the classroom (Nilsson, 2014). After their extensive review on professional development, which involved over 10,000 teachers, Jacob and McGovern (2015) found that while

teachers (and schools) are frequently inundated with information and help, this assistance is not actually helpful for enhancing classroom pedagogy. Their review revealed that for a PLD intervention to have a positive long-term effect, it needs to consider critical characteristics. The consensus from researchers who discuss effective interventions (e.g., Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; Griffith, Ruan, Stepp, & Kimmel, 2014; Tallerico, 2014; van Driel, Meirink, van Veen, & Zwart, 2012) indicate there are five critical characteristics for designing and implementing an effective PLD intervention, which are: *content focus*, *active learning*, *coherence*, *duration*, and *collective participation*. Each characteristic is now discussed.

Content focus refers to an emphasis on specific content that students need to learn and how they might learn it (Griffith et al., 2014). It may be the most important aspect to consider when designing an intervention, as research reveals teachers develop and improve their practice when there are clear links and associations made between the content that students should be learning, and how they could be learning it (Desimone, 2009; Garet et al., 2001).

Active learning requires teachers to dynamically participate rather than to subscribe to a more passive method such as a lecture (Griffith et al., 2014). Providing activities that allow teachers to critique their own practice or review student work are examples of encouraging teachers' active learning (Borko, 2004; Griffith et al., 2014). Desimone (2009) and Garet et al. (2001) maintain that when teachers are encouraged to, and able to, participate, they are more likely to view the PLD intervention as being effective. This characteristic reflects the transitioning from a historic view of professional development (something that is done to teachers) to a more enlightened view of professional learning (engaging teachers to participate).

Coherence sees strong alignment between the goals of the intervention and the school and teachers' own knowledge, beliefs and goals (Desimone, 2009). This characteristic of effective PLD interventions promotes "teachers' understanding that the content of the professional development is consistent with their own knowledge and beliefs and with school, district and state reforms and policies" (Griffith et al., 2014, p. 191). The consequence of coherence being overlooked means teachers may perceive the intervention as an isolated event, thus reducing its effectiveness and sustainability (van Driel et al., 2012).

The *duration* of effective PLD interventions has no ‘ultimate time’ since consideration needs to be given to the goals of the intervention (Desimone & Stuckey, 2014; van Driel et al., 2012). It is widely acknowledged teachers benefit from opportunities that allow for discourse to be spread out over time with opportunities for reflection and follow up (Desimone, 2009; Griffith et al., 2014). Griffith et al. (2014) identify that this consideration is in direct contrast with those more-traditional ‘one-shot’ workshop models in which teachers are presented with disjointed information that they may not be able to directly relate to their own practice. van Driel et al. (2012) maintain such short duration PLD interventions are an ineffective way of promoting professional learning.

Lastly, *collective participation* refers to the inclusion and promotion of collaboration amongst teachers in an effective PLD intervention to allow them to engage in important discussions and reflection about the professional development opportunity (Griffith et al., 2014). Garet et al. (2001) identify three advantages of considering this characteristic for inclusion in PLD interventions: teachers that work together are more likely to engage in discussion during the professional learning process; teachers who are from the same school or department are able to share common materials such as curriculum guidelines, lesson plans, and assessment information; and, teachers who teach similar students (e.g., same year level) are able to discuss their common and/or different student needs. Choosing a theme of shared interest to teachers from the same department or from the same year level, is an instance of how to encourage collective participation when designing effective interventions (Garet et al., 2001).

Incorporating these five critical characteristics, Desimone (2009) offers a useful conceptual framework for showing the relationship between an effective PLD intervention, enhanced professional learning and practice, and improvement of student learning. This conceptual framework is shown in Figure 2.8 on the following page.

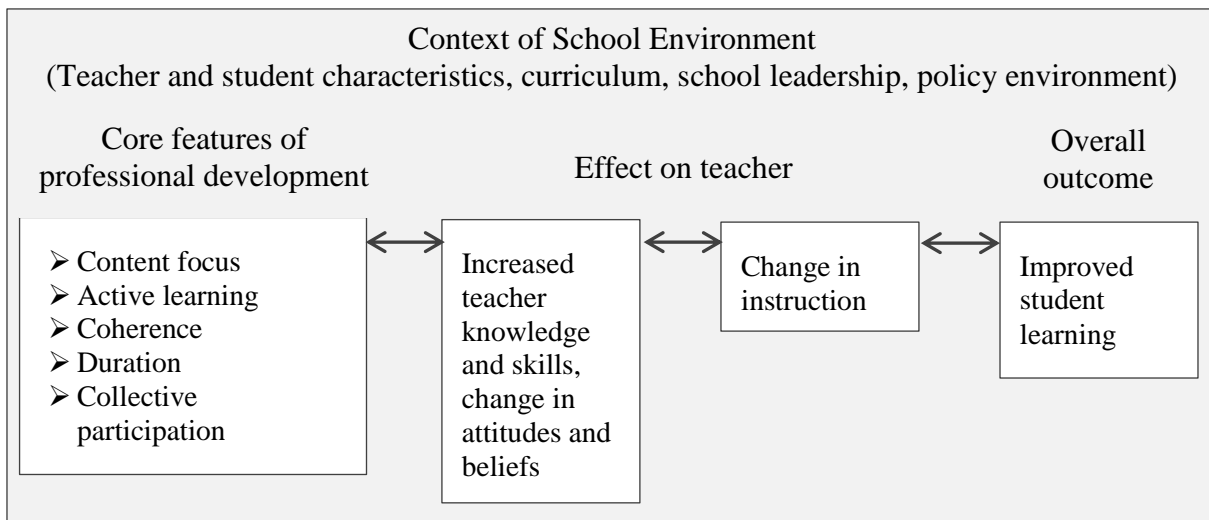


Figure 2.8: A conceptual framework for identifying how professional development may influence student learning (Reprinted with Publisher's permission, Desimone, 2009, p. 185).

Given there are certain considerations that make PLD interventions effective for teachers' professional learning, attention now needs to turn to how PLD interventions can enhance teachers' PCK.

2.6.3 Professional Learning and Development Interventions and PCK Development

Research shows that targeted PLD interventions for enhancing teachers' PCK is a worthwhile activity because ultimately it can strengthen student achievement in science (Daehler, Heller, & Wong, 2015). This relationship is shown in Figure 2.9 on the following page.

For PLD interventions to enhance teachers' PCK, they need to allow for teachers to collaborate, reflect, and discuss ideas about their practice and instructional strategies (van Driel & Berry, 2012). In addition, Evens, Elen, and Depaepe (2015) conducted a comprehensive review about how different PLD interventions had enhanced PCK, and they identified further suggestions, which are: utilising interactions between teachers and reflections on their practice; discussing the construct and/or conceptualisation of PCK and making it explicit to teachers; and having the PLD intervention run by an experienced facilitator.

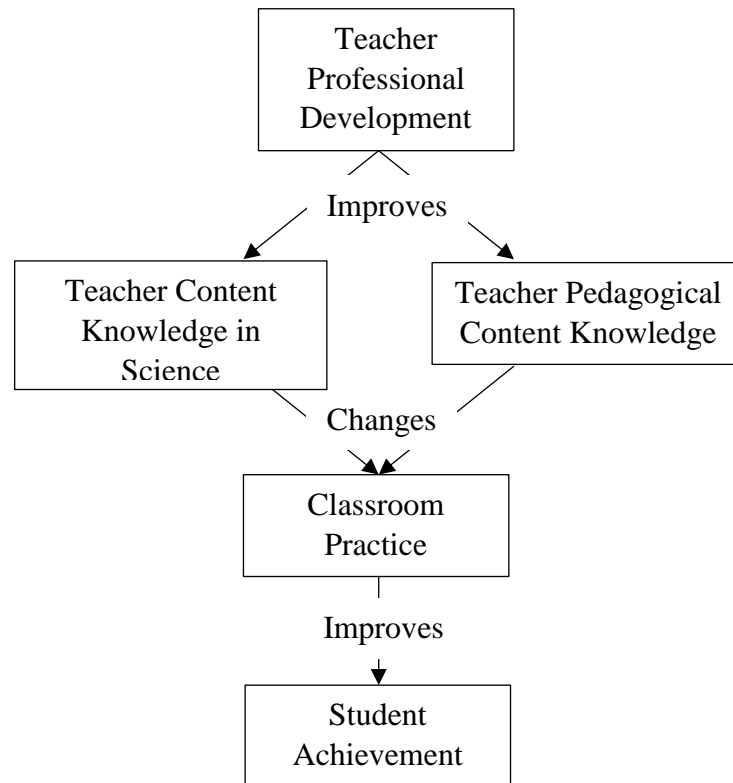


Figure 2.9: Impact of professional development on student achievement (Reprinted with Publisher's permission from Daehler et al., 2015, p. 47).

Several recent studies have investigated the positive impact that CoRe design has on teachers' PCK (see Section 2.5.2). It appears that using CoRe design in a collaborative way allows for teachers to enhance their professional knowledge. The elements of the CoRe design process encourage collaborative discussion and reflection about certain big ideas linked to a topic. This process aligns closely with the characteristics of effective PLD interventions to promote professional learning (see Figure 2.8).

The following section offers concluding thoughts and summarises each key point made throughout this literature review.

2.7 Concluding Thoughts

Curriculum goals for science education have changed over time to ensure they reflect what the students should be learning about in their current world and social context. Both internationally, and nationally, the goals of science education concern themselves with ensuring students become scientifically literate citizens, and extensive research has been carried out to identify what qualities these students need to have (e.g., NRC, 2012). In New Zealand, teachers are guided by the NZC which serves as a policy document to guide teachers with their planning and teaching (Ministry of Education, 2007). While this document does not explicitly identify students becoming scientifically literate as a goal, some of its documented aims are analogous to being scientifically literate.

Qualities that students need to be considered scientifically literate include having an understanding of: key scientific concepts (i.e., chemistry, physics, and biology concepts); the nature of scientific inquiry (scientific processes); and the nature of science (epistemology of science). Having this understanding allows students to develop scientific capabilities, such as: gathering and interpreting information, using evidence to support ideas, critiquing evidence; making meaning of scientific representations; and engaging with science (see Figure 2.1 on Page 25). The NZC also encourages teachers to instil students with competencies to provide them with the capabilities to contribute within a forward-moving environment by showing innovative thinking.

How students learn, and how they learn in science, has been researched extensively during the last century. Throughout that time, the adopted theory for students' learning by those in the research community has changed. Initially, most research in education around student learning focused on behaviourism. From here, developments were made and the new adoptive theory was constructivism. Currently, the theory that many working within the science education research community adopt is constructivism with the added influence of social interactions (e.g., student and teacher interactions). In this perspective on learning, students develop and construct personal knowledge which is dependent on their social environments. Within the constructivism learning theory, researchers identified that students' conceptual frameworks about certain concepts could be altered. Thus, the notion of conceptual change was developed.

Conceptual change in science can be viewed as a process that learners go through when they change their existing conceptual framework to align it more with the accepted scientific framework or understanding. To initiate this change, pedagogical approaches involve students being put in positions where they face problems or situations where their initial conceptual frameworks do not hold true. During this phase of conflicting frameworks, teachers carefully implement pedagogical strategies that allow students to develop new conceptual frameworks that will indeed be able to aptly address the problem or situation.

Historically, physics teachers used a teacher-centred approach where the teaching process was seen as knowledge transmittance. However, research indicates that many students enter physics classrooms with strongly-held preconceived conceptual frameworks that contain misconceptions. If students are to successfully undergo a conceptual change process, careful consideration must be given to the pedagogies employed by the teacher. One strategy that teachers may use during lessons to aid with this process is the use of models or analogies. Within this context, models and analogies represent scientifically accurate information in ways that makes it more accessible for students to understand. However, when trying to make information more accessible to students, there is a possibility that students may develop misconceptions.

Within this thesis, misconceptions is a catch-all phrase to encompass situations where student understanding does not align with the scientifically accepted reasoning. Throughout the 1980s and 1990s, extensive research was carried out that investigated misconceptions that students had when they were learning about electricity and magnetism. Research findings offered teachers' ways to alleviate these issues, which focused on skilful teaching to ensure students undergo conceptual change. Skilful teaching was dependant on both the content knowledge and pedagogical knowledge of the teacher. Thus, teachers that have a limited physics background may find it challenging to teach their students in ways that elicit or correct misconceptions.

In 1986, Shulman proposed his idea of pedagogical content knowledge (PCK) – a blend of both content knowledge and pedagogical knowledge. This academic construct came to be an important, and well researched, part of science education. Many researchers have examined PCK and its nature, and have concluded that it is

a special form of teacher knowledge, one that distinguishes novice teachers from experienced teachers. Experienced teachers, with rich PCK, are able to use student prior knowledge to ensure their instructional strategies meet the learning needs of those students. While there was some consensus on the general conceptualisation of PCK, many researchers had interpreted the construct differently. In search of consensus so that all researchers were using the same conceptualisation, two PCK Summits were held. A significant output from the 2nd PCK Summit was the Refined Consensus Model of PCK (RCM of PCK), which was used as a conceptual framework to inform this study as it unifies previous conceptualisations and thinking around PCK.

Trying to measure and analyse teachers' PCK is a difficult and complex task. Nevertheless, various researchers have tried to examine and determine teachers' PCK through a variety of methods (e.g., observation, interviews, document analysis). Even with these efforts, documenting a teacher's PCK and investigating changes to that PCK have proven to be difficult tasks in PCK research.

Another method to explore teachers' PCK is the use of content representations (CoRes). CoRes were developed as a process for investigating teachers' professional knowledge for teaching a certain topic (Loughran et al., 2000; Loughran et al., 2004). The CoRe itself is a spreadsheet-styled template and the first task for teachers is to identify the big ideas associated with the topic. Teachers can then have discussions and can reflect on their own practice to address the pedagogical prompts. Through this process, teachers can identify student misconceptions and prior knowledge, and which instructional strategies are most suitable for enhancing understanding. The responses from a completed CoRe provide useful insights into a teacher's PCK.

Since the initial development of CoRe design to explore teachers' PCK, other researchers have used CoRe design as a process to enhance PCK. In these studies, novice teachers worked with experienced teachers and content experts, and their PCK developments were researched. The findings from these studies indicate that CoRe design is a useful means for helping teachers develop their PCK, but there are limitations. Most notably, problems around the logistics of organising the activity became evident. While researchers saw potential with using CoRe design to enhance PCK, trying to get all of the participants together proved to be difficult.

Likewise, participants saw value in the CoRe design process but were sceptical about how it could be practically used given the time requirements.

While the idea of professional development is not new, recent developments make it a more effective process. From a historical viewpoint, professional development was seen as a top-down process that gave fragmented information to teachers, which was not particularly relevant to their classroom practice. This issue required a paradigm shift to change professional development to a process that became focused on pedagogy resulting in student learning. This paradigm shift results in many educators adopting the term professional learning over professional development. To align with New Zealand's Ministry of Education terminology, the phrase of professional learning and development (PLD) has been used in this thesis. PLD interventions represent the activity taking place, and professional learning is the outcomes from that intervention.

Part of the research conducted into PLD included identifying key characteristics that make these interventions effective. The characteristics that have been identified include the need for: focusing on what students need to know and ways for them to learn it, alignment between the goals of the intervention and the teachers' goals, and encouraging teachers to be dynamic participants and collaborate with each other.

From synthesising the information presented in this chapter, it is postulated that some teachers' PCK may need further development to ensure they are teaching their students in ways that promote understanding and elicit metacognition. To enhance their PCK, these teachers may benefit from collaborating with experienced teachers using CoRe design as a framework. The framework for exploring PCK and subsequent PCK development was the Refined Consensus Model (RCM) of PCK.

2.8 Chapter Summary

This chapter has provided an extensive review of the literature that is pertinent to exploring the research objectives and questions. The intent of this research is to explore teachers' pPCK and ePCK for Year 10 *Electricity and Magnetism*, and possible development to these knowledge bases of the participants after taking part in collaborative CoRe design. This exploration will allow a critique of the

effectiveness and suitability of CoRe design to develop teachers PCK. While capturing teacher's PCK is a difficult task, by critically examining previous PCK research and conceptual frameworks, components of PCK and quality indicators for those components become apparent.

The following methodology chapter identifies the key philosophical underpinnings of this research, the data gathering techniques, and how data was analysed. Throughout this next chapter information is also provided about the ethical and pragmatic considerations involved in this study, and a discussion about the trustworthiness of the claims made from this research.

Chapter Three

Methodology

3.1 Introduction

This chapter reiterates the research questions that guided the study. Then follows a brief account of the key ontological and epistemological stances of paradigms that commonly feature in education research. The specific theoretical framework underpinning this study is then identified followed by a detailed account of the research design and the rationale for decisions made during the design process. The research design includes the approach taken, the selection of participants and data gathering methods. Information about the research design is followed by how the trustworthiness of this study was ensured, how the data was analysed, and ethical considerations.

3.2 Research Objectives and Questions

This research aimed to:

1. Explore and establish the nature of personal and enacted pedagogical content knowledge (pPCK and ePCK), for the Year 10 topic *Electricity and Magnetism*, of teachers with a limited physics background.
2. Investigate the effectiveness and suitability of a professional learning and development (PLD) intervention, known as collaborative content representation (CoRe) design, when used for enhancing the pPCK and ePCK, for the Year 10 topic *Electricity and Magnetism*, of teachers with a limited physics background.

These objectives were developed into the following three research questions:

1. In the New Zealand context, what does the personal and enacted pedagogical content knowledge (pPCK and ePCK) of junior science teachers with a limited physics background look like for the Year 10 topic *Electricity and Magnetism*?

2. What impact does collaborative CoRe design have on the pPCK and ePCK development of junior science teachers with a limited physics background for the New Zealand Year 10 topic *Electricity and Magnetism*, when working collaboratively with experienced physics and junior science teachers?
3. What are teachers' experiences and perceptions of collaborative CoRe design as a professional learning and development (PLD) intervention for enhancing pPCK and ePCK?

3.3 Theoretical Considerations and Frameworks

3.3.1 Ontological, Epistemological, and Paradigmatic Considerations in Educational Research

Educational research is a systematic and controlled endeavour. It involves gathering and critically analysing empirical data, and then exploring patterns and relationships to develop new knowledge and understandings to address specific problems and to enhance the educational experience for students (Ferguson & Ferguson, 1997; Kerlinger, 1986; Labaree, 2003; Wiersma & Jurs, 2009). As it takes place in a multifaceted environment involving students and teachers, with influences from school management and governmental policy, educational research is a vastly complex and demanding task (Wiersma & Jurs, 2009). When researching in these complex contexts with multiple variables, different researchers approach their work from a variety of theoretical viewpoints and methodologies (Ferguson & Ferguson, 1997; Labaree, 2003). For new researchers it is useful to have a sound understanding of the theoretical viewpoints that underpin educational research, such as the role of ontological and epistemological considerations in determining how to undertake a particular piece of research (Grix, 2010; Mutch, 2013).

To support new educational researchers, Grix (2010) offers a useful diagrammatic representation of key theoretical foundations to be considered prior to carrying out research, which is illustrated in Figure 3.1 on the following page.

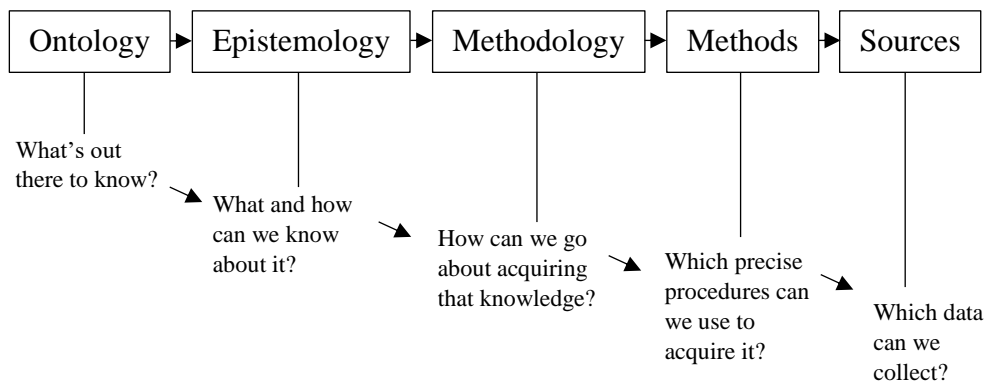


Figure 3.1: The interrelationship between the building blocks of research (Reprinted with Publisher's permission, Grix, 2010, p. 68).

Figure 3.1 places ontology in a pivotal position when making research decisions as it influences what information is accessible, and in turn, research objectives, questions, and data collection techniques. Gray (2014) provides a succinct and useful definition of ontology for this study, that is, the “study of being, that is, the nature of existence and what constitutes reality” (p. 19). Bryman (2016) offers two ontological positions of researchers, which he describes as objectivism and constructionism (or constructivism).

Objectivism, Bryman (2016) defines as:

An ontological position that asserts that social phenomena and their meanings have existence that is independent of social actors. It implies that social phenomena and the categories that we used in everyday discourse have existence that is independent or separate from actors.

In contrast, he views constructionism as:

An ontological position that asserts that social phenomena and their meanings are continually being accomplished by social actors. It implies that social phenomena and categories are not only produced through social interaction but that they are in a constant state of revision.

(p. 29)

For this research, my personal ontological positioning as a researcher subscribes to a constructionism view, as outlined by Bryman (2016). My perspective is that peoples' behaviour is determined by not only their intrinsic characteristics (e.g., knowledge, feelings, and attitudes), but also the social interactions each person may have and the social environment in which each person is immersed. Furthermore, the relationships that exist between people depend upon their attitudes and behaviours towards each other. For example, I would anticipate if the same teacher was placed in a different school context, their behaviour and pedagogical approaches would change. In addition to these ontological considerations, Grix (2010) explains that a person's ontological understanding of reality will in turn affect their understanding of the nature of knowledge, that is, their epistemology.

My ontological assumptions about reality influence my epistemological underpinning, where I see knowledge as a unique construct which is personal to each individual (L. Cohen, Manion, & Morrison, 2011). These theoretical foundations lead me to believe the knowledge I need to seek to answer my research questions includes: teacher's professional knowledge about science and education; attitudes towards and beliefs about teaching science, in particular Year 10 *Electricity and Magnetism*; curriculum and assessment knowledge; pedagogical and instructional strategies; their feelings of self-efficacy for teaching this topic; and, their attitudes towards and beliefs about professional development. By accessing these different pieces of information, before, during, and after a PLD intervention (within the same context), I argue it is possible to explore the effectiveness of that PLD opportunity.

The differences in ontological and epistemological perspectives of various researchers have led to the evolution of different theoretical frameworks for guiding educational research. These theoretical frameworks known as paradigms (Kuhn, 1962), each comprise a distinct collection of beliefs, assumptions, or propositions about how the world is viewed (Lincoln & Guba, 1985). When discussing research in science education, there are three main research paradigms to consider: positivism; interpretivism; and critical theory research (Bryman, 2016; Treagust, Won, & Duit, 2014).

Positivism stemmed from the empirical principles of inquiry characterising the physical sciences (Lincoln & Guba, 1985; D. Scott & Morrison, 2007). Within this

paradigm, researchers aim to develop “nomothetic knowledge” (i.e., generalised and universalised law-like statements) through a critical view of the world (Punch & Oamcea, 2014, p. 18). This goal means “social observations should be treated as entities in much the same way that physical scientists treat physical phenomena” (Johnson & Onwuegbuzie, 2004, p. 14). Typically, when using positivism to guide research, quantitative data is collected to make knowledge claims that are valid and reliable (Punch & Oamcea, 2014; Treagust et al., 2014). However, using a positivist approach in complex social settings such as schools can be problematic (Hitchcock & Hughes, 1995), as the “immense complexity of human nature and the elusive and intangible quality of social phenomenon contrast strikingly with the order and regularity of the natural world” (L. Cohen et al., 2011, p. 7). To account for complex situations involving human behaviour and interactions, the interpretivist paradigm was developed (Bryman, 2016).

The essence of the interpretivist paradigm relates to understanding complex social situations based on participant experiences and the contexts where they occurred, that is, they can only be understood from the viewpoint of the participant(s) (L. Cohen et al., 2011; Treagust et al., 2014). Interpretivist researchers seek understanding of participants’ behaviour and experiences based on interpretations that are ‘grounded’ in the particular context, situation, and environment (Bryman, 2016; Grix, 2010). Typically, interpretivist studies involve qualitative research approaches such as case study research, collecting large amounts of qualitative data from methods such as interviews, document analysis, and observations (Treagust et al., 2014). As researchers working within an interpretive paradigm engage with participants on a personal level, thought must be given to ethical considerations to ensure no harm occurs to participants and they are not coerced into the study (Clark & Sharf, 2007; Treagust et al., 2014).

There are critics of both positivism and interpretivism who argue that these paradigms present “incomplete accounts of social behaviour by their neglect of the political and ideological contexts of much educational research” (L. Cohen et al., 2011, p. 31). To these critics, interactions of privilege and/or oppression, which they attribute to power dynamics in society, are being over looked by researchers in these paradigms (Lincoln, Lynham, & Guba, 2011). Thus, the critical theory research paradigm was born. Like the interpretivist paradigm, researchers guided

by critical theory recognise the influence of social, gender, political, economic, and ethical experiences on a person's knowledge, ideas, and values (Kincheloe, McLaren, & Steinberg, 2011; Treagust et al., 2014). However, unlike interpretivism, this paradigm seeks to investigate inequality and power dynamics (Lincoln et al., 2011), with the central aim of emancipation (Fay, 1987; D. Scott & Usher, 2011). When outlining their views on critical theory as a research paradigm, Treagust et al. (2014) note it is often used as catch-all phrase encompassing other research paradigms such as "feminism, postcolonialism, postculturalism, emancipatory/participatory, postmodern, etc." (p. 15). What unifies this 'collection' of paradigms is that educational researchers conducting critical theory research tend to examine and explore the "current social values and roles in historical and cultural contexts and problematize many taken-for-granted ideas for the benefit of socially marginalised people" (Treagust et al., 2014, p. 10).

Having briefly discussed the three research paradigms most prevalent in current science education research, it is now necessary to outline and discuss the theoretical positioning of this study and how this positioning influenced its methodology.

3.3.2 This Study, the Interpretive Paradigm, and Qualitative Data

The aim of this study was to explore teachers' PCK and their PCK development as a result of collaborative CoRe design. By exploring participants' PCK development, and their perceptions and experiences of CoRe design, the effectiveness of CoRe design as an effective and suitable PLD intervention can be evaluated. This study investigated the development of teachers' knowledge over time, with the goal of using that information to develop theories. The theories developed were influenced by the context in which the research was carried out (Bryman, 2016). Thus, a research paradigm that endorses interpretations being made from teachers' opinions and beliefs about their teaching, their experiences with the professional development intervention, and their behaviour and actions in the classroom was required. These requirements meant working within the parameters of an interpretive paradigm was considered the most appropriate theoretical framework for guiding this study (L. Cohen et al., 2011; Treagust et al., 2014). To make trustworthy interpretations from data about teachers' professional

knowledge and knowledge development, interpretivist guidelines indicated qualitative data gathering methods were the most appropriate.

Three decades ago, Lincoln and Guba (1985) cautioned researchers about the subjective nature of making interpretations about human interactions from qualitative data. These authors asked the following question of the social science research community: “How can an inquirer persuade his or her audiences (including self) that the findings of an inquiry are worth paying attention to, worth taking account of?” (p. 290). Since this publication, qualitative researchers have raised important considerations for best practice qualitative research (e.g., Howe & Eisenhart, 1990; Kline, 2008; Tracy, 2010; L. L. Watts et al., 2017). In her synthesis of best practice for qualitative researchers, Tracy (2010) identifies eight criteria for excellent qualitative research, which are summarised below in Table 3.1.

Table 3.1: Eight criteria for excellence qualitative research (Tracy, 2010).

Criteria	Explanation
A worthy topic	The study must be timely, relevant, significant, interesting, or evocative.
Rich rigor	The theoretical conceptual frameworks must guide the inquiry and there must be an abundance of significant data to make claims. The context of the study, the participants, the data collection methods, and the data analysis must be appropriate to the goals of the study.
Sincerity	The claims made from the study need to be transparent and honest. Noting limitations, research bias, and mistakes in the research is key to this criterion being met.
Credibility	The research findings need to be reliable, plausible, and trustworthy. Triangulation of different data should be utilised.
Resonance	The write-up of the study should resonate with the intended audience. To achieve this criterion, the content should be presented in a way that is evocative and/or transferable to other contexts and situations.

Table 3.1 Continued.

Criteria	Explanation
Significant contribution	The outcome of the study should make a significant contribution to the academic world. For example, the study may impact knowledge by furthering conceptual understandings, or perhaps shedding light on a current issue.
Ethical	To ensure no harm is done to participants, ethical considerations are made when researching people.
Meaningful coherence	There is coherence throughout the entire study process from the objectives through to relevant literature, research questions, methods and procedures, and interpretations.

These criteria for excellent qualitative research have been closely adhered to in this study. For example, the worth of the study has been signalled in Chapter One and the rationale for using an interpretivist theoretical framework to provide rigour and direction for the study has been established. Each of the remaining criteria will be explicitly addressed at different points throughout this thesis.

3.4 Research Design

After developing the research objectives into operational research questions, reviewing relevant literature, and theoretical considerations for carrying out science education research, decisions about the research design needed to be made. The following six sections offer information about the approach taken, the participants, and how data was collected.

3.4.1 Approach

A multiple case study research approach was considered the most appropriate choice (Yin, 2014). This choice allowed for an in-depth comparison between participants' PCK and subsequent PCK development, and CoRe design experiences. Multiple case study approaches in educational research have been developed in recent years (Taber, 2013) as a variant of a 'single case study', which shares the same methodological framework (Yin, 2014). The case study methodology, common to both single and multiple case studies, is suited to

situations where analysis is needed that focuses on an individual's development in variable-rich contexts and circumstances (Hitchcock & Hughes, 1995). It is also applicable in situations where the objectives are concerned with how and why an individual's development occur over time or after a specific intervention (Yin, 2014).

By using a case study approach, researchers are able to delve into complex situations, like an individual teacher's professional knowledge, to provide a descriptive and in-depth analysis (L. Cohen et al., 2011; Swanborn, 2010). During this process, it is necessary for the researcher to collect different types of data, such as interviews and observations, to facilitate corroboration within the information (Heck, 2006), which is a type of triangulation (Bryman, 2016). When using a multiple case study approach, Yin (2014) argues the importance of strengthening the reliability of the findings by ensuring cases are replications of each other (i.e., data collection and sampling methods are not changed for different cases). Once sufficient data has been collected, the analysis of the multiple cases can begin.

A multiple case study approach is regarded as a means to produce more robust information than a single case (Herriott & Firestone, 1983; Yin, 2014). The robustness is improved as analysing data from a multiple case study has the advantage of increasing the "generalisability" of the research findings, in comparison to a singular case (Taber, 2013, p. 99). During this analytical process, it is recommended that data from each of the multiple cases is processed first as separate entities, to highlight features of interest. Singular cases can then be combined for a cross-case analysis which may highlight overlaps in the findings (e.g., Eisenhardt, 1989; Stake, 2006; Taber, 2013; Yin, 2014). It is during this process that the robustness of the generalisations made by the study can be strengthened, as aspects of individual cases that are extreme or unusual are highlighted when they are compared to the other cases within the study (Yin, 2014).

The multiple case study approach used in the context of this study can be described via Figure 3.2 on the following page, which depicts the entire research process.

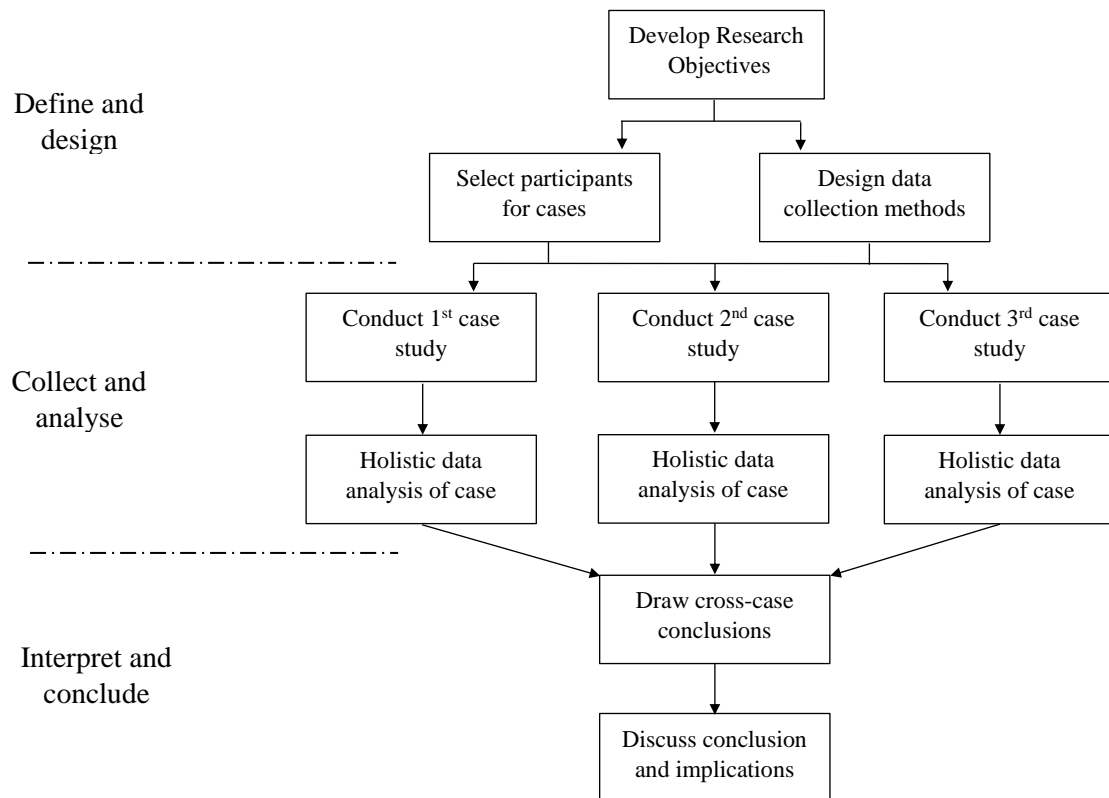


Figure 3.2: Multiple-case study procedure used by this study (Adapted with Publisher's permission, from Yin, 2014, p. 60).

The research questions were addressed by exploring Group One teachers' pPCK and ePCK development as individuals and their perceptions about CoRe design as a professional development intervention. Input from the other participating teachers, particularly their perceptions on CoRe design as a professional development intervention, were also used to address the questions about CoRe design as a professional development intervention.

The following section focuses on the participants who were involved in this study.

3.4.2 Participants

The researcher's initial contact with the school about the study and potential participants was made in a meeting between the researcher and the school principal. During discussions about the intentions of the study and the roles of participants, the principal began singling out potential participants with respect to their attributes and how these aligned with various roles within the project. Nine teachers were

identified and placed into three groups (three teachers in each, see Table 3.2 on the following page). Whilst all nine teachers took part in the study, the Group One teachers were the primary focus and each teacher represented an individual case for investigating pPCK and ePCK development.

Teachers were assigned to the three groups:

Group One: Practising science teachers with a limited physics background. The principal identified these participants as teachers who would benefit from their PCK being strengthened for the *Electricity and Magnetism* topic. When approached to take part in the study, these teachers were enthusiastic about developing their PCK for this topic and willing to have their PCK development as the focus of the research

Group Two: Experienced junior science teachers who do not have a strong background in physics. The principal regarded these teachers as effective teachers for junior science, but they were not physics specialist teachers. The principal and researcher agreed the presence of these teachers could bring useful pedagogical insights to the CoRe design process, thus contributing to the PCK development of the focus teachers.

Group Three: Experienced physics teachers. The principal endorsed these teachers as effective junior science and physics teachers and predicted these teachers would be able to tap into their extensive professional knowledge and experience to support and enhance the professional development of the whole group.

Table 3.2: Names (pseudonyms) of the participants and the groups they worked within during this research. Their contextual information can be found in Chapter Four, Section 4.2.2.

Group One	Group Two	Group Three
Alan	Lucas	Chris
Tony	Harry	William
David	Kate	Nick

Each Group One teacher taught two Year 10 junior science classes. They taught the topic *Electricity and Magnetism* to the first class prior to taking part in CoRe design (pre-CoRe design) and then taught the same topic to their second class after CoRe design (post-CoRe design).

3.4.3 Data Collection Process

To examine participants' initial baseline pPCK and ePCK, knowledge transitions and exchanges during collaborative CoRe design, and subsequent pPCK and ePCK development, three research phases were used. Each of these phases is now outlined.

Phase One involved gathering data to gain a baseline understanding of the Group One participants' initial pPCK and ePCK. Data to inform this understanding were first collected using semi-structured interviews about teaching science in general and then more specifically the Year 10 topic *Electricity and Magnetism*. Data was also obtained through classroom observation while the Group One teachers taught Year 10 *Electricity and Magnetism* to their pre-CoRe design class.

In Phase Two, data was gathered from all participating teachers as they took part in the two CoRe design workshops. Data from these workshops was gathered by means of unstructured observation and recording field notes, and all conversations were audio recorded. The purpose of collecting this data was to highlight instances where knowledge transitions and exchanges were occurring that may influence teachers' PCK.

During Phase Three, Group One teachers took part in semi-structured individual interviews, and Group Two and Three teachers took part in focus group discussions. Within these discussions, pPCK developments, the effectiveness (or not) of CoRe design, the suitability of CoRe design, and whether they saw it as a worthwhile professional development intervention were explored. Also in this phase, changes to Group One teacher's ePCK were investigated by using another round of classroom observation as they taught Year 10 *Electricity and Magnetism* to their post-CoRe design class.

A summary of these phases, when they occurred, and what data was collected is presented below in Table 3.3 to facilitate the reader's understanding of procedures.

Table 3.3: Three phases of data collection and what data was collected.

Phase	Date	Data Collected
1	June 2016	Audio-recorded, semi-structured individual interviews with Group One teachers about teaching science and <i>Electricity and Magnetism</i> topic to Year 10 students. Video-recordings of Group One teachers' classroom lessons when teaching <i>Electricity and Magnetism</i> topic (Class 1)
2	August 2016	Audio-recording and observations using field notes of teachers participating in <i>The Nature of Science and Scientific Inquiry</i> CoRe design workshop. Audio-recording and observations using field notes of teachers participating in the <i>Electricity and Magnetism</i> CoRe design workshop.
3	September 2016	Audio-recorded, semi-structured individual interviews with Group One teachers exploring their perceptions of CoRe design and its effectiveness for enhancing PCK. Audio-recorded, semi-structured focus group interviews with Group Two and Three teachers exploring their perceptions of CoRe design and to judge its effectiveness for enhancing PCK. Video-recording of Group One teachers' classroom lessons when teaching <i>Electricity and Magnetism</i> (Class 2). Audio-recorded, semi-structured interviews with Group One teachers to explore how they think their pPCK and ePCK had developed as a result of collaborative CoRe design.

During the initial design stage of the study, it was intended that Phases One and Three were going to occur in different years. However, the unintended attrition of two participants in 2015 (two people agreed to participate, but were suddenly unavailable when data collection was to commence), necessitated the decision to complete data collection in one year, as indicated in Table 3.3.

The primary data that was collected from the Group One teachers to develop cases came from interviews and classroom observations. It is important now to discuss the theoretical underpinnings of these data collection methods, justify their use, and describe how they were used. The next section begins with the purpose, nature and use of interviews in general, and why semi-structured interviews were selected for this study.

3.4.4 Interviews

3.4.4.1 Interviews for Collecting Data

Interviews are a common data collection tool used in educational research as they enable the exploration of participants' views and interpretations of phenomena within the context in which they are immersed (L. Cohen et al., 2011). While some people may perceive interviews as simple conversations between people about a given topic, Dyer (1995) explains that there are many differences between conversations and interviews: interviews have an explicit purpose, questioning tends to be limited to the interviewer, and there is a need for detailed answers.

When designing an investigation involving interviews, Kvale (1996) emphasises the importance of thematising and designing interviews before they are used in the field. The first stage of thematising interviews refers to reviewing the purpose of an interview in a given situation and what information is being sought. The second stage of designing interviews builds upon thematising, where the researcher needs to determine clear parameters about how the actual interviews are to be conducted. During this second stage of development questions and themes should be developed and ethical considerations taken into account (Kvale, 1996). These two stages of interview development are important because they must be compatible with the research objectives.

For this study, an interview type known as a semi-structured interview was chosen. This style allows the interviewer to have a pre-determined series of guiding questions, each with a set theme and prompts for probing where deemed appropriate, and a specific sequence for interviewing participants (Bogdan & Biklen, 2007; Bryman, 2016; Kvale, 1996). It also gives the interviewer the flexibility to seek additional clarification or explore participant responses further if deemed necessary (Bogdan & Biklen, 2007; L. Cohen et al., 2011). For example, there is an opportunity to alter wording or phrases within the questions to ensure the participant had understood the question, or to seek further clarification of information given in responses. By employing this interview style, participants were also encouraged to discuss and illustrate their professional knowledge, which would have been difficult to capture using only a specific set of questions. This semi-structured interview approach is similar to how other researchers have tried to capture teachers' PCK (e.g., Lee & Luft, 2008).

While the main advantage of using semi-structured interviews as a data collection method, compared to other methods, is the depth of information that can be explored (Desimone & Le Floch, 2004), there are also limitations when using such interviews. The most significant limitation relates to the reliability of the data (Dyer, 1995). In the context of interviewing, reliability concerns the need for interviews to consistently measure what they were designed to measure, across different participants (Gray, 2014). Issues of reliability can arise when the interviewer alters the script or their behaviour during the interview process. To minimise this problem during interviews, Gray (2014) suggests that the exact same guiding questions be used for all interviews and the same protocol be followed, for example, probing questions. This study chose guiding questions that were the same for all interviews conducted, and only one person conducted all of the interviews following a pre-determined procedure of probing questions.

The following section describes how interviews were used as a data collection tool in Phase One of this study.

3.4.4.2 Interviews in Phase One

To gain an understanding of the Group One teacher's pPCK, individual semi-structured interviews were utilised. A set of guiding questions were developed to probe: the participants' beliefs and attitudes about teaching science and Year 10 *Electricity and Magnetism*; their understanding about curricula goals; their approach to teaching the Year 10 *Electricity and Magnetism* topic including the strategies they use with students; their thoughts about use of assessments, and, their feelings of self-efficacy for teaching Year 10 *Electricity and Magnetism*. The development of these questions was based on PCK research literature including interpretations of the RCM of PCK and how other PCK researchers have conducted interviews. After the questions were developed, they were piloted with a volunteer teacher, Harriet (pseudonym), who was a non-physics science teacher and did not take part in the study.

Feedback from Harriet and other researchers revealed useful points to consider before using interviewing Group One participants. Firstly, the reminder that during the review of the transcript after the pilot interview that few participants would have read extended literature around PCK in a science education context. Thus, the wording of questions required changing to eliminate unfamiliar terminology and replaced with more accessible language that conveyed similar meaning. For example, rather than asking participants about their orientations and philosophy for teaching science, they were asked why they thought science was important to teach. Secondly, leading questions were minimised, although some were kept as lead-in questions to ensure some pre-identified themes were explored. Lastly, there is an issue of not following up on/probing further into areas of interest during the interview. This last consideration takes time for a researcher to master as it is dependent on experience. It was not until a retrospective review of the interview transcript that certain omissions became apparent. However, during the actual interviews, these considerations came to the fore as questioning was carried out and the ideas and discussion points emerging from the initial pilot interview with Harriet were applied to all the interviews used in the study.

After establishing contextual information about each Group One teacher in this initial interview, the questions focused on six areas of pPCK which were informed by the RCM of PCK. These six areas, along with an explanation about how each

was questioned and its rationale for inclusion in the interview are detailed below in Table 3.4 below.

Table 3.4: Question areas for pPCK interview and an explanation about that each area.

Question Area	Explanation
Personal philosophy of science teaching	Participants were asked about their opinions and beliefs towards teaching science, and their views on the inclusion of science in the New Zealand Curriculum (NZC) document. While opening parts of some questions can be seen to be leading, this decision made to allow for further exploration. For example, finding out <i>why</i> they thought something. During the interview, participants were asked to articulate their own interpretation of the goal for science education. Participants were also asked about their views on teaching <i>Electricity and Magnetism</i> , whether they see students acting as scientists in their classrooms, their understanding of the nature of science and scientific inquiry, and how they might incorporate their ideas into their lessons were also explored.
Knowledge of curricula	Participants were asked about what they thought Year 10 students <i>should</i> be learning about <i>Electricity and Magnetism</i> , and <i>why</i> . This technique was used rather than asking them to state what is in the NZC document to allow for participants to express their own interpretation of what is stated in the NZC document, and why they think their ideas are important. While the NZC document serves as a policy document to guide schools and teachers, the Achievement Objectives are broad statements that allow for a range of interpretations (Bull et al., 2014).
Knowledge of students' understanding in science	Three lines of questioning were used here: asking participants about what prior knowledge they might expect students to have prior to starting this unit, what misconceptions they might expect to encounter, and their views on how students learn in their classrooms. Again, while it can be seen that some initial questions to this part of the interview were leading, they were used to allow for further probing questions to explore their thinking.

Table 3.4 Continued.

Question Area	Explanation
Knowledge of instructional strategies	This area was addressed in three parts. The first question that participants were asked centred on their first lesson with the students when teaching Year 10 <i>Electricity and Magnetism</i> (i.e., what approach or strategy did they use). The rationale for this question stemmed from both the literature and the researcher's experience in teaching science. As shown in the literature review, learning about electricity and magnetism can be difficult for students due to the abstract nature of some concepts. It seems appropriate then, that the first lesson with the students is crucial to create an environment where they can develop these ideas. Secondly, the participants were asked about their sequencing of the lessons, which explored how they transitioned from their introductory lesson into the body of work, and to investigate the influences on their teaching, as the flow between concepts is important as it allows students to develop their understanding. The third question centred on specific strategies that they may have used: either successfully or unsuccessfully. This question was to ascertain what topic-specific strategies they may already be using prior to collaborating with experienced physics teachers.
Knowledge of assessment strategies	To explore participants' knowledge of assessment strategies, they were directly asked about how they determine whether their students had learnt certain concepts and skills, and how that information may be used. There were other questions in the interview as well which would also indicate their knowledge of assessment.
Sense of self-efficacy for teaching Year 10 <i>Electricity and Magnetism</i>	To explore their sense of self-efficacy, participants were simply asked to describe how confident and effective they felt when teaching Year 10 <i>Electricity and Magnetism</i> . Included here was asking how they might use different instructional strategies depending on their level of confidence, and what they might do in those situations.

The complete interview schedule for Phase One interviews with guiding questions and prompts can be seen in Appendix C1. All three interviews were audio recorded and transcribed at a later date for analysis. This strategy ensured that the researcher was able to focus on the interview itself, rather than attempting to rapidly write/type or trying to recall information (Kvale, 1996). When considering transcription, Kvale (1996) supplies important considerations such as emphasising the need for verbatim transcription, including any paralinguistic features such as pauses or sighs. He warns that this technique is necessary since transcripts are “are not copies or representations of some original reality, they are interpretative constructions”, which are essentially “decontextualised conversations” (p. 165), and that precise

information is required to make valid analysis. On the issue of reliability, Kvale (1996) indicates that this requirement is not as complex to address as validity. Different transcribers adopt different styles, and Kvale (1996) suggests a reliability check where two people transcribe the recorded data and then compare transcripts for any anomalies. Validity and reliability, as components of trustworthiness, are discussed in more detail later in this chapter.

As part of this study, interviews were also used in Phase Three in order to gauge the impact and suitability of CoRe design. The following section explains how interviews were used in that phase.

3.4.4.3 Interviews in Phase Three

In Phase Three, the focus was on evaluating the impact of CoRe design on the teacher's pPCK and ePCK, and data was collected from all participants using the same guiding questions in a semi-structured format. Group One teachers took part in individual semi-structured interviews while Group Two and Three teachers participated in semi-structured focus group interviews. All of the interviews were audio recorded. The rationale for using focus group interviews for Group Two and Three teachers is explained below.

Focus group interviews can be seen as interviews with more than one interviewee at a time (Flick, 2014; M. Watts & Ebbutt, 1987) and they were chosen for Group Two and Three teachers during this phase to promote: efficiency, diversity, and interactions between participants. Since focus groups involve groups of people rather than individuals, they are seen as being more efficient and cost effective at generating rich data because multiple participants can be interviewed at once and they tend to build upon each other's ideas (Flick, 2014; Patton, 2014; M. Watts & Ebbutt, 1987). Members of the focus groups in this study came from different backgrounds with varied experiences and perspectives, and the focus group setting allowed them to express and discuss their responses to questions amongst the group, making for more interesting and rich data (Patton, 2014). Such interactions within the focus groups also means that participants generally enjoy the process and provide 'checks' on each other's comments to minimise false or extreme views (Gray, 2014; Patton, 2014).

However, like any data gathering tool, there are limitations when using focus group interviews. There are two limitations discussed in the educational research literature which are pertinent to this study. The first limitation centres on possible power relationships causing conflicts between participants during the interaction, including how one person may contribute more or less compared to others (L. Cohen et al., 2011; Flick, 2014; Gray, 2014). The possibility of conflict arising from power relationships within this study had been identified and considered early in the design stages (e.g., one teacher dominating the discussion causing others to be reluctant to express their ideas). The issue of power relationships were discussed with participants individually who expressed they felt comfortable sharing their ideas in these focus group environments and thought no conflicts would occur, nor would one person be too dominating. There were no indications in subsequent focus group interviews that this limitation was impacting on data collection.

The second limitation can arise from the analysis of focus group data, namely the transcribing and attributing of thoughts and comments to individuals (L. Cohen et al., 2011; Flick, 2014; Gray, 2014; M. Watts & Ebbutt, 1987). For example, when transcribing the discussion, M. Watts and Ebbutt (1987) note that it can be difficult to decipher the conversation and attribute different parts to different members. While Kvale (1996) discusses the importance of verbatim transcription, as outlined earlier, Flick (2014) offers some useful guidelines about the manageability of the procedure, such as only transcribing the parts that are required to address the research objectives (still using a verbatim method), and using a format that is easy to follow, clear, and concise. Furthermore, Stewart and Shamdasani (2015) suggest there may be ideas that are discussed, which are not relevant to the research and verbatim transcription is not required. In situations where individual transcription is difficult, M. Watts and Ebbutt (1987) suggest crediting ideas and thoughts to the group as an entity rather than to individuals. This advice was heeded in this study for the focus group discussions, and verbatim transcription was done where appropriate. At times when it proved difficult for the reasons above, generalisations were made that were attributed to the group being interviewed.

The interview questions (see Appendices C2 and C3) used during Phase Three with all participants were designed to investigate their perceptions of and experiences with CoRe design, and whether they felt it made an impact on their pPCK and

ePCK. At the interview after the first CoRe design workshop, participants were asked about the usefulness and difficulties they encountered with CoRe design, and their experiences from the workshop. After the second CoRe design workshop, participants were asked specifically about the worth of the CoRe design process for the Year 10 *Electricity and Magnetism* topic, including the effects it may have had on their pPCK for teaching particular concepts

After the Group One teachers had finished teaching their post-CoRe design class in Phase Three, they were interviewed for a final time about their experiences throughout the whole study process (see Appendix C4 for questions). This final interview was to allow the Group One teachers to reflect on their professional learning and their teaching of Year 10 *Electricity and Magnetism* after being involved in CoRe design. The interview questions sought to identify differences in their teaching with their second class compared to their first class, and the linkages of these differences to CoRe design. Group One participants were also asked about what changes could be made to CoRe design to make it useable and worthwhile in their school.

To gain further insight into Group One teachers' initial pPCK, and ePCK development after CoRe design, observations of their classroom teaching were also carried out to enhance the trustworthiness of the findings via data triangulation. The following section provides details about the nature of these classroom observations and how they were used in this study for collecting data.

3.4.5 Observations

3.4.5.1 Observations for Collecting Data

An observation is a method of collecting data that allows the researcher to comprehend information from a first-hand perspective in relation to a specific context (L. Cohen et al., 2011), because the data is descriptive of the participant's behaviour within that setting (Gray, 2014). Observations involve “the systematic observation, recording, description, analysis and interpretation of people's behaviour” (Saunders, Lewis, & Thornhill, 2009, p. 288). Observations can be divided into different types depending on the nature of the observation, and the two features of observations pertinent to this study are the observer roles (e.g., Gold,

1958; Gray, 2014) and the structure of the observation (e.g., Mulhall, 2003; Saunders et al., 2009). Each of these features of observations are now visited in more detail to elaborate on their characteristics and use.

To comprehend the different roles that an observer may take, it is useful to adopt the framework offered by Gray (2014), which is shown in Figure 3.3. This framework shows the linkages between an overt/covert observation, and how involved the observer is with the participants. The result is four possible observer roles: announced participant, undercover participant, announced observer, and undercover observer.

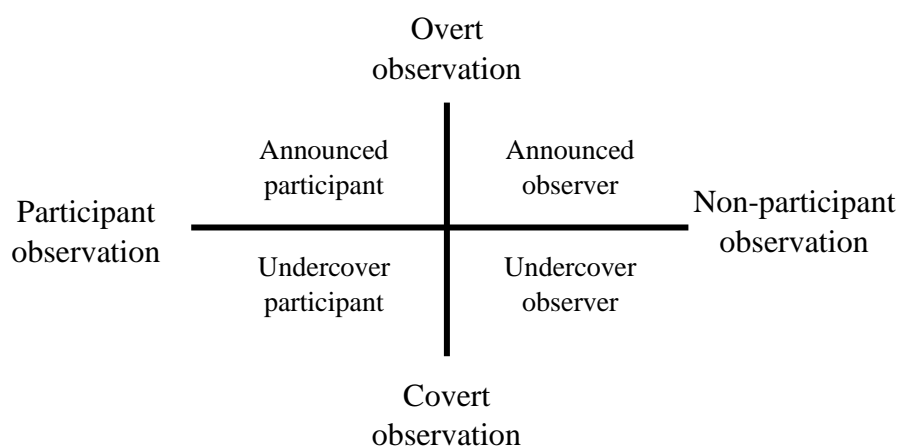


Figure 3.3: Observation research roles (Reprinted with Publisher's permission, Gray, 2014, p. 414).

Covert and overt observations refer to whether the participants being observed are knowledgeable that the observations are taking place. In educational settings, covert observations are considered unethical (Gray, 2014). All the observations done in this study were overt in nature, with all participants receiving detailed information about their participation in the study and informed consent was sought prior to data collection (see Appendices A and B).

Both participant and non-participant observations were used in this study, that is, both an announced participant and announced observer roles were utilised at different times. Participant observation refers to an observer being immersed in the natural setting of the participants and taking part in the activities being observed. In contrast, non-participant observation refers to an observer being removed from the

activities taking place, and simply observing the behaviours and actions of participants (L. Cohen et al., 2011; Gray, 2014).

Observations can also be characterised by their structure, and like interviews, they can be structured or unstructured (Mulhall, 2003). To differentiate, structured observations are highly systematic and involve the researcher predetermining what is to be observed, while unstructured observations may not have a predetermined objective since they tend to be responsive to what is observed (Saunders et al., 2009). During structured observations, the researcher has developed a set of predetermined behaviours, actions, or activities that are going to be observed. In addition, structured observations allow for elements of quantitative research methodology to be included if appropriate (Gray, 2014). Recording and analysing predetermined behaviours in observations can be facilitated by the development of an observational protocol or schedule that organises what is going to be observed during an observation (Creswell, 2014). Such a tool guides the researcher in what to look for, make notes about, and reflect on during the observation and enhances reliability through consistency. When exploring suitable options for observational protocols, Saunders et al. (2009) indicated two protocol design options available for researchers. Firstly, an ‘off-the-shelf’ observational protocol could be used, or a schedule developed specifically to address research questions and objectives in a particular study.

In contrast, unstructured observations involve the researcher becoming immersed within the episode being observed, in order to experience it in full and gain insights into what is occurring (Saunders et al., 2009). Mulhall (2003) cautions that the label ‘unstructured’ can mislead people to think the method is disorganised, when in fact the method simply does not follow a set of predetermined behaviours. This flexibility can allow the researcher to enter the field with some awareness of what they are looking for, but there is allowance for the focus of the observation to change. During this unstructured observational process, the researcher collects data by writing down and documenting what occurred in the field, often referred to as field notes (Creswell, 2014). However, manageability issues like speed of writing notes, means field notes can be selective in terms of what is recorded, thus leading to the development of an incomplete record (Gray, 2014). Before using field notes

for publishing to a wider audience, Gray (2014) suggests that they should be edited by adding in context and background information.

While observations are seen as useful data collection methods, there are also limitations, which need to be identified, since the issues that researchers encounter can have consequences on the trustworthiness of the data. The limitations that can occur during observations arise from two aspects of human behaviour: the way the participant acts when being observed; and, the interpretation of the researcher during the act of observation (L. Cohen et al., 2011; Wilkinson, 2000).

Participants acting in different ways when being observed is a challenging limitation for researchers to control. However, in this study to mitigate the effect, all participants were provided with information so they were aware of the purpose of the observation and were encouraged to behave naturally. Strategies to mitigate the limitation of researcher interpretation included: making detailed and complete notes about observed behaviour prior to analysis; using a structured observational protocol for analysis, including examples of what counted as evidence; and, ensuring data was gathered and analysed with an open mind and no prior expected outcomes.

Observations were used in all three phases of this study. The following two sections explain how observations were utilised in this study as data collection tools.

3.4.5.2 Observations in Phase One and Three

Observations carried out in Phase One and Three of this study involved observing Group One teachers as they taught Year 10 *Electricity and Magnetism*: Phase One before, and Phase Three after, taking part in CoRe design. The researcher took on the announced observer role to ensure that the observed teacher and students were aware of the observation so there was little influence on the lesson. All of these observations were video recorded. The decision to video record the lessons was made for the following two reasons: the researcher was a full-time teacher at the time of data collection, so physically observing lessons was challenging; and, recording ensured unfiltered and raw evidence of the events occurred in the participants' classrooms (Simpson & Tuson, 2003). In the initial design of the study, it was intended that the researcher would be present for some observations

while the rest were videoed, however, this task proved too difficult, so all lessons were recorded. By video recording the lessons, the pressure of rapidly recording what happened during the lesson was alleviated, as the video could be watched multiple times. This feature allowed detailed analysis and further scrutiny – an advantage over the achievements of a single observer sitting at the back of the classroom (L. Cohen et al., 2011; Gray, 2014; Simpson & Tuson, 2003). While videoing lessons proved useful, there are also considerations that need to be made when video recording observations. For example, L. Cohen et al. (2011) warn that the actual positioning of the camera may mean it is selective in capturing actions. Likewise, Simpson and Tuson (2003) caution that students may get in the way of the recording leading again to important aspects of the lesson possibly being missed. To mitigate these issues, the camera was placed at the edge of the classroom on a tripod to ensure recordings were obtained that showed the teachers' interactions with the students (see Figure 3.4). The teacher also wore a lapel microphone to ensure they could always be heard.

The recording equipment used was a high-definition Sony video camera with an attached shotgun microphone. The use of two microphones ensured the teacher's instructions were captured clearly, and the students' responses could also be heard. When required, a senior student from the school, Ryan (pseudonym), assisted the researcher by setting up the equipment. Ryan was competent at video recordings as he was heavily involved with and experienced in school audio visual activities. Ryan signed a confidentiality agreement with the researcher (see Appendix B5) and provided digital copies of the recordings to the researcher.

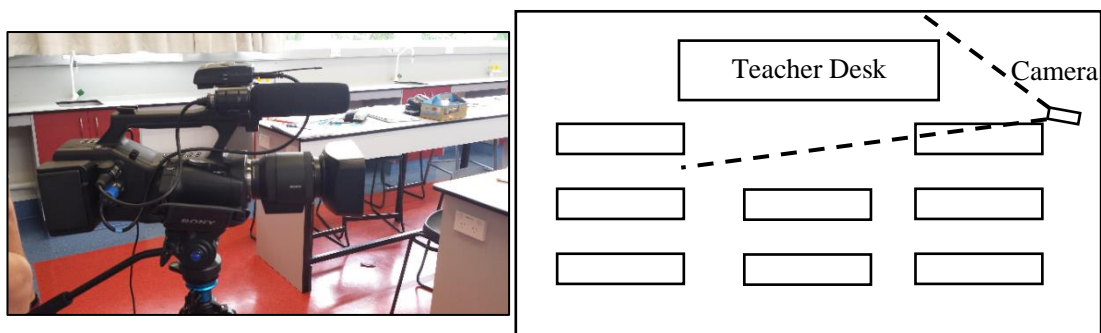


Figure 3.4: Camera setup with shotgun microphone and receiver for lapel microphone, and typical setup for recording in laboratories.

During these observations, the camera acted as the observer, and the live action in the videos could be viewed and analysed later by the researcher. As the camera was in the classroom or laboratory, an announced observer role was used. A semi-structured observation (O’Sullivan, 2004) format was adopted as it allows for features from both structured and unstructured observations to be included. This tool allowed the researcher to document all of the interactions that took place during the lesson, and to later analyse these interactions using predetermined indicators showing aspects of ePCK. Following the advice from Creswell (2014) and Saunders et al. (2009), a sophisticated data gathering tool in the form of a schedule or observational protocol was required, and subsequently created for this study.

The purpose of developing this observational protocol was to look for observable behaviours within lessons that gave insights into the application of the teacher’s pPCK, or their ePCK, without having to make inferences. Building on PCK studies and discussion and advice from the second PCK Summit, the protocol took form as a rubric that categorised and assessed different behaviours. The specific rubric designed for this study identified different components of ePCK and quality indicators that could be seen in the classroom. Two major considerations in the development of this rubric included alignment with the RCM of PCK resulting from second Summit and the intervention for professional learning that was used. Thus, the rubric focused on capturing components of ePCK with respect to the CoRe design prompts and process.

In the design process, rubrics from other PCK studies were examined for their suitability; notably the components of PCK being measured in each rubric and the specific language used to describe performance for each component. As a result, elements of rubrics from the following studies were selected to inform the rubric design in this study: Lee et al. (2007); Gardner and Gess-Newsome (2011); and, Park et al. (2011). The rubric design also took into account: the prompts used when developing a CoRe (Loughran et al., 2006) for a particular topic; and, the outcomes of discussions from the second PCK Summit, particularly the conversation around the exploration of a ‘grand rubric’ (see Chapter Two, Section 2.4.5). From this synthesis of information, three components of ePCK were identified as the focus for lesson observations: *subject matter knowledge*, *knowledge of student understanding*, and *knowledge of instructional strategies*. The nature and extent of

each ePCK component being observed was assessed using a set of specific indicators whose design was informed by the rubric literature above. A copy of the rubric including the components can be seen on the following pages. Each indicator was scored according to the level descriptors labelled *limited*, *basic*, *proficient*, or *advanced*.

To inform scoring against the rubric (see Table 3.5, Table 3.6, and Table 3.7), detailed notes were made about events that occurred during the observed lesson. For example, the teacher using a particular analogy in their teaching, or carrying out a practical demonstration, or engaging students with questions. Instances of ‘negative’ events, such as the teacher ignoring student questions or failing to build upon student ideas, were also noted. Brief contextual information about the particular class observed was also recorded. A full copy of the protocol and a completed one can be seen in Appendices D1 and D2.

Once the full protocol was developed, it was piloted by the researcher and Chief Supervisor using the same video-recorded lesson, and the analyses compared. Notes and revisions were made, and then a second pilot was done by the researcher, which was critiqued by the supervisory team. The new protocol was used on further observational data from this study and taken to the Second PCK Summit where it was critiqued by other PCK researchers. Upon returning to New Zealand, final revisions were made and then the protocol was used by the researcher and Chief Supervisor once more to ensure consistency. This iterative approach promoted robust reliability and the protocol was subsequently used for analysis.

Table 3.5: Rubric for scoring subject matter knowledge as a component of enacted pedagogical content knowledge (ePCK) from video observations. This rubric relates directly to CoRe Prompts One, Two, and Three (see CoRe template, Appendix E2).

ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriateness of concept(s) in relation to NZC – Physical World (Level 5)	No alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Little alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Adequate alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Close alignment of concept(s) in lesson with NZC – Physical World (Level 5)
Scientific accuracy of the explanation of the concept(s)	Explanation(s) were mostly inaccurate, which did not address the concept(s)	Explanation(s) were somewhat inaccurate, which loosely addresses the concept(s)	Explanation(s) were mostly accurate with only small inaccuracies seen, or they were too brief	Explanation(s) were accurate, which addresses the concept with no inaccuracies
Links and/or connections made to other concepts	No possible links and/or connections are made	Few of the possible links are made, but not connected with explanations	Some of the possible links and connections are made	Many of the possible links and connections are made
Links made (implicit or explicit) to the nature of science (NoS) and/or scientific inquiry (SI)	No links made to NoS and/or SI	Few of the possible links to NoS and/or SI are made	Some of the possible links to NoS and/or SI are made	Many of the possible links to NoS and/or SI are made

Table 3.6: Rubric for scoring knowledge of student understanding as a component of enacted pedagogical content knowledge (ePCK) from video observations. This rubric relates directly to CoRe Prompts Four, Five, and Eight (see CoRe template, Appendix E2).

ePCK Indicator	Limited	Basic	Proficient	Advanced
Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions	No recognition or acknowledgement of possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges most/all possible student prior knowledge, difficult concepts, and/or misconceptions
Teacher uses identified variations in student understanding and learning to guide instruction	No acknowledgement and/or use of variations in student understanding and learning to guide instruction	Acknowledgement of variations in student understanding or learning, but not used to guide instruction	Some acknowledgment of variations in student understanding or learning are used to guide instruction	Many instances where teacher acknowledged variations in student understanding or learning and used these to guide instruction
Teacher uses questioning to probe or extend student understanding	No questions are used to probe or extend student understanding	A few questions are used to probe or extend student understanding	An adequate range of questions are used to probe or extend student understanding	Many and varied questions are used to probe or extend student understanding

Table 3.7: Rubric for scoring knowledge of instructional strategies as a component of enacted pedagogical content knowledge (ePCK) from video observations. This rubric relates directly to CoRe Prompt Seven (see CoRe template, Appendix E2).

ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriate sequence for teaching concepts	No overall flow between concepts and the sequence confuses students	Some flow between concepts and the sequence allows some concept building to occur	Suitable flow between concepts and the sequence allows satisfactory concept building to occur	Clear flow between concepts and sequence allows effective concept building
Relevant examples and/or representations are used in the lessons, which appear to be pedagogically effective at portraying the concept	No examples and/or representations used	Examples and/or representations used that do not appear to be pedagogically effective	Examples and/or representations used have some relevance, but appear pedagogically limited	Relevant examples and/or representations used that appear pedagogically effective
Use of strategies that allow for metacognition	No use of strategies that allow for metacognition	Limited use of strategies that allow for metacognition	Adequate use of strategies that allow for metacognition	Much use of strategies that allow for deep levels of metacognition

To mitigate researcher bias when interpreting observations, it is vital to explicitly state what is meant by each ePCK indicator in the rubric, explain why the indicator is significant to the findings, and provide examples corresponding to the different levels of scoring for each indicator. To illustrate this practice, statements of meaning for each ePCK indicator and accompanying rationales are provided. Examples of what may be regarded as limited and advanced levels of scoring for each indicator are also given, using the Year 10 *Electricity and Magnetism* context.

Component One of ePCK: Subject Matter Knowledge (see Table 3.5)

Appropriateness of concept(s) in relation to the New Zealand Curriculum – Physical World (Level 5)

This indicator represents appropriate alignment between the content (concepts and/or learning objectives) the teacher is trying to cover in the lesson and the achievement objectives that are outlined in the Physical World section of the NZC. It is critical that the concept(s) covered are at the appropriate level for the students, which is considered to be Level 5 for Year 10 students. There is allowance within this indicator for situations where the teacher covers more than one concept in lesson also. This indicator provides insight into the nature of the teacher's understanding of curriculum content and levels and the ideas being taught to students. In particular, it indicator shows what links, if any, the teacher makes between certain concept(s) in the lesson and the achievement objectives from the NZC document.

Limited – There was no alignment between the concept(s) that were covered in the lesson and level five of the NZC. For example, the teacher taught electric field theory as a concept in a way that aligns closer to Level 7 of the NZC, as exemplified in school work plans, texts, and professional teaching resources, than to a Level 5 understanding.

Advanced – There was close alignment between the concept(s) that were covered in the lesson and Level 5 of the NZC. For example, the teacher taught voltage in a way that can be judged appropriate for students working at Level 5 of the NZC, as exemplified in school work plans, texts, and professional teaching resources.

Scientific accuracy of the explanation of the concept(s)

This indicator represents how scientifically accurate the teacher's explanation is about a certain concept, or concepts if more than one was covered in the lesson. It is an important indicator to consider for exploring teachers' ePCK, as scientifically accurate explanations are essential to ensure students avoid developing misunderstandings or misconceptions about certain concepts. This indicator should provide useful insight into teacher's subject matter knowledge about certain concepts.

Limited – The explanation(s) was/were inaccurate, and did not address the concept(s) correctly. For example, the main concept of the lesson was voltage across components in a simple series circuit, and the teacher explained it inaccurately by stating the voltage flows through components.

Advanced – The explanation(s) was/were accurate, the concept was addressed, and there were no inaccuracies. For example, the main concept in the lesson was voltage across components in a series circuit, and the teacher explained it accurately by discussing how the voltage is shared across components, and each voltage depends on the resistance of the component.

Links and/or connections made to other concepts

This indicator represents the notion that many concepts in science have connections to others, and it explores whether the teacher acknowledges and makes such links and/or connections to other concepts. Links between concepts are interpreted as present when the teacher makes reference to other related concepts, while connections are when those links are made and explained (i.e., how they are related). For example, in Year 10 *Electricity and Magnetism*, whilst current, voltage, and resistance may be taught as separate concepts, they are very much interconnected as each of these phenomena in a circuit affects the others. The indicator signals the teacher's own level of conceptual understanding and their linkages and connections with other relevant concepts.

Limited – No possible links or connections were made in the lesson. For example, the main concept covered in the lesson was about current flow, but

the teacher made no links or connections to other relevant concepts such as voltage, resistance, heat, or safety.

Advanced – Many possible links or connections were made in the lesson. For example, the main concept covered in the lesson was about current flow, and the teacher makes clear and frequent links between current flow and concepts like voltage, resistance, heat, and safety, and explained how they were related.

Links made (implicit or explicit) to the nature of science and/or scientific inquiry

This indicator represents the possible links that the teacher could make to the nature of science and/or scientific inquiry in a lesson. The reason for grouping these separate ideas (i.e., and/or) reflects how they are conflated in the NZC. The recognition of implicit and explicit instances captures all possible links that were made in the lesson. This indicator acknowledges that students need to have an understanding about the nature of science and scientific inquiry to become scientifically literate citizens of society (e.g., NRC, 2012).

Limited – No links to the nature of science and/or scientific inquiry were made in the lesson. For example, the teacher taught the concept of voltage but makes no implicit or explicit links to the nature of science or scientific inquiry.

Advanced – Many possible links to the nature of science and scientific inquiry were made in the lesson. For example, the teacher taught the concept of voltage and makes links to historical advances such as Galvani's experiments with frog legs (e.g., Piccolino, 1998), the contribution of Volta to early ideas about voltage and some of his early experiments (e.g., Trasatti, 1999), through to modern understanding (appropriate for their level). Through this process the teacher explicitly talks about the nature of science, how knowledge is tentative and verified, and how scientific investigations are done in order to generate new knowledge.

Component Two of ePCK: Knowledge of Student Understanding (see Table 3.6)

Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions

This indicator represents whether the teacher acknowledges students' prior knowledge and misconceptions, and if they acknowledge a particular concept as being difficult to grasp. To effectively advance students' understanding so they can further develop their conceptual frameworks, the teacher needs to be aware of areas of contention and difficulty in students' learning.

Limited – No recognition or acknowledgement of student prior knowledge, misconceptions, and/or difficult concepts. For example, the teacher taught the concept of voltage without exploring what students may already know, nor did they show any insights about possible misconceptions or acknowledge the difficulty that students may face with understanding what voltage is.

Advanced – Recognises and acknowledges most or all possible student prior knowledge, misconceptions, and difficult concepts. For example, the teacher taught the concept of voltage by first exploring what students already knew, and used their own professional knowledge and experience to identify and highlight (in constructive rather than critical ways) aspects of students' mental models that are not helpful for understanding the abstract nature of voltage.

Teacher uses identified variations in student understanding and learning to guide instruction

This indicator builds upon the previous one in that it represents how teachers use information about variations in student understanding and learning to guide further instruction. It recognises and highlights aspects of the teacher's pedagogical reasoning, that is, the reasoning behind their actions in the lesson.

Limited – There was no use of knowledge about student understanding or their variations in learning to plan and guide the lesson. For example, the teacher taught students about magnetism without reference to prior learning and/or misconceptions, and regardless of whether students showed

understanding or not of the concept during the lesson, they followed a pre-planned lesson schedule without making any pedagogical changes.

Advanced – There were many instances where the teacher acknowledged student understanding and variations in their learning in the manner they taught the lesson. For example, the teacher began the lesson by seeking students' views on aspects of magnetism, and built the lesson on those understandings. At times when the teacher noticed students were having difficulty in understanding concept, the teacher went back over the information using modified pedagogical techniques; forgoing other concepts that were previously going to be covered in the same lesson to ensure they had developed their understanding of fundamental concepts first.

Teacher uses questioning to probe or extend student understanding

This indicator represents the extent to which the teacher probed or extended student understanding during the lesson using appropriate questions. It has close links with the previous two indicators, illustrating how effectively the teacher monitors student understanding during the lesson (formative assessment). Failure on the part of the teacher to monitor learning means that students may be left unsure of a concept as the teacher moves onto the next concept. Or, perhaps students already have a sound understanding of a concept, and without exploring their understanding and extending their learning, the teacher unnecessarily teaches that concept.

Limited – No questions were used by the teacher in a lesson. For example, the teacher taught students about making simple electric circuits, and during the lesson no questions were asked to probe student understanding, rather they continued following a set instructional sequence.

Advanced – Many and varied questions were used by the teacher during a lesson to probe and/or extend learning. For example, the teacher ran a student-centred lesson on making simple electrical circuits, and throughout the lesson the teacher moved around the classroom asking students about what they were doing, and why, and to explain their thinking.

Component Three of ePCK: Knowledge of Instructional Strategies (see Table 3.7)

Appropriate sequence for teaching concepts

This indicator assesses how well the teacher sequences their instructional strategies to help students develop effective mental models of concepts. For student to develop such mental models, appropriate instructional strategies need to be used that show linkages between concepts. Without appropriate sequencing, students may have confusion about concepts or develop misconceptions.

Limited – No instructional strategies used to show linkages between concepts. For example, the teacher began the lesson on voltage and then shifted into magnetism without a clear explanation about the links. Students may be left unsure about the connection between the two.

Advanced – Teacher facilitates students’ development of appropriate linkages between concepts through an instructional sequence that allows for students to develop effective mental models. For example, the teacher taught students about resistance, which was used to develop a discussion about current flow in wires and energy.

Relevant examples and/or representations are used in the lesson, which appear to be pedagogically effective at portraying the concept

This indicator represents what examples and/or representations are used by the teacher to aid student understanding, and how effective they are at illustrating the desired concept. Use of examples and representations is known to help students develop their conceptual understanding, especially when the abstract nature of some concepts requires well developed mental models for comprehension. For example, the teacher relates a concept to real-life situation that are likely to be familiar with students (e.g., static electricity and lightning). The use of representations may be an instance where the teacher represents a concept by using models or analogies (e.g., computer simulations for circuitry). This indicator also provides insight into the teacher’s personal understanding of the concept(s) they are teaching (i.e., their subject matter knowledge).

Limited – No examples or representations were used in the lesson. For example, the teacher taught students about the repulsion of charges, but only used notes with no representations or examples to support their explanation.

Advanced – Examples and/or representations are used that appear to be pedagogically effective. For example, the teacher used examples such hair standing up when jumping on trampolines, and used a computer simulation to represent what was happening when teaching students about repulsion of charges. Both strategies appeared to be pedagogically effective at portraying the concept.

Use of strategies that allow for metacognition

This indicator measures whether a teacher used strategies that allows students to think about and question their own understanding to challenge their own conceptual frameworks and thought processes, and undergo conceptual change (see Chapter Two, Section 2.3.1). For students to develop and advance their conceptual understanding, they need to engage in metacognition.

Limited – No use of strategies that allow for metacognition. For example, the teacher taught a lesson about conductors and insulators where students copy notes and no strategies were used that encouraged students to challenge their own thinking.

Advanced – Frequent use of strategies that allow for deep levels of metacognition. For example, when teaching students about current flow in conductors, a variety of strategies were used such as: role-playing electrons in a wire; asking students to explain in their own words about why current flows in different substances; or, encouraging debates between students about their understanding of the phenomena occurring.

The following section provides information about how and why observations were carried out in Phase Two of the data collection.

3.4.5.3 Observations in Phase Two

During both CoRe design workshops, the researcher acted as an announced participant (see Figure 3.3 on Page 122). Adopting this role during the observation meant participants were aware of the researcher's presence and the reasons why they were being observed, and there was also the opportunity for the researcher to engage with the participants. This mode of observation allowed for participant-researcher discussions about different aspects of the CoRe design process during the workshop (e.g., discussing CoRe design prompts). During this phase, an unstructured type of observation for data collection was employed as there were no predetermined behaviours within the workshop that were being targeted. This structure allowed the researcher the freedom to record information and take field notes of any conversations and behaviours that occurred. All conversations amongst the participants were audio recorded and the transcriptions were done in the same way as the focus group interviews, as discussed earlier.

The following section provides information about the facilitation of the CoRe design workshops.

3.4.6 CoRe Design Workshops

In this study, CoRe design was used as a PLD intervention for colleagues to share their ideas about teaching certain ideas and concepts. During the intervention, participants had the opportunity to further develop their own professional knowledge about teaching by taking part in collaborative professional learning activities. The particular topic focused on for teacher's professional learning via CoRe design was Year 10 *Electricity and Magnetism*. CoRe design allows researchers to assess and critique teachers' understanding around various topics in science as well as giving a method of presenting that knowledge (Loughran et al., 2004).

Following the advice of Evens et al. (2015), an experienced facilitator, Sarah (pseudonym) was used to run the workshops. For the CoRe workshops, three Working Groups were formed comprising one teacher from each of the participant groups (see Table 3.2 on Page 112) so each Working Group represented a variety of experiences and ideas. The participants were randomly assigned to a Working

Group and the membership of these Working Groups is shown below in Table 3.8, along with participants' original group (see Section 3.4.1).

Table 3.8: Membership of the Working Groups for CoRe design, and participants' original group.

Original Group	Working Group One	Working Group Two	Working Group Three
Group One	Alan	Tony	David
Group Two	Lucas	Harry	Kate
Group Three	Chris	Nick	William

The next two sections provide a brief overview of the administration of the CoRe design workshops. Detailed information about the interactions that took place and the ideas that were discussed can be found in Chapter Five – Phase Two Findings.

3.4.6.1 Piloting CoRe Design

CoRe design is a time consuming process (e.g., Bertram & Loughran, 2012), as the researcher had personally experienced. Thus, the decision was made to engage teachers in this study in a pilot CoRe design process, so they could learn the process basics. For this pilot CoRe design experience, a science topic was chosen that drew on all domains (i.e., physics, chemistry, biology, and Earth science) so no one teacher in the workshops had dominant expertise in terms of content. After reviewing both the NZC (Ministry of Education, 2007) and the school's junior science curriculum, a nature of science and scientific inquiry based unit was chosen as the most suitable for the pilot CoRe design.

As preparation for the first CoRe design workshop, all participants were provided with a reading about the nature of science and scientific inquiry (N. G. Lederman et al., 2014), which they were asked to read. The task enabled participants to revisit, and/or refresh/further their understanding of, the nature of science and scientific inquiry to inform discussions during the CoRe design process.

Sarah had prepared a PowerPoint presentation for the occasion (see Appendix E1). After welcoming the participants, she started proceedings by reiterating the nature and purpose of the study they were taking part in. The presentation included: the meaning of PCK; the origin and purpose of CoRes; how CoRe design has been used in other research for enhancing teacher's professional learning; and, how CoRe design was going to be used in this study. While Sarah addressed these prompts used in CoRe design, each participant was provided with a blank CoRe template and an exemplar CoRe on chemical reactions from Loughran et al. (2006, p. 92) (see Appendices E2 and E3). This initial part of the workshop gave participants an introduction to the construct of PCK, CoRes, and the process of CoRe design.

Sarah then introduced the topic and context of the pilot CoRe, which was teaching Year 9 students about the nature of science and scientific inquiry. Referencing the N. G. Lederman et al. (2014), she reminded the participants that nature of science refers to knowledge in science, while scientific inquiry refers to processes in science. Participants were then asked to carry out the *Views about Scientific Inquiry (VASI)* questionnaire (J. S. Lederman et al., 2014) to prompt and explore their understanding about the nature of scientific inquiry (see Appendix E4). After completing the questionnaire, she facilitated discussions around the different questions from the questionnaire before organising all participants into their Working Groups (see Table 3.8). She then asked them to brainstorm nature of science and scientific inquiry concepts and skills that they wanted their students to learn. To assist them in this task, participants were provided with the NZC document (Ministry of Education, 2007) and the school's junior science scheme for the current topic most aligned with this work (see Appendices E5 and E6).

The brainstorming session led into the identification of 'big ideas', as propositional statements, around teaching students about the nature of science and scientific inquiry. As a first step, individual Working Groups shared their concepts with each other and with the whole group. Then, as a whole group, the participants were asked to identify between five and seven big ideas that students needed to understand about the nature of science and scientific inquiry. Once these ideas were agreed upon, the separate Working Groups began completing the CoRe document by addressing and discussing each of the prompts. During this stage, Sarah moved around the room to engage with the participants and facilitate discussion around the

prompts. The discussions that took place during the CoRe design workshops were audio recorded.

As this initial workshop was always intended as an introduction to the CoRe design process, it was not anticipated that the entire CoRe template would be completed. The Working Groups continued their discussions, filling in their CoRes for approximately an hour. At the conclusion of the session, the partial CoRes were submitted to the researcher and they were combined into one single CoRe.

3.4.6.2 Electricity and Magnetism CoRe Design

The Year 10 *Electricity and Magnetism* CoRe design workshop took place one week after the pilot workshop about the nature of science and scientific inquiry. The same three Working Groups were used for this workshop (see Table 3.8 on Page 139) and the workshop was again facilitated by Sarah. To ensure the participants were aware of the workshop intent and the thinking required, and to make the workshop as efficient as possible, Sarah provided the following information on the whiteboard:

CoRe Design – Year 10 Electricity and Magnetism

Intent today: To collaboratively build topic specific professional knowledge for Year 10 *Electricity and Magnetism*.

- Possible resources? What resources would be useful?
- Brainstorm appropriate concepts and skills.
- Establish big ideas.
- Complete CoRe – share professional knowledge (at the end).

The workshop began by exploring the participants' experiences during the last CoRe design workshop and their perception of the PCK construct. After this reflective discussion, participants were directed to the information on the whiteboard, and then given some resources. The resources provided were: a blank CoRe document; the NZC document (Ministry of Education, 2007); relevant pages from the school's *Junior Science Scheme of Work* booklet, and the Achievement

Standard for NCEA Level 1 featuring *Electricity and Magnetism* (see NZQA, 2010). This information can be found in Appendix F (the NZC resources, school information about best practice and curriculum links, and the blank CoRe are the same as the first workshop).

Each group was asked to develop their own set of big ideas which they then shared with the others. This activity allowed each group to identify what they saw as being important learning, and then by combining each group's thoughts, collective big ideas could be developed that represented the entire group's thinking. Once the collective big ideas were developed, the participants suggested that it would be a more efficient process if each Working Group addressed only two or three big ideas, rather than all of them. As the facilitator, Sarah allowed them to take this direction. Each Working Group dealt with different big ideas, so collectively all ideas were addressed, and the three partial CoRes were combined at the end of proceedings.

The workshop concluded after three hours, and the CoRe information from each Working Group was collated by the researcher to form a single CoRe. Copies of this complete CoRe were sent to all participants to ensure accurate transference of information had occurred, and to allow the Group One teachers to use this document for planning purposes for their post-CoRe design classes.

3.5 Trustworthiness of this Study

Trustworthiness refers to the academic integrity of qualitative studies (Guba & Lincoln, 1994; Lincoln & Guba, 1985; Shenton, 2004) and it is an important consideration for excellent qualitative research (Tracy, 2010). Trustworthiness of qualitative inquiries is established by adhering to four criteria, which are: credibility, transferability, dependability, and confirmability (Bowen, 2009; Guba & Lincoln, 1994; Lincoln & Guba, 1985; Shenton, 2004).

The following sections explain these terms further and how they were addressed in this study.

3.5.1 Credibility and Triangulation

To work within an interpretivist paradigm with qualitative data, the researcher is required to make interpretations. However, the accuracy of these interpretations need to be addressed to ensure the reader has confidence in them (Bowen, 2009; Lincoln & Guba, 1985). To develop credibility, Gray (2014) recommends “examining the study design and methods used to derive the findings” (p. 186), which requires scrutiny of the research’s decision making during the design phases of the study, such as which data collection methods to use and how to analyse data, to ensure the data is credible. Lincoln and Guba (1985) suggest that engaging with the participants over time to build rapport and trust will also ensure the research is credible, as it will minimise distortions.

Triangulation refers to corroboration of interpretations of data by combining different sources of data and/or different methods of gathering that data (Bryman, 2016). If interpretations from two (or more) different data sets corroborate with each other, the researcher has increased confidence in that interpretation (L. Cohen et al., 2011). Universally different interpretations may indicate contradictory findings or new findings.

Throughout this study, suggestions from authors about ensuring research is credible and data it triangulated were adhered to whenever possible. For example, during the data collection phases the researcher established trust and rapport with the participants by working with them over time, being approachable and empathetic, and sharing teaching experiences. In terms of triangulation, both styles of triangulation identified above were employed. Data was collected from multiple sources (i.e., different participants) and different data collection methods (e.g., interviews, observations, and document analysis) were used. By following these guidelines, the researcher’s confidence in making interpretations was increased.

3.5.2 Transferability

As a criterion for trustworthiness, transferability refers to the generalisations that can be made from the study and their application in other contexts (Gray, 2014; Lincoln & Guba, 1985). In quantitative studies, Lincoln and Guba (1985) argue that statistical evidence supporting generalisations should be provided, which is an

impossible task for qualitative researchers. To establish transferability in qualitative studies, these authors discuss and recommend the strategy of a ‘thick description’, where the reader with provided with detailed information about the context from which the data was gathered and interpreted (Bryman, 2016; Lincoln & Guba, 1985). With a thick description, readers are given a “database for making judgements about the possible transferability of findings to other milieux” (Bryman, 2016, p. 384).

Again, for this study, these recommendations were heeded. Throughout the study’s data collection phases, details of contextual information (e.g., the school environment, participants’ backgrounds, and interactions during the CoRe design workshops) were noted and reported in the findings chapters to ensure the reader has an appreciation of the context from which the findings emerge. Such information helps the researcher and reader to make judgements of possible transferability to other situations.

3.5.3 Dependability and Confirmability

As the means for ensuring dependability and confirmability in qualitative studies tend to overlap in the literature (e.g., Bowen, 2009; Bryman, 2016; Gray, 2014; Lincoln & Guba, 1985), these criteria have been addressed together in this section. Dependability refers to evaluating the reliability of the interpretations made in the study, which relates to how consistent those interpretations are over time (L. Cohen et al., 2011; Dyer, 1995; Gray, 2014). Confirmability refers to showing how the researcher has acted in good faith throughout the research process, and that “personal values and theoretical inclinations” have not impacted on the findings and interpretations (Bryman, 2016, p. 386). Bowen (2009) calls confirmability the “internal coherence of the data in relation to the findings, interpretations, and recommendations” (p. 306).

As alluded to earlier, techniques that are suggested for ensuring dependability also ensure confirmability. When discussing dependability, Lincoln and Guba (1985) indicate that if measures are taken in qualitative research to ensure credibility, then the study is also dependable. Although, they do also suggest that separate techniques should be used to deal with dependability directly. These techniques

include: triangulation, having more than one researcher interpret data, and the use of an audit trail (Bowen, 2009; Bryman, 2016; Gray, 2014; Lincoln & Guba, 1985). Triangulation, as discussed earlier, is a process of combining data from different sources or through different data gathering techniques for corroboration. Audit trails involve keeping accurate records of all phases of the research such as field notes, transcripts, and data analysis decisions in a way that can be checked and appraised by another researchers (Bowen, 2009; Bryman, 2016). Although Bryman (2016) reveals the use of audit trails in qualitative research is not popular because of the demand it places on auditors, as large amounts of data are typically collected in qualitative studies.

In this study, all three techniques above to enhance dependability and confirmability (i.e., triangulation, interpretations from other researchers, and an audit trail) were utilised, although the latter two were conflated. For triangulation, data was sought from multiple participants using the same data gathering tools while the participants were immersed in the same context. Data was also obtained using different collection methods such as interviews and observations. The nature of this study, being a doctoral thesis, allowed for active input from a supervisory team allowing for an audit-like situation with multiple researchers' input. To aid with the audit trail aspect, when primary data has been reported in the following findings chapters, a reference to the particular data source is noted.

Throughout the research process detailed information was kept about each aspect of the research, using notes and transcripts from audio and video recordings, and feedback was sought from the supervisory team. Feedback throughout the research process included discussions with the supervisory team about theoretical underpinnings, data collection, and data interpretations. For example, when critiquing the observational protocol, meetings were held between the researcher and supervisors to discuss interpretations of the data to ensure inter-rater reliability.

The following section describes how the data was analysed and reported in this study.

3.6 Data Analysis and Reporting

Data analysis involves organising and examining data to identify themes, trends, and connections in the data, in regards to the research objectives (L. Cohen et al., 2011). In this study, data analysis occurred some months after the data collection phase in the study to accommodate the researcher's own teaching commitments. As a first step in the data analysis process, the large amount of qualitative data collected needed to be organised and collated in way that allowed the researcher to make sense of it (Bryman, 2016; L. Cohen et al., 2011). After exploring different qualitative data organisation methods, the decision was made to utilise NVivo, which came highly recommended by Bryman (2016, p. 602) as "one of the best" computer-assisted qualitative data analysis software packages available. Bryman (2016) recommends NVivo as it can make the organising, coding, and retrieval of data faster and more efficient, and it also allows the researcher to think about the connections between related ideas in the data. Essentially, NVivo is a platform that allows the researcher to work with a large amount of qualitative data, and organise data in a way that reduces human error when comparing data sets and examining links between the data (L. Cohen et al., 2011). Within NVivo, data can be categorised easily within folders, interviews can be directly transcribed, codes can then be attributed to fragments of information, and the data about a certain code retrieved for analysis. This software package was subsequently used to assist with analysing data.

A thematic approach guided the whole analysis process. The first step of organising involved systematically arranging the different data sets in a logical way based on the research objectives. For this process, data was organised into three main categories: interviews, CoRe design workshops, and observational videos. Within each of these categories, data was then categorised by which phase it was collected in and from which participant. The second step of coding data involved taking the organised data sets and indexing information in these sets to make comparisons between the different data sets and participants, and one piece of data may be attributed to more than one code (Bryman, 2016; L. Cohen et al., 2011). When using

NVivo, coding data was done by applying a node⁵ to particular piece of information (Bryman, 2016). The last step entailed the identifying of themes, which are recurring ideas that captured important aspects of the coded data in relation to the research objectives and questions (Braun & Clarke, 2006). Coding data and identifying themes requires flexibility from the researcher (Braun & Clarke, 2006) and the use of both deductive and inductive approaches to these analytical steps provide this flexibility. These approaches are now explained.

Deductive analysis methods involve identifying codes and themes for analysis which are derived from theory (Bryman, 2016). For this process to occur, conceptual frameworks are critically examined by first identifying “researchable entities” (Bryman, 2016, p. 21), which are aspects of the conceptual framework that can be investigated. These researchable entities are then used to inform the codes and themes for the analytical process (Bryman, 2016). In this study, the conceptual framework represented in the RCM of PCK (see Chapter Two, Section 2.4.5) was used to guide deductive analysis. Further explanation on this conceptual framework and its use in data analysis is discussed shortly in Section 3.6.1.

In contrast, inductive methods of analysis involve coding the data by identifying recurring ideas, that is, allowing themes within the data to emerge, which do not necessarily fit within the conceptual frameworks guiding the study (Bryman, 2016; L. Cohen et al., 2011). This inductive method can be seen as a ‘grounded theory’ approach to analysis whereby theories are derived from the data (Bryman, 2016). To help with understanding these two approaches, Bryman (2016) offers a useful conceptualisation, which is shown as Figure 3.5 on the following page.

Using deductive and inductive methods of analysis is encouraged by Yin (2014) when working with case studies. He states that theory should be used to guide data analysis, then by “playing’ with the data” (p. 136), patterns may emerge that offer additional relationships. By analysing data using both an inductive and deductive approach, the research can be involved with developing theory from observations and investigations, as well as investigating implications from theory (L. Cohen et al., 2011).

⁵ Nodes are seen as synonymous with codes, and they are a way of referencing particular pieces of information that have something in common so the researcher is able to then see all of those referenced fragments in one place (QSR International, 2017).

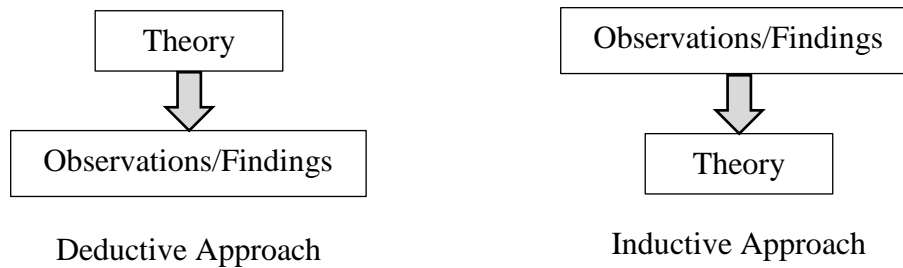


Figure 3.5: The relationship between theory and findings for deductive and inductive approaches (Reprinted with Publisher's permission, Bryman, 2016, p. 23).

Such an approach was taken by Hume and Berry (2013), who investigated the effectiveness of CoRe design for helping pre-service teachers develop their PCK. These authors note the value of using a coding system deduced from PCK theory because it allowed them to identify explicit themes (the five components of PCK identified by Magnusson et al. (1999)) for analysing their data to address their research objectives and questions. At the same time the use of inductive methods allowed them to highlight recurring ideas in their data to address their sub-questions about the dialogue between mentor teachers and pre-service teachers. Thus, their coding of data was done in relation to these questions rather than having predetermined codes.

Since a deductive approach to thematic analysis requires a theoretical framework to provide a lens for the initial organising and coding of data, it is important to explore which framework was used and how.

3.6.1 Conceptual Framework for Data Analysis – RCM of PCK

In this study, the research objectives were concerned with identifying participants' pPCK and ePCK development as a result of collaborative CoRe design. To facilitate thematic analysis related to these objectives, the RCM of PCK from the second PCK Summit was used as a conceptual framework. This model was chosen for two reasons. Firstly, it was developed using ideas from well-respected and established members of the science education research community taking all previous PCK models and conceptualisations into account. It, therefore, provides an agreed upon and unified way to view and research PCK. Secondly, analysing data within the

parameters of this framework should provide valuable and useful information to the science education research community about the usefulness of this model in research and teacher education. Figure 3.6 below reshows the RCM of PCK.

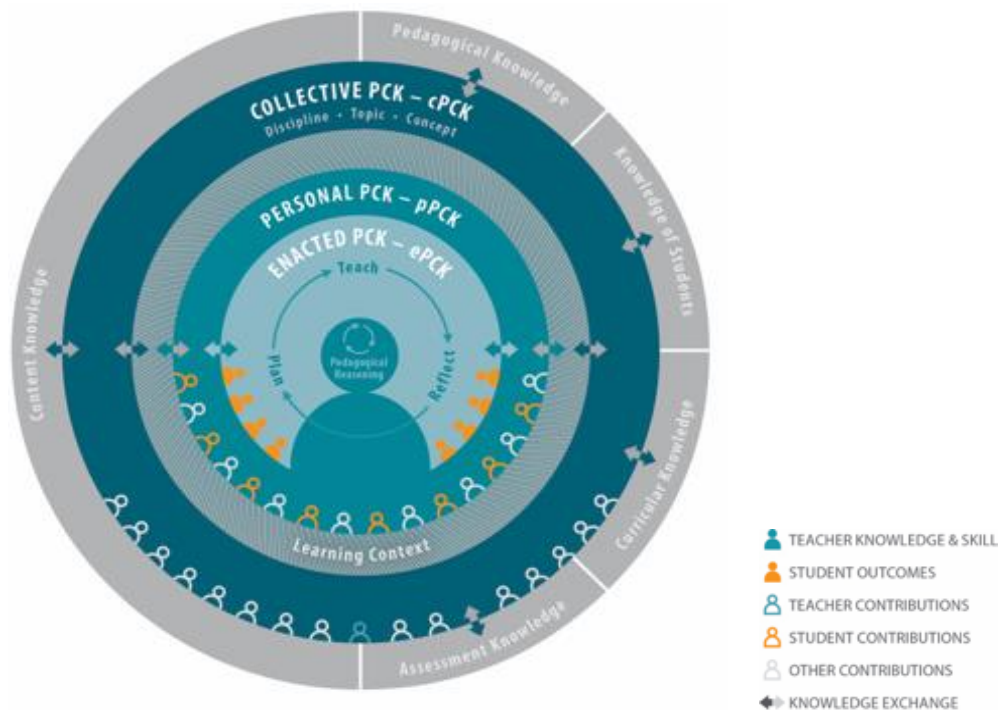


Figure 3.6: Refined Consensus Model of Pedagogical Content Knowledge (RCM of PCK) (Carlson & Daehler, 2018).

Analysis of data to determine the initial pPCK of Group One teachers was done using data gathered from interviews during Phase One of the study. During Phase Three of the study, these teachers were asked what impact they thought CoRe design had on their pPCK.

When critically examining this model to identify researchable entities, five themes for deductively analysing a teacher's pPCK were identified:

- Subject matter knowledge
- Knowledge of curriculum
- Knowledge of students' understanding and learning
- Knowledge of topic-specific instructional strategies
- Knowledge of assessment strategies

Further to these five themes, two more were identified as significant since they can act as an ‘amplifier or filter’ on knowledge exchange and transformation processes in the model. These further two deductive themes were:

- Personal philosophy for teaching science
- Sense of self-efficacy

These themes were used to identify relevant codes to enable the indexing process of the interview data in NVivo. The identified codes are presented in the findings chapter. Analysing the ePCK of the Group One teachers was done using the rubric outlined earlier in this chapter (see Table 3.5, Table 3.6, and Table 3.7, on Pages 128-130). The development of this rubric was informed by the RCM of PCK, the discussions from the second PCK Summit, and the CoRe design intervention. As such, the components of ePCK identified and included in the rubric served as the themes for analysis, with the specific indicators and their level descriptors acting as codes for indexing the observational data. These themes and codes are presented below:

- Subject matter knowledge
 - Appropriateness
 - Scientific accuracy
 - Links and connections to other concepts
 - Links to nature of science and scientific inquiry
- Knowledge of student understanding
 - Prior knowledge, misconceptions, and difficult concepts
 - Variations in student learning to guide instruction
 - Questioning to gauge or probe student understanding

- Instructional strategies
 - Sequencing of concepts
 - Using examples and representations
 - Strategies that allow for metacognition

To analyse the effects on teachers' pPCK during the CoRe design workshops, this RCM of PCK was also used. When examining the interactions within the second CoRe design workshop, the same five themes for analysing pPCK were used (the other two were not considered not relevant for this analysis). Further information about this process can be seen in Chapter Five, Section 5.4.4.

3.6.2 Reporting the Findings

The complexity of the study design and the large volume of data that was collected meant the most efficient way to present the findings was to devote a chapter to each phase of the research (Chapters Four, Five, and Six). Throughout these findings chapters, there are excerpts from discussions, interviews, and classroom observations to illustrate codes, themes, and trends. To improve clarity and understanding of some of these conversations, minor editing has been done. Where appropriate, paralinguistic features such as pauses, or sighs are provided in square brackets in the excerpt. When primary data is used in the findings chapters, a reference to that data source is also highlighted to ensure an audit trail of data.

Since the major focus of this study was on the pPCK and ePCK development of the Group One teachers, and their experiences with CoRe design as a PLD intervention, a case study approach was used to report the findings. Thus, their interview and observational data is kept separate in the findings chapters to highlight each teacher as a single case. A cross-case analysis utilising data about each teacher's knowledge, knowledge developments, and CoRe design experiences is performed and discussed in Chapter Seven.

3.7 Ethical Considerations

When carrying out qualitative research with human participants, ethical issues need to be considered to ensure that there is no harm to participants (Tracy, 2010). This study delved into teachers' professional knowledge and their practises by exploring their thoughts, behaviours, and experiences. For this type of human research to happen effectively, O'Neill (2008) emphasises that researchers need to be granted access to the teachers' professional environment by the teachers themselves (as well as school management). To gain this access so teaching, learning and professional practises can be studied, the researcher must develop a respectful and non-judgemental relationship with the participants to minimise any possible harm (O'Neill, 2008). To develop researcher-participant relationships successfully in this study, certain key ethical considerations were explored and addressed.

Universities within New Zealand govern their own ethics in relation to human participants (see University of Waikato, 2015b) and produce guidelines for human research, which are developed from information provided by the Ministry of Health. For ethical research, the Ministry of Health indicates:

- There should be respect of participants' rights such as privacy,
- Participants must volunteer and not be coerced or deceived,
- Participants can withdraw from the research,
- Participants need to be provided with detailed information and informed consent sought,
- No participant should be identified,
- The researcher should be suitably qualified to undertake research,
- Vulnerable participants must not be exploited, and
- Research should respect the social and cultural sensitivity of participants.

(Ministry of Health, 2006, p. 6)

Detailed information was provided to the principal of the school, and informed consent was sought as the first step in data collection. Once consent was obtained

from the principal, detailed information was also provided to all participating teachers and parents of the students involved, and again informed consent was sought. For example, there was a strong likelihood that the teachers' level of (or lack of) knowledge and practice would be disclosed to others, particularly in collaborative activities. Participating teachers were made aware of this possibility when they were invited to take part and it was made explicit to them that any observations and data recorded during the study would be kept confidential and only used for research purposes. Information letters and informed consent documentation can be found in Appendices A and B. All collected data was treated as confidential and kept securely on a password protected computer. The names of all participants and the school have been changed to pseudonyms to protect all identities.

Furthermore, prior to any data collection, this study was scrutinised and approved by the Postgraduate Studies Office at the University of Waikato during their confirmed enrolment process (see University of Waikato, 2015a), and the ethics application was approved by the University of Waikato Ethics Committee (see University of Waikato, 2015b).

3.8 Chapter Summary

This chapter presented the research methodology for this study. The interpretivist paradigm was considered the most appropriate theoretical framework for the goals of this study, which indicated qualitative data should be gathered. A multiple case study approach was used utilising individual semi-structured interviews, lesson observations, focus group discussions, and observations and document analysis from workshops.

Trustworthiness was established by using techniques promoted by experienced qualitative researchers, such as: triangulation, where different sets of data and different data collection methods were used for corroboration; establishing authentic researcher and participant relationships based on trust and rapport; the use of an audit trail to keep an accurate record of field notes and transcripts, which was discussed with the supervisory team; a thick description of the context of the research and participants to allow others to make judgements about transferability;

and, the researcher acting in good faith throughout the study and reporting and mistakes and limitations.

Data was analysed thematically using both deductive and inductive approaches, where the deductive approach was informed primarily by the RCM of PCK. The inductive approach allowed for recurring ideas in the data linked to the research questions identified.

Throughout the research process, ethical considerations were enacted; participants received detailed information about the study, informed consent was obtained, and pseudonyms have been used.

The following three chapters present and analyse the data that was collected. Each chapter represents a research phase (i.e., before CoRe design, during CoRe design, and after CoRe design). Within each chapter, the findings are presented with respect to the deductive and inductive themes.

Chapter Four

*Phase One Findings: Generating a
Baseline Understanding of pPCK
and ePCK*

4.1 Overview

This chapter contains the information obtained from Phase One of the study, which was used to generate a baseline understanding of Group One participants' personal and enacted pedagogical content knowledge (pPCK and ePCK). The information is presented in four sections: Section 4.2 provides contextual information about the school environment and all participants in the study; Section 4.3 is data taken from the initial interviews with Group One teachers to identify the nature of their initial pPCK; Section 4.4 presents the observational data collected from the Group One teachers' Year 10 *Electricity and Magnetism* lessons prior to the teachers taking part in the content representation (CoRe) design workshops, which is used to gain an insight into their initial ePCK; and, Section 4.5 highlights and discusses themes that emerged during an inductive data analysis of the interviews and lesson observations. Lastly, there is a summary of this chapter.

4.2 Contextual Information

This study was conducted in a New Zealand school with full-time practising science teachers as participants. Contextual information about the school was sourced from the school's website and their latest 2014 Education Review Office (ERO) report⁶. To protect the anonymity of the study school, which was agreed upon in the informed consent agreement, it is inappropriate to cite the school's 2014 report directly. However, an edited report is provided in Appendix H, which is the report in full except for any references that could identify the school (this edited report also has page numbers which are used to reference direct quotes).

Background information about the participants, such as their qualifications, subject specialisations, and number of years teaching is provided. This information was sourced from their initial interviews.

⁶ ERO reviews schools periodically to see how they are reaching positive learning outcomes for students, such as students': "knowledge, skills, attitudes, and habits" (ERO, 2017a). Data gathering processes usually involve: an on-site school visit; examination of school documentation such as policies and programme guidelines; interviews with senior management, curriculum leaders, teachers, and students; and observation of a sample of classes. In their final report, which is made public, ERO decides when the next review will be held (ERO, 2017a, 2017b).

4.2.1 The School Environment

This study was conducted at River High School (pseudonym) in New Zealand. Their ERO (2014) report provided key contextual information about the school; and evaluated how well students were learning and engaging in classes, how the school's curriculum promoted learning, and how well placed the school was to sustain and improve its performance. A primary focus of the report was assessment, with an emphasis on how assessments were done and how information from these assessments was used.

ERO (2014) reports that River High School is a large (2,000+ students) urban secondary single-sex boys' school with a decile rating of seven⁷ that caters for students from Year 9 to Year 13. The school's website states that the New Zealand National Certificate of Educational Achievement (NCEA) is the main qualification offered at the school. Within the subject choices section of their website, River High School states that English, mathematics, science, and social science are compulsory for students in Year 9 and 10, and they drop social science in Year 11 while the others are still mandatory. In Year 12 at River High School, the only compulsory subject is English, and students select five other subjects for a full programme. Year 13 has no compulsory subjects for students and they can choose up to six subjects for a full Year 13 programme (school website).

The ERO (2014) report judges that the school is "using achievement information very effectively to support student learning and engagement" (ERO, 2014, p. 2) and its "curriculum has a strong academic focus" (ERO, 2014, p. 3). Curriculum leaders and their departments use student achievement information to carry out an "annual evidence-based review" (ERO, 2014, p. 2) of each year's curriculum goals and targets, and the findings are used by departments to set future targets. These school-wide findings are reported to the school board and individual student achievement information is reported to parents as noted in the ERO (2014) report:

⁷ Decile ratings in New Zealand refer to the socio-economic backgrounds of the students and their families, in relation to other schools from around New Zealand. Decile one is the lowest (high proportion of students from low socio-economic backgrounds) and decile 10 is the highest (high proportion of students from high socio-economic backgrounds). The intention of this decile rating is not to judge the quality of education from different schools, but for the government to provide appropriate funding. The lower the decile rating, the more funding the school receives (Ministry of Education, 2016).

Student achievement information, especially in Years 11 to 13, is regularly reported to the board and is used well to inform strategic and resourcing decisions... Parents of students in Years 9 and 10 receive written reports twice yearly about their students' marks and grades in tests and examinations.

(p. 2)

4.2.2 Participants

This section offers background information about each of the nine participants in the study. All the information reported here came from initial interviews with the participants in Phase One.

Table 4.1 shows the names of the different group members, along with a summary of their background information – further detailed information follows in the text. Table 4.1 is organised into three sections to distinguish information from each of the three participant groups.

Table 4.1: Background information of participating teachers showing group memberships, names, subject specialisations, years at River High School, and total years teaching.

Group	Name (pseudonym)	Subject Specialisations	Years at River High School	Years Teaching (total career)
	Tony	Biology	6	6
1	David	Horticulture and Agriculture	20+	29
	Alan	Physical Education	3	10

Table 4.1 Continued

Group	Name (pseudonym)	Subject Specialisations	Years at River High School	Years Teaching (total career)
2	Harry	Biology	20+	35
	Kate	Chemistry	8	8
	Lucas	Biology and Horticulture	7	10
3	Nick	Physics and Electronics	17	17
	William	Physics and Electronics	15+	40+
	Chris	Physics and Electronics	15	35

4.2.2.1 Group One Teachers

The teachers in Group One were the focus of this study and each teacher represents an individual case. Tony, David, and Alan were practising science teachers with a limited physics background. When approached to take part in this study, they all expressed interest in a professional development opportunity to enhance their PCK for teaching Year 10 *Electricity and Magnetism* and accepted invitations to participate (see Appendix A2). To facilitate this study, each teacher taught the *Electricity and Magnetism* topic to two Year 10 science classes. In each case, the teacher was observed teaching this topic to one class before taking part in CoRe design, and then observed teaching their other class after taking part in CoRe design.

Tony

Tony was in his sixth year of teaching during the study. He completed a Bachelor of Science (biology, and resources and environmental planning) in 1995 and worked in the New Zealand fishing industry and pest control for the next 15 years. In 2010, he undertook teacher training gaining a Postgraduate Diploma in Teaching and his first teaching position was at River High School. In his initial interview, he acknowledged strengths in biology when he began teaching, but weaknesses in

other areas, stating: “biology is sort of my thing... my background knowledge of electricity for example, prior to being a teacher, was zero” (Tony, initial interview).

David

David was an experienced teacher having taught for 29 years in total. When he was at university, he did a conjoint programme completing both a Bachelor of Education and a Bachelor of Science (biology). His science qualification had a focus on horticulture and agriculture. David originally taught biology, horticulture, junior science, and junior mathematics at a large (1,800+ students) urban co-education school that was decile seven. He stayed at this school for five years before a career shift into farming for two years, followed by teaching at a private training institute in New Zealand where he taught a range of horticulture and agriculture courses for four years. His next position was at River High School teaching junior science classes and a range of junior and senior horticulture and agriculture courses. When talking about the teaching junior science during his initial interview and being involved in this study, David commented “this is a good one for me, because electricity is one of the topics I am least confident with” (David, initial interview).

Alan

Alan began his teaching career in England in 2006. His qualification was a Sports Development and Physical Education Bachelor degree, and in England he taught physical education at a single-sex boys’ school. He moved to New Zealand in 2012 where he was officially required to take a postgraduate teaching course at a New Zealand university before being able to teach in New Zealand classrooms. During this postgraduate course, he studied physical education and science education, and said that it was his “first formal qualification in science, and it was junior science” (Alan, initial interview). Alan began teaching science and physical education at River High School in 2014, and completed his teaching qualification in 2015.

4.2.2.2 Group Two Teachers

Lucas, Harry, and Kate comprised Group Two. They were experienced science teachers who had a limited physics background. During initial conversations with the principal about possible participants, these teachers were endorsed as effective science teachers and the principal felt they would offer useful insights to the study (Principal, River High School, personal communication). In their initial focus group interview, these teachers talked about being confident when teaching Year 10 *Electricity and Magnetism*.

Lucas

Lucas had been teaching continuously since 2006 at three different schools, including River High School. He had a Bachelor of Forestry Science and a Postgraduate Diploma in Teaching and his subject specialisation was biology and horticulture. His first teaching position was a small (approximately 450 students) low-decile rural school in New Zealand, which was co-educational. He taught at this school for two years before moving overseas to teach in Asia. While in Asia, he taught biology for two years under the International Baccalaureate system (see International Baccalaureate, 2017). When Lucas returned to New Zealand, he gained a position at River High School, teaching a range of junior and senior general science, horticulture, and biology classes. When asked about how confident he was teaching Year 10 *Electricity and Magnetism*, he responded “[I’m] more comfortable with biology and chemistry than physics, but very comfortable teaching electricity and magnetism up to Year 11” (Lucas, initial focus group interview).

Harry

Harry was a very experienced teacher having started his career in 1981 at a small (approximately 350 students) low-decile rural school in New Zealand, which was co-educational. He had a Bachelor of Science (Honours) majoring in botany, and a postgraduate teaching qualification. For over 20 years prior to this study Harry had taught at River High School and his subject specialisation was biology. He often took advanced classes in senior biology and junior science. Throughout his extensive career, he also had curriculum leadership roles where he mentored new

staff or other staff who needed support within the science department. Harry felt that he was effective at teaching Year 10 *Electricity and Magnetism*, explaining “I am more effective in subjects I don’t know, because when I am teaching familiar subjects, I tend to be blasé sometimes and assume things. I tend to do better in physics and chemistry [than biology]” (Harry, initial focus group interview).

Kate

Kate began her teaching career in 2008 at River High School having previously gained a Bachelor of Science (chemistry), and a Postgraduate Diploma in Teaching. Her subject specialisation was senior chemistry, and she also taught a range of junior science classes where she had a large input into programme and assessment design. Kate was often tasked with teaching accelerate classes and classes where students need extra support. She also performed a curriculum leadership role within the school, and participated in science events within the wider education community (such as subject association meetings and conferences involving other schools and teachers). Kate felt capable when teaching junior *Electricity and Magnetism*, but did point out that it has “taken time to get [her] competency up in physics” and that during her career she has approached physics teachers for help when required (Kate, initial focus group interview).

4.2.2.3 Group Three Teachers

Chris, William, and Nick comprised Group Three. They were experienced at teaching physics to Year 12 and 13 and general science to Year 9, 10, and 11 students. All three teachers also taught senior electronics. They also regularly attended physics professional development workshops and conferences outside of the school whenever possible.

Chris

Chris was a very experienced physics and science teacher, having taught both subjects for over 35 years. He completed his science and teaching qualifications in South Africa, and described how his Bachelor of Science degree “contained a

significant portion of physics and chemistry” (Chris, initial focus group interview). Chris initially taught for 20 years at a large co-educational school in South Africa where students came from low to average socio-economic backgrounds. He moved to River High School, and for 15 years his teaching often included both accelerate junior science and senior physics classes. He expressed how he “feels pretty good about his electricity lessons” after teaching them, particularly as “the more experienced you are, the more aware you are of where the pitfalls are, and so you can help the students” (Chris, initial focus group interview).

William

William was the most experienced teacher in this study, with over 40 years of experience teaching science and physics. He had taught at River High school for longer than 15 years. William gained his Bachelor of Science (chemistry and physics) and his teaching qualification in England. Prior to his teaching career, William also had five years of industry experience. During his time at River High School, William carried out various curriculum leadership and management roles, for example, establishing appropriate programmes for senior physics and electronics. He was also responsible for adapting these programmes to align with governmental policy changes, such as reform and revision of national curriculum documents. He taught accelerate classes for junior science and senior physics, and classes where students may need extra support. William felt that he was effective at teaching physics because he focused on teaching students fundamental concepts. He offered examples from his current class, for instance “when [students] are trying to work out the strength of a magnetic field, and it’s milli-Tesla or something, a lot of them forget about the powers; so, I make sure I go over that” (William, initial focus group interview). Furthermore, he commented how students’ assessment results were reflecting his point: “it’s pleasing that they are starting to get the fundamental points” (William, initial focus group interview).

Nick

Nick began his teaching career in 1999 at River High School with Master of Science (Honours), majoring in physics, and Postgraduate Diploma in Teaching

qualifications. Throughout his teaching career, Nick had performed various curriculum leadership and management roles within the school. He has mentored new staff and other staff who needed support within the science and physics departments, and helped to develop junior science and senior physics programmes, including assessments. His teaching often included accelerate junior science classes and senior physics classes. Nick felt that he was effective at teaching Year 10 *Electricity and Magnetism*, explaining that “the advantage we [Group Three teachers] have is the background knowledge, and with electronics, you can sometimes just chuck in interesting facts here and there, and extend concepts” (Nick, initial focus group interview).

The following section reports on the Group One participants’ initial interview, which were conducted prior to taking part in CoRe design.

4.3 Initial Interviews with Group One Teachers

To gain an insight into the Group One teachers’ initial pPCK, semi-structured interviews were conducted prior to their teaching of the *Electricity and Magnetism* topic to their first Year 10 science class (see Appendix C1 for questions). Interviews were audio recorded and transcribed for analysis. As a multiple case study approach guided this study, the interview data from each Group One teacher was treated as an individual case to facilitate cross-case comparisons.

Data were initially organised using themes deduced from the refined consensus model of PCK (RCM of PCK), which was the analytical lens used to explore and identify the nature of participants’ pPCK. Note that the decided themes ‘personal philosophy for teaching science’ and ‘self-efficacy’ were considered relevant in determining the nature of pPCK because of their amplifying/filtering effect on teachers’ knowledge. These initial themes were further unpacked to identify codes, which were used to identify relevant fragments of the interview data. To facilitate the reader’s understanding of the coding process for analysing initial pPCK, the themes and codes and their inter-relationships have been detailed in Figure 4.1 on the following page. Arrows within this figure show how a particular code was coded further. Interview data was also used for an inductive analysis, which is reported in Section 4.6.

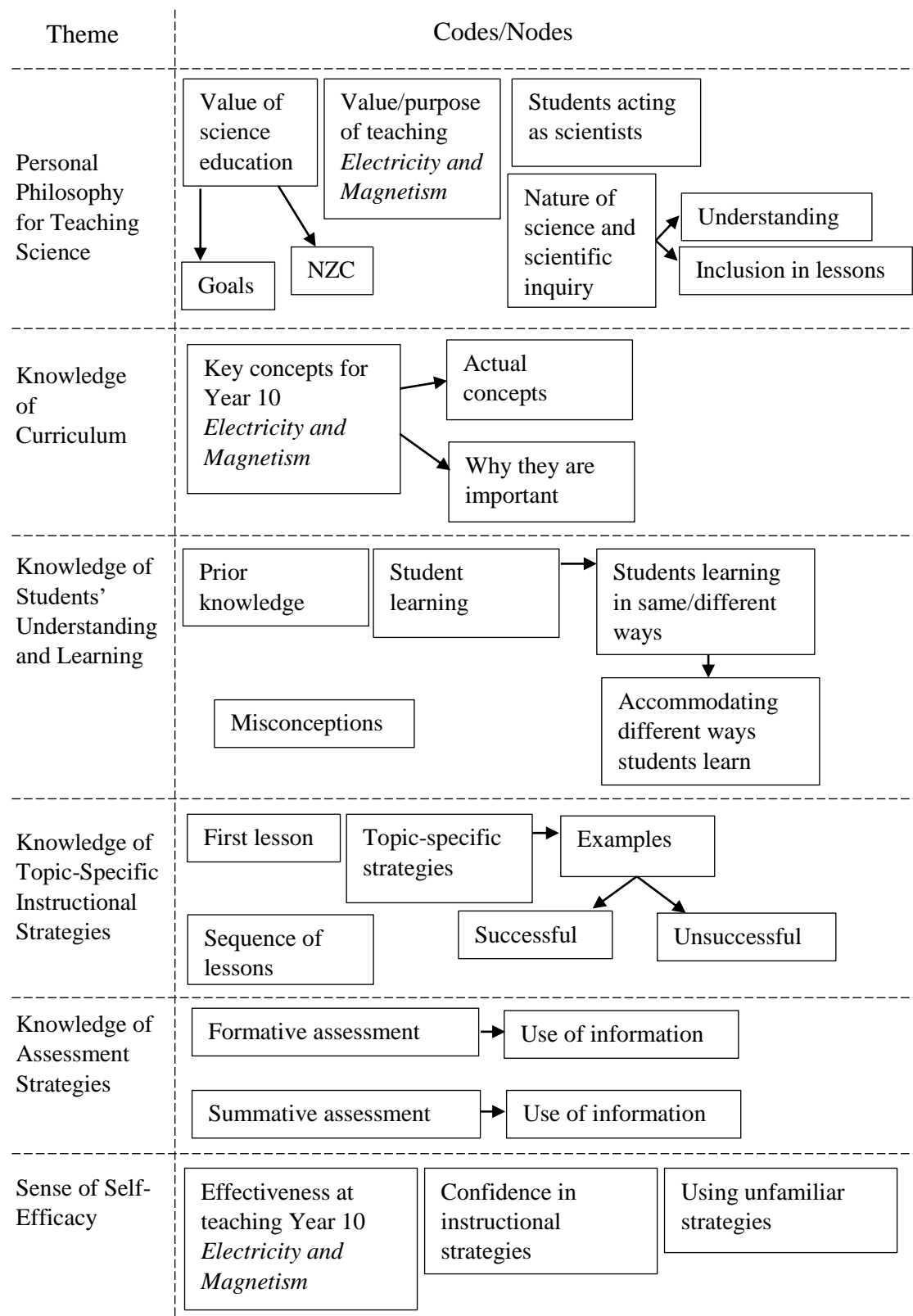


Figure 4.1: Coding structure for analysing participants' pPCK. Each box represents a separate code, with arrows highlighting links between codes.

4.3.1 Tony's Initial Interview

4.3.1.1 Personal Philosophy for Teaching Science

Interview data revealed that Tony saw value in science education as it helps students to understand their world. He reasoned:

It helps people to understand the world around them, you know, phenomena. From just photosynthesis, grass growing, things being born. How everything works, it's like technology, it all comes from science.

(Tony, initial interview)

When asked why science was included in the New Zealand Curriculum (NZC), Tony reiterated his initial comment:

I guess they [the Ministry of Education] have identified it due to that reason, it is helping people to develop an understanding their world.

(Tony, initial interview)

Tony's interpretation of the goals of science education focused on teaching students skills and ways to understand phenomena, rather than teaching them content, as such. He stated:

We can't teach them everything. But we need to teach them how we can find out stuff... there are laws, and reasons, and explanations behind things that happen.... I like people to be able to think, if they wanted to, how that all actually works. A car for example, you turn the ignition on and the car goes. You know, maybe in their minds when you're teaching science, you are not necessarily teaching them how car goes, but enabling them to think about stuff going on, and join dots and stuff.

(Tony, initial interview)

However, when the interview focus shifted from science as ‘a whole’ to goals for the Year 10 *Electricity and Magnetism* unit, Tony’s focus and goal changed to assessment. He stated:

That’s the thing. I want them to do well in the test.

(Tony, initial interview)

When prompted about the test and who wrote it, Tony explained:

The teacher in charge of junior science. We have got certain SLOs [specific learning outcomes] that we have to cover. We have got to talk about static and circuit electricity, and Ohm’s law.

(Tony, initial interview)

When asked about the source of the SLOs, Tony was unsure where they come from, responding:

Err... maybe the curriculum? I don’t actually know. But they are there [Junior Science Manual, see Appendix F1].

(Tony, initial interview)

In response to further questioning about the role of the SLOs in his teaching, he revealed they were his top priority and did not go teach beyond their scope, commenting:

First and foremost, I need to make sure I cover those, because of the time limitations we have... No, not really. I try and cover them.

(Tony, initial interview)

When discussing students acting as scientists, Tony indicated that while it was desirable, it was only possible in an ideal world:

[Sigh]. *I guess so. However, what I said earlier was about an ideal world. Then on the other hand I am talking about the reality we have as teachers.*

(Tony, initial interview)

Building upon his answer, Tony was asked how he would do it differently in an idealised situation. He talked about using a question to engage students, while also changing the learning context by having less students and more time:

In my ideal classroom, kids would be able to have a big question and do things to answer the big question... For example, if you were talking about electricity, maybe electric motors. Maybe build something. I like that idea of, what's that word, self-directed learning and looking for stuff. You do learn better when you are finding out stuff that you want to know. So, I guess in my ideal world that would be the case and there would probably only be 15 kids in the class, and we would have more time to teach this stuff.

(Tony, initial interview)

His explanation about the nature of science was brief: “science is about finding out why things happen” (Tony, initial interview). In terms of incorporating the nature of science into his lessons, he talked about how he tries to promote students to be inquisitive in his lessons:

I do ask, and I like them to ask questions. I do explain stuff, and we use Google to find stuff that I don't know. I guess I want them to be curious about what's going on. I want them to be interested in what's around them. I like to encourage them to, if you want to know something, then try and find out.

(Tony, initial interview)

As for scientific inquiry, Tony was unsure what the phrase meant, asking:

So, are we talking about, a person doing research at the university?

(Tony, initial interview)

However, with prompting from the researcher about scientific processes and asking how scientific processes could be incorporated into lessons, he alluded to using questions but raised issues related to contextual restraints and the effectiveness of such a strategy:

[Long pause and sigh]. If you want to do that, you need more questions at the start of the topic. It comes back to a time limitation to be honest, and then how do you measure how successful it is? How do you tell if they've learnt something?

(Tony, initial interview)

The following section reports on findings related to Tony's knowledge of curriculum.

4.3.1.2 Knowledge of Curriculum

Tony's initial views about what students should be learning at a Year 10 level for *Electricity and Magnetism* were influenced by requirements in the following year of schooling. He explained:

Well for Year 10's, you need to be thinking about what they need to do in Year 11. So, it's all about Ohm's law and electromagnetism, static electricity. So, we need to cover those aspects in Year 10, to try and give them a bit of a grounding, pardon the pun, for next year.

(Tony, initial interview)

When asked about any other reasons for learning *Electricity and Magnetism* concepts, Tony's reiterated his philosophy of learning concepts that students can relate to their lives. He argued:

*Yeah, you know, I mean everything has electricity running through it.
It is all around.*

(Tony, initial interview)

The following section reports on findings related to Tony's knowledge of students' understanding and learning.

4.3.1.3 Knowledge of Students' Understanding and Learning

Tony thought that students would need some prior knowledge before starting the *Electricity and Magnetism* topic. He explained:

[Students] need to have a basic knowledge of things like conductors, metals, and know what an electron is... I would expect them to know what an electron is, but apart from that, everything else is new to them.

(Tony, initial interview)

As for possible misconceptions, Tony suggested that students have little conceptual understanding of electricity (as a phenomenon), reasoning:

I think they just have no idea. I don't think they really think about it. It is just something that is just there. You know, you turn it on, light goes on.... I don't think they are really thinking about it to be honest.

(Tony, initial interview)

Tony was aware students had different learning needs and styles, commenting “they all learn differently” (Tony, initial interview). To accommodate for students’ needs, he first talked about using videos, although he indicated that those were for enjoyment:

A good thing we do is videos [Tony talked about a YouTube channel he uses]... We watch those for a bit of a laugh.

(Tony, initial interview)

He also emphasised the point of students making circuits so they could make cognitive linkages to concepts:

Also, I reckon a lot of students are tactile learners – they like to make things. Then once they can see it, hopefully they can make sense of it when it comes to circuit diagrams, or doing stuff like that. It will make sense.

(Tony, initial interview)

The following section reports on findings related to Tony’s knowledge of topic-specific instructional strategies.

4.3.1.4 Knowledge of Topic-Specific Instructional Strategies

For his introductory lesson, Tony described how he aimed to do something fun, like use the Van der Graaf generator:

Normally I would start with something fun, like maybe get the Van der Graaf machine out and charge it up... I try and do something fun.

(Tony, initial interview)

After his first lesson, Tony explained how he focuses on giving students definitions via notes before introducing them to practical activities that illustrated the defined

concepts. Following practical work, students are then taught about using multimeters to gather data and how to draw circuit diagrams:

I give them some notes about what is electricity, some definitions for voltage and current. I try and get them onto the electrical trolley as soon as possible... It has got power packs, lamps, multimeters... So, try and get them onto those to make a circuit. Try and get them to make a series and parallel circuit, and know what it is. And then, so make these circuits then show them how to correctly connect a multimeter to measure voltage and current. Then after that we draw circuit diagrams and components. Ohm's law. But yeah, the electrical trolley is one of the first things I do. Give them a bit of an idea in their mind of what they are doing.

(Tony, initial interview)

He went on to describe three other practical instructional strategies that he had used for this topic and considered them successful for similar reasons. They included:

Making electromagnets

So, you get your battery, some wire, and I get... A bit of a competition. Who can make the best one, and we make the electromagnet and see who can pick up the most paperclips in a line... So that's a good fun thing to do, and at the same time they have got to know how to make an electromagnet. So that is a good one.

Making compasses

I also make compasses from a leaf. So, we get a paperclip and rub it on a magnet and stick it on a leaf in water, and you can see it orientate itself to magnetic north. I like to get the compasses and the magnets out, and show the interaction with a compass and magnetic fields.

Making simple circuits

Then just doing the differences between parallel and series circuits. That's just a good thing to do, draw a table and measure voltage and current. So, they make the circuit, draw it, and measure the current and voltage when they add different lamps, and look at the differences.

(Tony, initial interview)

The following section reports on findings related to Tony's knowledge of assessment.

4.3.1.5 Knowledge of Assessment Strategies

Tony determined if students had learned important concepts by their ability to "pass the test" (Tony, initial interview). He talked about his approach to formative assessments during lessons, which featured strategies for preparing students for the upcoming test. He explained:

We do a lot of practice, and ask a lot of questions in class to prepare them [for the test].

(Tony, initial interview)

When asked about how he might use information obtained from formative assessment tasks in class, Tony talked about not recording it, but identifying students who need assistance and how that information influences lessons:

I don't record it. But I do identify students who I think need work. So, you know, you can figure out who's onto it and who's not... Let's say you've been doing some Ohm's law and no one is getting it. Then spend some more time on it the next day.

(Tony, initial interview)

The following section reports on findings related to Tony's sense of self-efficacy.

4.3.1.6 Sense of Self-Efficacy

Tony was asked about how capable he felt when teaching Year 10 *Electricity and Magnetism*, and why he felt that way. He explained that while he was not an expert in physics, he was competent in his teaching of this topic and there were certain advantages from a pedagogical perspective in his lack of specialist physics subject matter knowledge:

[Long pause]. *I would put myself as competent, certainly not at super-duper... I am not a physics guy, you know. There are definitely things I don't know about it. But then again, when you come from that level, you are a bit closer to the level of the students, so you understand a bit about... I try and make things as simple as possible.*

(Tony, initial interview)

When asked about his level of confidence when using the instructional strategies he talked about earlier, Tony said he was confident, reasoning:

I've done them before, so I know that they work.

(Tony, initial interview)

Tony was also asked whether there were other activities he had used, that he did not feel confident about in his teaching. He remembered having issues when first making circuits and using multimeters, recalling:

When you've got your power pack, and you've got all these leads, trying to hook up a voltmeter in a parallel circuit, and stuff doesn't work. But now, I have done it enough that I feel confident to drive that sort of stuff. Well multimeters, I must admit, have I got it on the right thing?

(Tony, initial interview)

Tony affirmed he would use an instructional strategy that he was unfamiliar with, for example, learning a new strategy from a physics teacher, if he thought the strategy was worth using. However, he would trial the strategy first before using it

with his students to be assured that it was an effective learning strategy and he understood how to implement it, particularly so students did not lose confidence in his teaching ability. Tony elaborated:

Yeah, but I would make sure... I would do it [an unfamiliar instructional strategy] first so I knew how to do it... If I thought it was really awesome, and I wanted to use it, then I would find out what I needed to use, and then I would try and do it. Then, if I couldn't do it, I would go back to them. But I would definitely not do it... I would do it before showing the kids. Because the last thing you want is to do something that doesn't work. Then they think you don't know what you're doing or whatever. So, you try and make sure... You want to make sure it is going to work before you do it.

(Tony, initial interview)

The following section reports on findings related to David's initial pPCK interview.

4.3.2 David's Initial Interview

4.3.2.1 Personal Philosophy for Teaching Science

Interview data revealed that David saw value in science education as it allows students to expand their understanding of the world. He reasoned:

I couldn't teach science if I didn't think it was worth doing. I think science is really important... It allows them to expand their own understanding of the world they are in, and I think that is really important.

(David, initial interview)

David argued that science is included in the NZC to acknowledge the close relationship between science and our society:

I think that as a society, we are so tied into science now, that's the way we deal with our world, we approach everything fairly scientifically...

I think we advance as individuals and as a society because we get into trying to understand how things work, and trying to experiment and try new things... I think that as a society we have invested a lot in people understanding, people experimenting, people pushing boundaries in terms of knowledge and technology, and that sort of thing.

(David, initial interview)

His interpretation of the goals for science education primarily focused on students learning skills and attitudes, as opposed to students only learning content. He explained:

I think that if we have kids that are prepared to question things, and prepared to try things out, and prepared to interpret what they see and what they find, in a meaningful way, then I think we have achieved a hell of a lot. I think there is some content that is useful; obviously we know a huge amount of scientific knowledge, and we can't teach all of it. But if we can instil the sort of attitudes and values that lead to that, then kids are much better able to understand that and make better use of it.

(David, initial interview)

When the focus of the interview shifted from science education in general, to Year 10 *Electricity and Magnetism* specifically, David's attention was again on teaching skills and attitudes, specifically those related to real-life problem solving, along with some fundamental concepts. He commented:

Electricity and magnetism is an interesting one, because kids can see the effects all around them; we are so dependent on electricity. But often, they have really no concept of what's going on. For instance, just the idea of a complete circuit, is foreign to a lot of those kids at Year 10... I guess, like probably a lot of the stuff we do at the junior school, we are building not so much a complete understanding, but giving them the tools that they can use later to nut out problems, or follow or

develop a better understanding later... I guess giving them an overall science attitude that allows them to do that. But also, in terms of particular content stuff, it's giving them the terms, or at least some of the terms and some of the ideas, that they can use, or they can hopefully understand.

(David, initial interview)

When asked about particular concepts that he does teach, David pointed out that the concepts are largely predetermined and provided via specified outcomes:

The stuff they learn is largely directed by outcomes that are specified, which are handed down from on high [as SLOS in the Junior Science Manual, see Appendix E6].

(David, initial interview)

He described how he follows these provided outcomes closely, with little deviation compared to other topics, aiming to methodically cover each outcome in a one-hour lesson:

I tend to follow the SLOs [for the Electricity and Magnetism unit] more than I do with other topics. I tend to make it a one-hour package each time and tick them off as I go down. Whereas in the biology topics, I am much more inclined to improvise and do my own thing, or give them anecdotes.

(David, initial interview)

When asked about students acting like scientists in his classroom, David felt this pedagogical approach was disregarded by himself and his departmental colleagues. However, he did indicate that students should act in this way, but it was not practical in his classroom:

[Laughter]. *In a lot of ways, we [departmental colleagues] suppress that... In a lot of ways, I think we should, but in practical terms, in terms*

of running a classroom it is very difficult to do that. There are many complicating factors. But, yes, ideally yes.

(David, initial interview)

David offered a detailed response about how students might act like scientists in his classroom. He believed that students could use equipment, make their own discoveries, and explain what they had done. However, he identified that timetable constraints and students' behaviour could limit this pedagogical approach:

If I didn't have discipline issues with kids, and if I didn't have a timetable that I was constrained by... We are going to start off with some gear, I am going to show you how it works, and then here's a whole lot of stuff and I want you to play with it. I want you doing interesting stuff, but I also want you to tell me what's going on... So, students are thinking about it, and they are doing stuff that is interesting to them, and in that way, I think if kids can do stuff that they were interested in anyway, they learn a lot more. They get a lot more out of it. I think it is difficult to do that in the school and class setting.

(David, initial interview)

David spoke extensively about his understanding of the nature of science. He focused on the evolution of science as a human enterprise and a process for discovery that generated new knowledge, and how that process was carried out. He emphasised questioning and experimenting as important outcomes:

That [the nature of science] goes back to attitudes about understanding the world... For a long time, things happened, and we didn't understand them. We came up with ways to avoid that, by saying things like God made it that way, and it was accepted that that's how it was. There were people who challenged it, who wanted to know more, who explored things, but they got into trouble... I think now, as a society, we want to encourage people to question things. And I think, I guess in terms of

teaching science, that's what we want to be doing. We want to be encouraging people to enquire and to experiment.

(David, initial interview)

When asked about how he incorporates these ideas of questioning for understanding and experimenting into his lessons, David revealed he was not strong in this area. However, he believed trying to be animated and to avoid telling students their responses were wrong were important pedagogical attributes he was working on:

[Laughter]. I am not good at that... I guess that one of the important things I see is to be excited and interested. Also, one of the things that I have seen in the past, and try to avoid it, is the tendency so say, that's the wrong answer to something unexpected. I think in science we shouldn't be doing that, I try hard not to do that.

(David, initial interview)

As for his understanding of scientific inquiry, David's response centred on controlling variables and being analytical. He explained:

It means being analytical, and trying to control... Having more understanding about the factors that are coming into play.

(David, initial interview)

However, when incorporating these ideas into his lessons, David revealed they were often overlooked because of the time constraints, stating:

[Deep sigh]. I don't know. I think the idea of science fairs, investigations, individual investigations or group projects... There is a lot of potential there, but [sigh] we have moved away from that because of the practicality. I don't feel that it is feasible within the constraints we have. Occasionally it is, but there are always time constraints.

(David, initial interview)

The following section reports on findings related to David's knowledge of curriculum.

4.3.2.2 Knowledge of Curriculum

David's views about the *Electricity and Magnetism* concepts his Year 10 students should be learning aligned with his personal philosophy about the value of science education. Essentially, he wanted students to have a basic understanding of electricity and how it works that they could apply to their use of electricity in their everyday lives. David explained:

I think they need to have some understanding of what's going on in the wires. What electricity is, or what it can do. Obviously, there is a heck of a lot more to it than what is feasible... Our lives in New Zealand revolve around electricity so much. We use electricity for all sorts of things, I can see us using more electricity in the future. We do so much with electricity, that I think it is essential that they have a basic... Even if they never have to do anything specifically beyond having to plug something in and turn it on. At least having some idea about why that works is a good thing.

(David, initial interview)

The following section reports on findings related to David's knowledge of students' understanding and learning.

4.3.2.3 Knowledge of Students' Understanding and Learning

David believed that students would have some prior knowledge, particularly about components, before starting this unit:

I think most of them have got an idea... They know what lightbulbs are. They know what they call batteries. They know that you get electricity out of them, but they also know that there is mains electricity.

(David, initial interview)

When asked about possible student misconceptions, David reported that Year 10 students had little prior understanding of electrical circuits and related concepts (or terms) such as voltage, current, or resistance:

Often that one about complete circuits... For some of them, it is a real eye opener... I think the idea of voltage and current and resistance is a real mystery. What any of those things are is real mystery to some kids.

(David, initial interview)

David was aware that students had different learning styles and needs. To accommodate for their needs, he advocated giving students flexibility in their learning opportunities and allowing students to follow areas of their own interest, within boundaries. However, he also identified issues with that approach, particularly when students are doing valid work, but it is not going to be tested. David explained:

I think there are vast differences actually. I believe kids have quite big differences in how they learn... I think giving them flexibility, and giving them freedom to learn within guidelines or some boundaries.... So, I think the more freedom you can give kids in a topic, the more likely they are to find things that work for them. But there are two things that come to mind. One, you are going to have kids that just don't bother. And I guess there are various reasons why that is. But there are also kids doing absolutely valid stuff, but not within what we're going to test them on. And that's a bit of an awkward one, because on one hand I want to encourage them to do that, but I know that they're not going to show up very well when I am reporting what they've learnt.

(David, initial interview)

The following section reports on findings related to David's knowledge of topic-specific instructional strategies.

4.3.2.4 Knowledge of Topic-Specific Instructional Strategies

For his introductory lesson, David described using the provided SLOs as a guide, while also trying to make concepts relatable to prior knowledge or experiences:

We start off talking about static... That is in the list [of SLOs], and that is the order that it is set in. We do lightning, and getting shocks from cars. I try with all my units, to start off with things that kids have got at least some idea of, so it's not totally foreign to them. So, they have got something to hang it on, or something to build from.

(David, initial interview)

From this initial lesson, he described briefly how he wanted to students in follow up lessons to further their understanding about static electricity through experimental play, and then work with simple circuits:

Develop the idea of static electricity and we have a bit of a play with the Van der Graaf generator. From there we look at some nice basic circuits.

(David, initial interview)

In his pedagogical approach, David emphasised letting students “play” with equipment to generate interest, challenge their thinking, and extend learning. He reasoned:

I think that kids learn a lot more when they play with things. They remember well, and they find it interesting if they have a play. Sometimes they find something didn't expect. But the role of the teacher there is to facilitate that, to get the gear, give some direction, and then challenge them and ask what's going on there? How come you got something different from him? What's going on?

(David, initial interview)

During this discussion, David perceived that this strategy might have limitations linked to getting students to think, which teachers need to address proactively:

Kids often avoid thinking, if they can. And I think the teacher is responsible for not allowing them to do that. To pin them down to get them to think. Some kids, by the time we get them, have got out of the habit of thinking, for various reasons and in various ways. I think we have got to do everything we can to get them to think.

(David, initial interview)

The following section reports on findings related to David's knowledge of assessment strategies.

4.3.2.5 Knowledge of Assessment Strategies

David argued that assessment in science is not done effectively by himself or his colleagues. He recognised only content was tested, and there is more to science than just content (e.g., skills and attitudes) but that is too difficult to assess. He explained:

I don't think I do that very effectively at all [assessment in science]. I don't think as a school, or schools in general, do that very effectively. We test content... But to me, that's not really what science is about. Content is important, in so far as it gives you tools to work with. But in terms of what I'd like to achieve [skills and attitudes], I don't think we can measure it.

(David, initial interview)

When asked about his approach to formative assessment, David indicated that he was low-key in his ongoing monitoring of learning, preferring to identify particular concepts that need further attention. This information informed some of his follow up teaching. He explained:

[Long pause]. Very informally. I try to do that in terms of just asking kids what they've learnt or how this works, or what's going on here. I

use that in terms of establishing where I haven't successfully covered stuff. What I need to reiterate; what we may need to explore in a bit more depth... It's useful to know if kids have grasped this already, and we might need to move on, or try a different approach.

(David, initial interview)

The following section reports on findings related to David's sense of self-efficacy.

4.3.2.6 Sense of Self-Efficacy

David was asked about his self-perceived effectiveness in relation to how capable he felt when teaching Year 10 *Electricity and Magnetism*. He talked about being less confident in this unit compared to others, but felt adequate nonetheless, stating:

*I don't have the confidence with this topic that I have with other topics...
I am not too concerned about it though. I don't think I am hopeless.*

(David, initial interview)

David sought assistance if there was an instructional strategy he wanted to use, but was unsure about (e.g., learning a new strategy from a physics teacher). While there was a range of staff in his department, David explained he was only comfortable approaching those staff with whom he had working relationships:

*I think I would be inclined to ask someone to run me through it again.
We have got a reasonable sized department, and there are some [people] I am confident to talk to in that way, and others that I am not...
There are always going to be people you get on better with, and that is what it boils down to. So, I think I would be more inclined to say run me through this, how does it work, run me through it again.*

(David, initial interview)

The following section reports on findings related to Alan's initial pPCK interview.

4.3.3 Alan's Initial Interview

4.3.3.1 Personal Philosophy for Teaching Science

Interview data revealed that Alan saw value in science education as students could relate aspects of science to their lives. He reasoned:

Yes, definitely. It is something I have learnt more so over the last couple of years, the fact that science is everywhere. The fact that you can relate it into aspects of everyday life.

(Alan, initial interview)

When asked why science was included in the NZC, Alan reiterated his initial comment, and added that learning science is part of a balanced education:

Again, because it is important in everyday life. Knowing about science, and what we cover in science is a huge part of a well-rounded education.

(Alan, initial interview)

Alan's interpretation of the goals for science education accentuated his view on the value of science education, that is, students relating their understanding of scientific phenomenon to their lives. He also argued that science encourages students to be curious and ask questions about scientific phenomenon and aspects of their lives:

I think science, the subject itself, the way it is taught, lends itself for students to be inquisitive and ask questions about life; not just about science itself. I think the inquisitive nature of science is definitely a life skill. As well as that, the content is everywhere. You see it every day. And knowledge about it is in itself a life skill. It helps the students daily.

(Alan, initial interview)

When the focus of the interview shifted towards teaching Year 10 *Electricity and Magnetism* specifically, Alan's attention was again on students relating scientific

concepts to their lives. In relation to those concepts, he wanted students to understand the scientific theory underpinning the concept, while also modelling their understanding:

I want them to be able to understand the theory behind it, and not only that, but demonstrate it practically. We talk a lot about why things happen; I mentioned about being inquisitive, we relate everything to say that the electrical aspects that you find in every home... For example, when one car headlight goes out, why doesn't the other one? They learn the theory behind it, but they also put it into practice as well, which I think is important.

(Alan, initial interview)

Alan challenged the phrasing of students acting as scientists. He argued that once his students were learning about science, they were automatically acting as scientists:

If, by that, you mean use... I don't like the word... terminology, what would you say? Curriculum based terminology? Then yes. Then I'd ask you what a scientist is. I think I tend to make clear that soon as they come into the classroom in Year 9, when they go into a science lab or science classroom, then they're scientists because they are learning about science.

(Alan, initial interview)

As for specific skills that Alan wanted his students to develop when they were acting as scientists, he focused on students proving any claims using evidence, explaining:

I like them to be evidence driven. We make emphasis on proving things. Once they have proved it, then comes the 'what else could happen?'

(Alan, initial interview)

Alan was unsure about the nature of science, asking: “the nature of science, as in, science is everywhere?” (Alan, initial interview). The researcher aided Alan by talking about the nature of scientific knowledge and how that knowledge may be generated. He was then asked how he incorporates students’ learning about the nature of science into his lessons, and he explained that it was achieved by following the provided schemes of work:

I think that comes under following the curriculum within the schemes of work that we have. Everything that we have within the schemes of work, especially Year 10 science, is very thorough.

(Alan, initial interview)

Alan explained the schemes are developed by “the head of department” (Alan, initial interview) and he does not go beyond guidelines provided in his teaching. Although he does reflect on lessons to enhance his teaching the following year, commenting:

I am still in the stage with science, that probably no [I don’t expand outside of the schemes]. I do reflect on my lessons though, and these reflections will change the way I teach next year.

(Alan, initial interview)

When espousing his understanding about scientific inquiry, Alan reiterated his earlier comments about being evidence driven, and following a method or procedure when carrying out an investigation:

Science is evidence based. There is a scientific method when you are looking at possible different results and answers... Procedures that you follow to carry out the scientific investigation.

(Alan, initial interview)

The following section reports on findings related to Alan’s knowledge of curriculum.

4.3.3.2 Knowledge of Curriculum

Alan's views about the *Electricity and Magnetism* concepts his Year 10 students should be learning aligned with his personal philosophy about science education. He wanted students to learn about aspects of electricity that they could relate to in their lives. He stated:

I think they should learn about how it affects them in everyday life. Household electricity and static electricity; I think they are important... It is something they experience every day. So, they know what is happening around them in their world.

(Alan, initial interview)

The following section reports on findings related to Alan's knowledge of students' understanding and learning.

4.3.3.3 Knowledge of Students' Understanding and Learning

Alan explained that students would have some limited prior knowledge since they were likely to have experienced electricity related phenomena. Students, in his view, would be able to describe or recognise a particular phenomenon, but may lack the understanding to why it occurs. Alan explained:

I think that the topic that it is, I expect them to be able to talk around what they see. Through experience, there is a little bit of prior knowledge, but not much. So, we talk about static electricity. They know that a spark is caused by static electricity. They know that when they rub their feet on the carpet and the spark they get when they touch the door handle is static electricity. It is just filling in the gaps to why.

(Alan, initial interview)

As for possible student misconceptions that students may have, Alan indicated that 'misconception' was the wrong phrase. Rather, students found it difficult to make

links between what they were doing in science and every day phenomena. Alan reasoned:

I don't know whether I would say misconception, I think a lot of them take it for granted.... Some students struggle making the link between science and everyday life. They see science being purely an academic subject found in a book. I don't think they realise how much it is around them every day.

(Alan, initial interview)

Alan was aware that students had different learning styles and needs, and contextualised his response using his upcoming pre-CoRe design Year 10 class. To accommodate student needs, he advocated the use of practical work and encouraging students to explain concepts using their own words:

With this class, the practical side is definitely more beneficial, I would say, to all of them. When it comes to more theory and written work, students struggle a bit more. It is about doing the practical, and then getting them to put it into their own words.

(Alan, initial interview)

The following section reports on findings related to Alan's knowledge of topic-specific instructional strategies.

4.3.3.4 Knowledge of Topic-Specific Instructional Strategies

For his introductory lesson, Alan described how he explores students' prior knowledge, while encouraging students to recognise the broad range of responses in relation to electricity:

To find out what prior knowledge that they have... We will talk about when they heard the word electricity before, and what it links with. Most of them come up with household appliances. A lot of them will say electric shock, a couple of them may say lightning. I think with that, the

good thing is that they start to realise that all the broad answers, there aren't any wrong answers.

(Alan, initial interview)

From this initial lesson, Alan detailed how he wanted students in subsequent lessons to learn about household and static electricity, while continually relating concepts to familiar examples (e.g., appliances):

We go to household electricity. From there, we will touch on static electricity and we will look at advantages of it and the problems that it causes. Talking about a photocopier always blows their minds. Then we move onto, I guess, the more technical, the more electronics base of electricity. Moving through that and relating it to... So that they know electricity involved in household appliances. So, they know that it is involved, and this is how it is involved in appliances.

(Alan, initial interview)

When asked about how he teaches the magnetism component of the unit, Alan reiterated using practical work to accompany theoretical explanations:

Again, theory followed by practical. I think that is the best way.

(Alan, initial interview)

Alan described a particular strategy that he uses with his students to develop student understanding about voltage sharing in simple circuits. His description repeated his earlier comments about scientific inquiry; being evidence driven and proving a theory:

I put a box on the board saying where the series circuit the voltage is shared, or what have you, and then I've asked them to go and prove it. I've explained to them that it is just a theory and I want them to see if it is true or not. But I want them to bring evidence.

(Alan, initial interview)

When asked about any issues he has had in the past with instructional strategies, Alan recalled having issues when teaching students to use voltmeters. However, he attributed this issue to the particular group of students that he is teaching:

We have to go two steps forward and one back. We have to cover connecting a voltmeter in parallel, and then again. But, that depends on the group really. I have to go over it a couple of times.

(Alan, initial interview)

The following section reports on findings related to Alan's knowledge of assessment.

4.3.3.5 Knowledge of Assessment Strategies

Alan determined if students had learned important concepts by asking questions, and having them explain their answers to him:

Through question and answer. And through answering questions and tasks in their books. But generally, through them being able to explain it to me.

(Alan, initial interview)

Alan explained that he sometimes collates the information that he received from students to give back to them, as it gives them further direction in their learning:

We collate it and sometimes I type it up and give it to them to stick into their books. It gives them some guidance with their writing

(Alan, initial interview)

The following section reports on findings related to Alan's sense of self-efficacy.

4.3.3.6 Sense of Self-Efficacy

When Alan was asked how capable he felt when teaching Year 10 *Electricity and Magnetism*, he acknowledged that he had room for professional growth, but there were certain advantages from a pedagogical perspective to having a recent science qualification. He explained:

I think I have definitely got a lot to learn. I am still very young I guess within teaching science, on that side of it. But on the other side of it, I think because my scientific qualification and background has purely been this, it is quite specific for what I teach them.

(Alan, initial interview)

In the situation of learning about a new instructional strategy, but not being confident using it, Alan explained that he would seek assistance (which he had done before), particularly around practical activities:

I am not afraid to ask, and I have watched other staff do practicals. I have had 20-minute PDs [professional development] on doing a few things which has helped. I try and not shy away from practicals.

(Alan, initial interview)

Whether he would use an instructional strategy if he was feeling unsure about it, Alan again talked about seeking assistance, and indicated he would not use it until he was confident:

[Long pause]. No, probably not, no. I would do it eventually. I would find out about it. So, I would do it within that topic, but I wouldn't do it if I was unsure going into the lesson.

(Alan, initial interview)

The following section reports on the Group One participants' lesson observations prior to taking part in CoRe design.

4.4 Observing Group One Teachers (Pre-CoRe Design)

To gain an understanding of the Group One participants' ePCK prior to taking part in CoRe design, observations of their lessons were carried out as they taught *Electricity and Magnetism* to their first Year 10 class. As explained in Chapter Three, Section 3.4.5.2, these lessons were video recorded for analysis at a later date. However, some unforeseen events meant some data was unable to be gathered. For example, there were times when Ryan (video camera operator) was unavailable because of his own commitments (such as classes or assessments) or he was unwell, or the recording equipment was unavailable. Nevertheless, sufficient lessons were recorded for each teacher throughout this topic to allow for a credible and dependable analysis of their ePCK.

Of the lessons that were video recorded in Phase One, four from each participant were used for this analysis. The four lessons chosen included: the introductory lesson to the unit; a lesson where the students were carrying out practical work; and two other lessons that reflected concepts that each Group One teacher talked about during their CoRe design workshop experience.

Observational data was analysed using an observational protocol based on the rubric presented in Chapter Three (see Appendices D1 and D2 for examples of the blank protocol and full completed protocol respectively). To present the extensive and complex data emerging from each lesson in a clear and comprehensible manner, a table template has been developed which represents one lesson. Within this template, abbreviations have been used to represent aspects of the rubrics (see Pages 128 – 130). Table 4.2 on the following page shows abbreviations for level descriptors and ePCK indicators.

Preceding the observational data is contextual information about the class such as student behaviour and engagement, and equipment and resources used. Contextual information was noted on the observational protocol and this data from all four observed lessons was collated for reporting purposes.

Table 4.2: Abbreviations for level descriptors and ePCK indicators used in table template for reporting observational data.

Abbreviation	Level Descriptor
L	Limited
B	Basic
P	Proficient
A	Advanced
ePCK Indicator	
Appropriateness	Appropriateness of concept(s) in relation to NZC – Physical World (Level 5)
Accuracy	Scientific accuracy of the explanation of the concept(s)
Concept links	Links and/or connections made to other concepts
NoS/SI links	Links made (implicit or explicit) to the nature of science and/or scientific inquiry
Prior knowledge	Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions
Variations in understanding	Teacher uses identified variations in student understanding and learning to guide instruction
Questions used	Teacher uses questioning to probe or extend student understanding
Sequencing of concepts	Appropriate sequence for teaching concepts
Examples and representations	Relevant examples and/or representations are used in the lessons, which appear to be pedagogically effective at portraying the concept
Metacognitive strategies	Use of strategies that allow for metacognition

Each table includes judgements made of the levels to which the ePCK indicators had been met using the level descriptors as guidance and evidence supporting each judgement is supplied.

4.4.1 Tony's Pre-CoRe Design Observations

4.4.1.1 Contextual Information

The four pre-CoRe design lessons selected for analysis of Tony's observational data included his: introductory lesson; third lesson, featuring explanations and discussions around series and parallel circuits; fourth lesson, where students made simple circuits; and, sixth lesson, developing explanations about voltage, current, and resistance.

There were 30 students on the roll in Tony's pre-CoRe design class (school records) and they were well-behaved most of the time. There were only a few instances where Tony had to deal with students being off-task or disruptive. Students were engaged in the lessons, particularly during practical activities (observational protocol).

Tony's teaching style was identified as teacher-centered with lessons frequently featuring a pre-made PowerPoint that he directed students to copy into their notes, including underlining keywords because they are going to be tested (observational protocol). This PowerPoint was used with other classes, as evidenced by the use of a different class code on the title page during his introductory lesson, which a student pointed out. Tony responded to the student by saying "don't worry, it's a good PowerPoint" (Tony, first lesson, pre-CoRe design). During his practical lesson he did not use his PowerPoint. In another lesson, the data projector was not working, so Tony used the whiteboard. In this instance, he was observed to express frustration and said "right, plan B... I have to write this, this sucks" (Tony, sixth lesson, pre-CoRe design). Tony transferred the PowerPoint notes from his computer screen to the whiteboard.

4.4.1.2 Tables for Observational Analysis

The four tables for Tony's pre-CoRe design lessons are on the following five pages.

Table 4.3: Tony's first pre-CoRe design lesson. The concepts covered were charged particles and static electricity.

Subject Matter Knowledge		
Appropriateness	P	Tony showed students some demonstrations with the Van der Graaf generator, for example how it could make a neon light glow or make a metal spinner turn. It could be argued that both of these demonstrations are better suited to teaching students about electric field theory, which is covered in Level 7 or 8 of the NZC.
Accuracy	P	Tony's explanations were classified as mostly accurate. He frequently referenced electricity as electrons. It is more accurate to refer to charged particles, with electrons being an example.
Concept links	B	Tony made some links between concepts, but did not provide an explanation about the connection. For example, making the link between electricity and energy, but not explaining how they are related.
NoS/SI links	L	There were no instances that could be attributed to this indicator.
Knowledge of Student Understanding		
Prior knowledge	B	There were some instances where Tony referred to student prior knowledge and difficult concepts, but he did not elaborate on these ideas or concepts. For example, he asked his students to brainstorm what they knew about electricity. Students then reported back to Tony who wrote several ideas on the whiteboard. He never referred to these ideas again, opting to erase them from the board and then switching to his PowerPoint so students could take notes.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	B	Tony asked a few questions of his students throughout the lesson. However, these questions were predominately recall, requiring a one-word response which did not extend their understanding. For example, asking students 'what is the charge on an electron?'
Knowledge of Instructional Strategies		
Sequencing of concepts	B	There was some flow between the sequencing of concepts, but the connections were not obvious. That is, concepts were 'stand-alone' snippets of information rather than connected concepts leading to a big idea.
Examples and representations	P	Tony used some examples and representations, but they appeared to be pedagogically underdeveloped and did not seem to be effective. For example, his use lightning for explaining static electricity; while it can be a useful example, it was not used in a way to enhance students' understanding.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

Table 4.4: Tony's third pre-CoRe design lesson. The concepts covered were explaining and discussing differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	P	Tony showed students a YouTube video where a person talks about generating a high voltage spark using capacitors, transformers, and an alternating current power supply. It could be argued that these concepts are better suited to Level 8 of the NZC.
Accuracy	P	Tony provided brief accurate explanations with little elaboration. For example, explaining current in a series circuit and how a blown bulb stops current, but not elaborating why.
Concept links	B	Tony made some links between concepts, but did not provide an explanation about the connection. For example, he made a weak link between lamp brightness and voltage, but did not explain the relationship.
NoS/SI links	B	There were some implicit links to learning about the nature of science, such as students learning about conventions and terminology, and using models to represent abstract concepts. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	B	There were some instances where Tony referred to student prior knowledge and difficult concepts, but he did not elaborate on these ideas or concepts. For example, asking students about their understanding of what components mean, followed by a brief explanation, without actually acknowledging their prior knowledge.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	B	Tony only asked his students a few questions during the lesson. These questions were predominately recall, requiring a one-word response which did not seem to probe for or extend their understanding. Tony also asked a question and then answered it himself without engaging with the students.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The flow between concepts in this lesson was suitable, but there were times when a shift from one concept to another was not made explicit. Further explanations were warranted to help students develop their understanding and linkages between concepts.
Examples and representations	P	Tony used some examples and representations, but they seemed pedagogically underdeveloped and may not have achieved his intended outcome. For example, when he used a simulation to explain voltage Tony was unsure what it represented, stated it was a "bit dumb" and that they should watch a video instead, which was unrelated to lesson objectives.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

Table 4.5: Tony's fourth pre-CoRe design lesson. The concept covered was making and exploring simple circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	P	While accurate, Tony's explanations during this lesson were brief. For example, not elaborating on why voltage is measured on either side of the component to determine the size of energy transformations.
Concept links	B	Tony made some links between concepts, but often his link lacked an explanation of why or how they are connected. For example, he briefly linked voltage and energy, but did not elaborate on their relationship.
NoS/SI links	P	Tony made some implicit links to the nature of science and scientific inquiry. For example, talking to students about the origin of terminology (e.g., why the symbol for current is I) and explaining aspects of carrying out an investigation, gathering data, and comparing results to theory.
Knowledge of Student Understanding		
Prior knowledge	P	Tony referred to the work students had done in the previous lesson. He also addressed the difficulty of using multimeters to measure voltage and current a few times, and tried to give the students further explanation about these concepts as a whole group. There was no indication about misconceptions, although Tony did mention they would have issues with using multimeters correctly.
Variations in understanding	B	Tony had started his class on a task making circuits in small groups, and then visited each group to assess progress. Upon noticing students were having the exact same issues, he asked students to gather around a working circuit, so he could explain further. However, that technique was ineffective as students were still confused. He did try to do a similar exercise towards the end of the lesson, but it was also ineffective as students expressed confusion.
Questions used	B	Tony asked a few questions of his students during the lesson. However, these questions were predominately recall, requiring a one-word response which did not seem to extend student understanding. For example, asking what type of circuit they had made, but not asking them to justify their answer.

Please see following page for Knowledge of Instructional Strategies

Table 4.5 Continued.

Knowledge of Instructional Strategies	
Sequencing of concepts	B The strategy Tony used was to work with series circuits first followed by parallel circuits, which would be appropriate for this group of students. However, the flow between the two circuit types was confusing for the students, often leaving them unsure what they were doing. While the strategy was suitable, it required further development to allow students to see the clear flow between concepts to develop their understanding.
Examples and representations	B The only instance attributed to this indicator was a quick demonstration taking measurements with multimeters. However, this demonstration was ineffective, as evidenced by students' multiple questions during the lesson about what they were doing.
Metacognitive strategies	L There were no instances that could be attributed to this indicator.

Table 4.6: Tony's sixth pre-CoRe design lesson. The concepts covered were voltage, current, and resistance.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	P	While accurate, Tony's explanations during this lesson were brief. For example, while he mentioned the inverse relationship between current and resistance, he did not elaborate why that relationship exists.
Concept links	P	When he talked about the Ohm's law relationship, he did mention the interconnectedness of voltage, current, and resistance. He focused primarily on the inverse relationship that exists between current and resistance, but did not provide an explanation to why they are linked in an inverse way.
NoS/SI links	B	Tony made some implicit links to learning about the nature of science, such as students learning about conventions and terminology. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	L	There were no instances that could be attributed to this indicator.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	B	Tony asked one question of his students during the lesson, which was about the relationship between current and resistance in a circuit.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The flow between concepts was classified as suitable. There were times when concepts changed, and careful explanations would have been useful to allow students to develop their understanding and linkages between those concepts.
Examples and representations	P	Tony used some examples and representations, but they appeared to be pedagogically underdeveloped. For example, he used analogies/diagrams to represent voltage, current, and resistance. However, there was little explanation. He also represented current and resistance in a conflated way, rather than distinguishing them as separate concepts.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

4.4.2 David's Pre-CoRe Design Observations

4.4.2.1 Contextual Information

The four pre-CoRe design lessons selected for analysis of David's observational data included his: introductory lesson; fourth lesson, featuring explanations and discussions around series and parallel circuits; fifth lesson, where students made simple circuits and measured current; and, sixth lesson, where students made simple circuits and measured voltage.

David's teaching style was identified as student-centered, where he allowed students to explore and experiment with equipment during practical lessons. The practical lessons often had little structure and while students were interested in using the equipment, some of David's 30 students (school records) were off-task and disruptive. There were also times when David attempted to engage the whole class in a discussion, but he had difficulty with student behaviour (observational protocol). For example, during his sixth lesson, David had to deal with student behaviour issues (such as students being disruptive while he was trying to talk) over 20 times during the lesson (David, sixth lesson, pre-CoRe design).

David wrote notes for students on the whiteboard in all four lessons, and he had a notebook with him which contained some of that information. His students also had a Year 10 science text book which they were required to keep with them and use periodically as a resource (observational protocol).

4.4.2.2 Tables for Observational Analysis

The four tables for David's pre-CoRe design lessons are on the following four pages.

Table 4.7: David's first pre-CoRe design lesson. The concept covered was static electricity.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts well.
Concept links	P	David only made one connection during this lesson, but it was done well. He explored the connection between sub-atomic particles and their relationship to electricity, in particular, static electricity occurring when those particles are separated.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	P	David explored student prior knowledge about static electricity by asking them about their previous experiences. While he did not show any indication of recognition about misconceptions, he did talk to his students about the difficulty of using language in a science-specific context versus an everyday context.
Variations in understanding	P	David tried to use student responses to his questions to his advantage. He used the information that students provided to construct the next question (or set of questions) in an effort to scaffold their understanding. At times though, this strategy was unsuccessful.
Questions used	A	David used multiple and varied questions to explore student understanding and their prior knowledge about electricity related phenomena.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The flow between the concepts that David was teaching was suitable. Further explanations during some concept transitions would have helped students make stronger connections.
Examples and representations	B	There was little data which could be attributed to this indicator. David mentioned a few examples of phenomena related to static electricity, but these were not used to enhance student learning.
Metacognitive strategies	B	At one point in the lesson, David tried to get his students to challenge their own thinking and undergo a metacognitive process. He asked students to read a section from their text books, and then relate that information to their own personal real-life experiences with static electricity. He then asked his students to explain what was happening with regards to that phenomenon.

Table 4.8: David's fourth pre-CoRe design lesson. The concept covered was differences between series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	P	David spoke to his students about electrical power. During the discussions that took place in the Year 10 <i>Electricity and Magnetism</i> CoRe design workshop, this concept was deemed to be more appropriate for the following year (i.e., Level 6 of the NZC). Although, this concept was not the focus of David's lesson.
Accuracy	P	The explanations that were offered were accurate, but brief. For example, only briefly explaining the different pathways for current in series versus parallel circuits, without elaborating further.
Concept links	B	David made some links, but did not provide explanations between them. He also overlooked many of the possible and important ones within this lesson. For example, a useful link would have been between energy and energy conservation in different circuit configurations.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links
Knowledge of Student Understanding		
Prior knowledge	L	There were no instances that could be attributed to this indicator.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	P	David appeared to use a range of questions for probing student understanding. For example, asking them about what they noticed when they compared different types of circuits. However, these techniques were ineffective as he had frequent classroom management issues, such as students being disruptive.
Knowledge of Instructional Strategies		
Sequencing of concepts	B	The intent of transitioning from series to parallel circuits is appropriate. However, there was little flow as David's explanations confused students and they were unsure about the point of the lesson.
Examples and representations	P	David used the example of lighting in a house to explore the advantages and disadvantages of series versus parallel circuits. He also used conventional circuit diagrams on the whiteboard to represent circuits. Both of these seemed to be pedagogically effective as most of the students engaged with the explanations. However, David did go 'off-topic' about recessed lighting in houses. This conversation appeared to be of interest to David, but it had little relevance on the concepts being taught.
Metacognitive strategies	B	At one point in the lesson, David tried to get his students to challenge their own thinking and undergo a metacognitive process. He asked them to think about the type of wiring they might have in their homes (i.e., series vs. parallel) in relation to what they had been learning about, and to justify their answers to him.

Table 4.9: David's fifth pre-CoRe design lesson. The concept covered was exploring current in simple circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	P	David provided brief accurate explanations with little elaboration. For example, he briefly explained current flow in series versus parallel circuits.
Concept links	B	David made some links, but did not provide explanations about how they are related. He also overlooked many of the possible and important links within this lesson. For example, linking brightness and energy being used by bulbs in different configurations would be a useful link for students at this level.
NoS/SI links	P	David made implicit links to the nature of science in terms of using correct conventions, such as symbols and diagrams to represent circuits. He also made implicit links to scientific inquiry as he was promoting his students to carry out an investigation, gather data, and then explore trends that appeared in the data.
Knowledge of Student Understanding		
Prior knowledge	B	The only instance of this indicator was when David referred to concepts that students were meant to have understood from the previous lesson.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	P	David used a range of questions to probe student understanding. For example, drawing circuits on the board and asking students how they knew it was a series or parallel circuit. However, these techniques were ineffective as he had classroom management issues, such as students being disruptive.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The flow between the concepts that David taught was suitable. At times during the lesson, David could have offered further explanations when concepts transitioned to help students to make strong connections and see linkages.
Examples and representations	B	There was little data which could be attributed to this indicator. David only used some circuit diagrams to represent different aspects of circuits.
Metacognitive strategies	P	David discussed what an ammeter actually does, in terms of measuring flow of charge, with his students. He then related this discussion back to a practical circuit allowing them to challenge what they had previously thought. David also explored the pattern of the gathered data – he wrote voltages on the board for different circuits and wanted students to think about what the data represented. While this second strategy seemed to be useful, the recess bell had gone and students were very eager to leave class, so it may not have been as effective as David anticipated.

Table 4.10: David's sixth pre-CoRe design lesson. The concept covered was exploring voltage in simple circuits.

Subject Matter Knowledge		
Appropriateness	P	David spoke to the class about the phenomenon of electrons experiencing a force when interacting with a magnetic field, which in turn, generates electricity. It could be argued that this concept aligns with Level 7 of the NZC. Although, it was not the focus during the lesson.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts well.
Concept links	B	David made some links between concepts, but did not elaborate on their connection. He also overlooked many of the possible important links and connections within this lesson. For example, linking and explaining voltages across components to the supply voltage, and to energy used would have been useful.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	L	There were no instances that could be attributed to this indicator.
Variations in understanding	B	There were many opportunities for instruction to be guided by student understanding, but it did not occur. There was one instance when David worked with a group and a student was confused between series and parallel circuits, and David tried to address the issue. This teaching episode may have been more beneficial if it was used as a whole class activity.
Questions used	B	David used a few questions, but these were not used to probe understanding, per se. Rather he was wanting students to share their collected data with him, so they could analyse the results as a class.
Knowledge of Instructional Strategies		
Sequencing of concepts	L	The intent of the lesson was appropriate, but the actual sequencing of concepts in the lesson left most students quite confused about what they were learning. At the end of the lesson, when David was calling on students to offer data, it was evident that many of them had no idea what they should have been doing during the lesson. It appeared that many students gained very little learning from this lesson.
Examples and representations	B	There was little data which could be attributed to this indicator. David used circuit diagrams to try and show his students how to practically use a multimeter to measure voltage, but it was ineffective and left the students confused about the task.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

4.4.3 Alan's Pre-CoRe Design Observations

4.4.3.1 Contextual Information

The four pre-CoRe design lessons selected for analysis of Alan's observational data included his: introductory lesson; second lesson, featuring explanations and discussions around static electricity; third lesson, featuring explanations and discussions around series and parallel circuits; and fourth lesson, where students made simple circuits.

There were 19 students in Alan's pre-CoRe design class and they were also accompanied by a teacher aide (school records). Members of this class were a lower ability group (compared to other Year 10 classes) and they did one less topic during the year to allow for a slower pace of learning (school records). The students were well-behaved most of the time, and there were only a few instances where Alan had to deal with students being off-task or disruptive. Students were engaged in the lessons and enjoyed doing practical work (observational protocol).

Alan's teaching style was identified as student-centered, and he typically related many concepts to everyday occurrences that students may be familiar with. For example, in his introductory lesson, Alan made many references to household appliances and how they transferred electrical energy (Alan, first lesson, pre-CoRe design). Alan's practical lesson had some structure, but students were also allowed to direct their own learning by experimenting with equipment (Alan, fourth lesson, pre-CoRe design). He wrote all notes on the whiteboard, and during his introductory lesson, he gave students a glossary list of keywords without their definitions. Students were to update it regularly, so they had a complete list by the end of the unit. Throughout the lessons, Alan also made references to how some concepts will be assessed (observational protocol).

4.4.3.2 Tables for Observational Analysis

The four tables for Alan's pre-CoRe design lessons are on the following four pages.

Table 4.11: Alan's first pre-CoRe design lesson. The concepts covered were representing electricity as energy and energy transformations.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that Alan offered in this lesson were accurate and addressed the concepts well.
Concept links	A	Alan made many of the possibly links between different concepts during this lesson and explained the connection. For example, explaining the link between chemical potential energy, electrical energy, and energy transformations.
NoS/SI links	L	There were no instances that could be attributed to this indicator.
Knowledge of Student Understanding		
Prior knowledge	P	Alan explored some student prior knowledge, but it was only briefly referred to in the lesson. For example, students wrote some of their ideas about electricity on the board, but Alan only referred to them briefly.
Variations in understanding	B	While Alan identified some variations in student understanding, it was only loosely used to guide instruction. Alan had an agenda that he wanted to follow with little deviation.
Questions used	P	Alan used an adequate range of questions with his students. For example, exploring their understanding about energy and energy changes when trying to develop a collective understanding about electricity.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequence was about identifying prior knowledge about electricity and then trying to define electricity. Alan tried to achieve that by framing the lesson around a task of drawing a title page where he encouraged his students to be creative and add anything in that was related to electricity. His sequence from what is electricity into energy transformations was suitable.
Examples and representations	A	Alan used many different examples and representations to aid student understanding about energy transformations, which were pedagogically effective.
Metacognitive strategies	B	There was one task where students were asked to think about their own perception of electricity in order to identify some key terms. The point of that exercise was to gather key terms from the whole class and then generate an understanding that represented all of their thinking.

Table 4.12: Alan's second pre-CoRe design lesson. The concepts covered were charged particles and static electricity.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that Alan offered in this lesson were accurate and addressed the concepts well.
Concept links	A	Alan made many links between concepts and explained the connection between them. For example, he explained the link between sub-atomic particles, charge separation, and static electricity.
NoS/SI links	L	There were no instances that could be attributed to this indicator.
Knowledge of Student Understanding		
Prior knowledge	P	Alan referred to information from the previous lesson, which was brief. He also briefly talked about how it may be useful if they can relate their prior knowledge to what they were learning.
Variations in understanding	B	While Alan identified some variations in student understanding, it was only loosely used to guide instruction. Alan had an agenda that he wanted to follow with little deviation.
Questions used	P	Alan used a few questions to probe understanding, which he used in both whole class settings and when working with individual groups. For example, exploring students understanding of words in a general context to then relate to science.
Knowledge of Instructional Strategies		
Sequencing of concepts	A	Alan started with a detailed explanation about atoms and their sub-atomic components, which flowed clearly into what static electricity is and tried to use some examples of static electricity from everyday life.
Examples and representations	P	Alan used examples and representations, but they appeared to be pedagogically limited, and could cause confusion or develop misconceptions. For example, his use of an analogy where two swimming pools, that are different distances away from a person, to demonstrate path of least resistance required further explanation.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

Table 4.13: Alan's third pre-CoRe design lesson. The concepts covered were differences between series and parallel circuits, and making simple circuits.

Subject Matter Knowledge	
Appropriateness	P One of the concepts that Alan talked about during that lesson was electron flow. It could be argued that it would be more appropriate to use the idea of current being charged particles, leaving electron flow and conventional current until Level 6 or 7. However, that was not a focus in the lesson.
Accuracy	P Most of the explanations that Alan offered in this lesson were accurate and addressed the concepts well. The exception was the confusion between current and electron flow.
Concept links	B Alan made some brief links between concepts but never elaborated to make the connection clear to students. For example, a brief link of voltage and brightness in a circuit, without elaborating on the relationship.
NoS/SI links	B There were some implicit links to the nature of science in terms of using symbols and conventions, although there was no discussion about why they used those conventions. No scientific inquiry links.
Knowledge of Student Understanding	
Prior knowledge	P Alan talked to his students about issues associated with a closed circuit, which is a common misconception reported in literature. He also explicitly spoke about the difficulty of working with, and actually making, parallel circuits. No recognition of prior knowledge.
Variations in understanding	B Alan had a set agenda that he wanted to follow with little deviation. After addressing the difficulty of working with parallel circuits, he did a quick activity to try and aid student understanding, which had mixed success.
Questions used	B Alan used very few questions to probe understanding. When he did use them though, they were in both whole class settings and when working with individual groups. For example, he asked students to make predictions about what might happen when resistance is increased.
Knowledge of Instructional Strategies	
Sequencing of concepts	B Instances during the lessons indicated a suitable flow. However, students ended up quite confused. For example, when Alan wanted them to make a parallel circuit with lamps and switches, they appeared quite unsure and confused. By the end of the lesson, it was clear that students had not achieved Alan's intended goals.
Examples and representations	P Alan used examples and representations, but they appeared to be pedagogically limited, and could cause confusion or develop misconceptions. For example, when he represented current as electron flow, and stated it was from positive to negative, which reflected his own understanding of current.
Metacognitive strategies	B Only one weak link to a metacognitive strategy was made. Students were challenged by Alan to create a parallel circuit with switches and lamps, with the aim being to independently control each lamp. The point of the task was to make students think about their understanding of electricity and simple circuits to create that new circuit.

Table 4.14: Alan's fourth pre-CoRe design lesson. The concepts covered were difference between series and parallel circuits: making simple circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	B	Alan's explanation about placing the multimeter in parallel, that is, putting it "side-by-side" to components in the circuit was brief and it may have confused his students. A more useful explanation, which also relates to defining voltage, is about measuring how much energy a component uses, which is why one wire needs to be on either side. Also, the point of that lesson was to explore the differences between series and parallel circuits. While there was time available at the end of the lesson, Alan missed the opportunity to sum up the practical work that the students had done and actually explain the link between what they were doing and the lesson objective.
Concept links	B	Alan made some brief links between concepts but never elaborated to make the connection clear to students. For example, not elaborating on the link between voltages in different circuit arrangements.
NoS/SI links	B	There were implicit links to the nature of science in terms of using symbols and conventions, although there was no discussion about why they used those conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	L	There were no instances that could be attributed to this indicator.
Variations in understanding	B	While there were no instances of Alan identifying prior knowledge, difficult concepts, or misconceptions in the lesson, he moved around the room assisting students individually and in groups, to aid their understanding.
Questions used	L	Alan used no questions with his students while they were making circuits.
Knowledge of Instructional Strategies		
Sequencing of concepts	B	Instances during the lessons indicated a suitable flow. However, students were confused. For example, he wanted students to measure voltage then current for different circuits. While the approach is quite suitable, the way it was enacted made it confusing for the students, which was evidenced by students constantly asking about what they were doing during the entire lesson.
Examples and representations	B	Alan did use some representations and examples, but they were not effective. For example, telling them the analogy of parallel being side-by-side appeared to be not useful at all.
Metacognitive strategies	L	There were no instances that could be attributed to this indicator.

4.5 Comparing Group One Teacher's Interviews and Observations

This section compares the findings from Group One teachers' interviews and observations presented earlier. This comparison highlights themes between teachers' comments during their initial pPCK interview and what was observed in their lessons, that is, their ePCK. Themes showed either similarities or dissonance between their intentions and practice.

4.5.1 Tony

When comparing Tony's pPCK and ePCK, there were eight themes that suggested either links or dissonance between his pPCK and ePCK, which are summarised below.

Themes showing links or matches between pPCK and ePCK data:

- The influence of assessment on Tony's teaching. This theme was quite prevalent throughout his pPCK interview, and it was apparent in the classroom. During the interview, Tony spoke about wanting his students to pass tests, and while teaching, he made frequent references to taking notes and learning definitions as they would be in the test.
- Tony's lack of understanding about the nature of science and scientific inquiry in the interview was also apparent in the lessons, as he made very few links.
- Tony's topic-specific strategies that he espoused in the interview were seen in his lessons: making and measuring circuits, and having students learn definitions and rules. He also used an analogy to represent voltage, current, and resistance, which seemed ineffective.
- Tony talked about not going too in-depth when he was teaching concepts because he did not have the knowledge. During the lessons, his lack of in-depth explanation was apparent, as he often overlooked underlying principles. Rather, he directed students to learn (and copy down) rules when working with simple electrical circuits.

Themes showing dissonance between pPCK and ePCK data:

- Tony talked about how he wants his students to be inquisitive and curious in class, and ask questions. However, when they displayed these qualities, he rarely engaged with what the students were saying, and sometimes ignored them.
- Tony spoke about students learning science so they could understand the world around them. He tried to use examples in his practice, but these were largely ineffective at teaching the desired concept.
- In his interview, Tony talked about finding out about student understanding and using that information to guide instruction. However, these actions rarely happened.
- In the lessons, Tony did use practical work to help students understand, as he talked about during his interview. However, the practical work was largely ineffective at teaching the desired concept. He also used a video (that he talked about during the interview), but not for explaining concepts, rather it for entertainment at the end of a lesson.

4.5.2 David

When comparing David's pPCK and ePCK, there were seven themes that suggested either links or dissonance between his pPCK and ePCK, which are summarised below.

Themes showing links or matches between pPCK and ePCK data:

- During the interview, David talked about his reliance on the SLOs and how he follows them with little deviation. This was apparent in his lessons, as his very first task was to get his students to write the SLOs into their books. From there, it was apparent that he worked down the list of SLOs.
- David's espoused topic-specific instructional strategy of allowing student to play with the equipment to make their own discoveries was seen in the lessons. This strategy was implemented with little structure and it was quite ineffective at times. For instance, there were multiple times when it was clear

that students were unsure about what they were doing or looking for when working with equipment.

- David indicated that one of the difficult tasks for teachers is getting students to actually think about what they are doing. It was apparent in the observations that he had difficulty trying to achieve this, with one major issue being classroom management.
- David spoke about not incorporating aspects of the nature of science and/or scientific inquiry into his lessons, which was evident in his classroom teaching.

Themes showing dissonance between pPCK and ePCK data:

- David expressed that the goal of science education was about learning science in ways that helped students make links to real world situations. However, he rarely used examples to assist with his explanations of concepts. He did ask students about their own experiences; but their responses were not really used to inform the lesson.
- One of David's personal goals as a science teacher was not to dismiss students' incorrect answers, but rather build on them and use them to further understanding. There were a few times in his lessons where he tried to achieve this goal (showing a link to between his pPCK and ePCK), while in many other instances, he largely directed the lesson and did not use student ideas.
- David talked about using formative assessment in an informal way to find out what students knew, and use that information to inform the lesson. This practice was rarely seen in his observations.

4.5.3 Alan

When comparing Alan's pPCK and ePCK, there were six themes that suggested either links or dissonance between his pPCK and ePCK, which are summarised below.

Themes showing links or matches between pPCK and ePCK data:

- Throughout his interview, Alan referenced the notion of students relating what they were learning in the classroom to their everyday lives multiple times. His philosophy was enacted during his lessons where he tried to use many real-life examples to exemplify the point he was making. The strategy appeared to be effective at helping students understand a concept.
- Alan's topic-specific instructional strategy that he talked about during the interview was using multimeters to collect data. That strategy was seen in the lessons. During the interview he also talked about the difficulty of teaching students to just use the multimeters first, which was also seen.
- Alan indicated that he followed the provided schemes of work because he was new to teaching science, and the guidelines were quite thorough. This was evident in his lessons as the concepts were appropriate for the level.
- For his first lesson, Alan stated in his interview that he planned to explore students' prior experiences with the concepts of electricity and magnetism, so he could then use them to guide the lesson. Alan had students write their ideas on the whiteboard and asked them to draw a title page (showing some of those things from the board). He talked about some of the ideas briefly, but mainly focused on the concept that electrical appliances use electricity (relating back to his real-world philosophy).

Themes showing dissonance between pPCK and ePCK data:

- Alan spoke about how he wants his students to act like scientists in his class, meaning they were inquisitive and evidence-driven. However, during his practical lessons, Alan did not reinforce this idea by encouraging students to collect data and explore patterns.

- Alan talked about providing students with ‘theory’ which can then be followed up with practical work to reinforce their understanding. While he did do some theory work, and then practical work, he did not explicitly link them to help students’ conceptual development.

4.6 Inductive Themes from Phase One

The development of themes for the analysis and presentation of findings related to participants’ pPCK and ePCK has been deductive to date, using the RCM of PCK as an analytical lens. Participants’ interview data were also reviewed in conjunction with their observation data to highlight any recurring ideas that emerged as themes about the nature of their pPCK and ePCK. Again, this information is presented for each participant in turn so a cross-case analysis can be conducted.

4.6.1 Inductive Themes from Tony’s Data

When combining and reviewing Tony’s Phase One data, one overarching trend emerged: the prevalence of teaching to assessments. While his personal goal for science education featured learning about everyday phenomena, his became different when talking about teaching a particular topic (i.e., Year 10 *Electricity and Magnetism*). For example, when talking about this unit of work, Tony “I want them to do well in the test” based on “certain SLOs that we have to cover” which was his “first and foremost” priority (Tony, initial interview). Furthermore, when asked about extending beyond those SLOs, Tony said “no not really. I try and cover them” (Tony, initial interview). It was evident during his interview that Tony also had the following year’s work in mind, when he said “... you need to be thinking about what they need to know for Year 11” (Tony, initial interview).

This focus on assessment was also apparent in his observational data. In lessons one, three, and six, he emphasised the taking of tidy notes and the underlined keywords as they would be useful when revising for tests and examinations. For example, in lesson one, after putting definitions on the screen via his PowerPoint, Tony asked students to take notes and then said “make sure that if it is bold [on the

screen] you underline it, so you can see if when you want to do revision” (Tony, first lesson, pre-CoRe design).

While assessment influenced Tony’s practice, he also talked about his ideal situation. If able, Tony wanted to move away from teacher-centered and assessment-driven teaching to student-centered work where students develop scientific skills. For instance, when asked about students acting as scientists he sighed and said that his goal for science education “was about an ideal world” and if he could do it differently, “kids would be able to have a big question and do things to answer the big question... I like that idea of self-directed learning and looking for stuff” (Tony, initial interview). However, to actually achieve such pedagogy, Tony, in his interview, took a long pause, sighed, and said “... it comes back to a time limitation to be honest, and then how do you measure how successful it is? How do you tell if they’ve learnt something?” (Tony, initial interview).

4.6.2 Inductive Themes from David’s Data

Examining the analysis of David’s overall Phase One data, there were no emergent themes in addition to those covered by the deductive analysis. However, there was a theme that emerged from his interview that could be attributed to the deductive framework, that is, his conflict about the purpose of teaching science.

He knew what he wanted to achieve and how, but was limited by the school context, particularly assessments. Throughout his interview, there were many pauses, sighs, and laughter when he spoke about teaching science in way that aligns with literature about being scientifically literate. For example, when asked about students acting as scientists, he laughed and said “in a lot of ways we suppress that” (David, initial interview). He revealed that while students should act in that way, “it is very difficult to do that” (David, initial interview). He acknowledged that if students were encouraged to work in that way, and were to do “absolutely valid stuff” it was not necessarily reflected in their reports about their learning because “we test content” (David, initial interview).

4.6.3 Inductive Themes from Alan's Data

The overall analysis of Alan's Phase One data also revealed no emergent themes to those covered by the deductive analysis. Like David's data, there was another theme that emerged from his interview and observational data that fell within the deductive framework. Alan placed large emphasis on students relating scientific concepts to everyday occurrences and phenomena. For example, when his philosophy of teaching science was explored, he alluded to this point twice when he said "science is everywhere. The fact that you can relate it into aspects of everyday life" and "the content is everywhere. You see it every day... it helps the students daily" (Alan, initial interview). Throughout the interview, Alan referred to learning about concepts related to everyday experiences five more times.

This theme of linking science concepts to everyday occurrences that students could relate to was also apparent in three of Alan's lessons (Alan, first, second, fourth lessons, pre-CoRe design). While the examples he did use were useful, there were times where further explanation would have aided student understanding. For example, further elaboration on his lightning example when teaching static electricity would have been useful to enhance student understanding (Alan, second lesson, pre-CoRe design).

4.7 Chapter Summary

This chapter has presented the research findings from Phase One of this study to generate an initial understating of Group One participants' pPCK and ePCK prior to taking part in CoRe design. Contextual information about the school and all of the participants in this study was also presented here, which was obtained from the schools ERO (2014) report and participants' initial interviews. During this first phase, Group One participants took part in individual semi-structured interviews to explore their initial pPCK, and were also observed as they taught Year 10 *Electricity and Magnetism* to their pre-CoRe design class to explore their initial ePCK. Their pPCK and ePCK findings were then compared to identify links and/or dissonance. The findings for each teacher have been presented separately to allow for cross-case comparisons.

The following chapter presents the findings from Phase Two of this study.

Chapter Five

Phase Two Findings: CoRe Design

Workshops as Professional

Learning and Development

Interventions

5.1 Overview

This chapter contains data obtained from Phase Two in this study, where collaborative content representation (CoRe) design workshops were used as professional learning and development (PLD) interventions. Information is presented in three sections: Section 5.2 provides brief contextual information about the two workshops; Section 5.3 presents the data from the nature of science and scientific inquiry CoRe design workshop; and, Section 5.4 presents the data from the Year 10 *Electricity and Magnetism* CoRe design workshop. The researcher acted as an announced participant (see Figure 3.3 on Page 122) in both workshops. All discussions were audio recorded and the researcher took detailed field notes. This data was analysed and presented in a similar way for both workshops, as detailed in the following sections. Lastly, there is a chapter summary.

5.2 Contextual Information of CoRe Design Workshops

As mentioned in Chapter Three, three Working Groups of participating teachers were created for the CoRe design workshops. Table 5.1 reshows the membership of the Working Groups and the original group of each participant.

Table 5.1: Membership of the Working Groups for CoRe design, and participants' original group.

Original Group	Working Group One	Working Group Two	Working Group Three
Group One	Alan	Tony	David
Group Two	Lucas	Harry	Kate
Group Three	Chris	Nick	William

Both workshops were held on-site at River High School. Since the intent of the CoRe design workshops was to enhance Group One teachers' pedagogical content knowledge (PCK) for Year 10 *Electricity and Magnetism*, the workshops needed to occur between their two Year 10 science classes for comparison purposes. After

consultation with school management, participants, and the CoRe design facilitator, the workshops were scheduled at a time to suit all parties. The first workshop was held in a classroom while the second one was held in a physics laboratory so specialised equipment was available if needed. Both workshops ran for approximately three hours with a short break halfway through.

All resources (e.g., stationery) were provided to the participants during the workshops and they were run by an external facilitator, Sarah (pseudonym). Sarah discussed the process of the workshop at each event, organised the participants, and ensured they kept to a schedule. At the end of the workshops, participants shared information and then handed their completed work to the researcher. Participants were also asked by Sarah to share their experiences and impressions of the workshops. CoRes were collated, typed, and sent to all participants to ensure accuracy.

5.3 The Nature of Science and Scientific Inquiry CoRe Design Workshop

The nature of science and scientific inquiry CoRe design workshop was a pilot workshop to introduce all participants to CoRe design. The desired outcome was participants' familiarity with the language, prompts, and process of CoRe design, rather than production of a CoRe for the nature of science and scientific inquiry topic. Prior to the workshop, Sarah had prepared a PowerPoint presentation, to guide the participants through this initial workshop, and several handouts for each of them (see Appendix E).

The first stage in analysing data from this workshop involved describing and narrating the initial interactions that took place and how the process was completed. These descriptions are below in Sections 5.3.1 and 5.3.2 and include how Sarah introduced the workshop and how participants: engaged with the process; identified appropriate concepts and big ideas; and, then completed the CoRe template. Further analysis was done using an inductive approach to identify recurring ideas and discussion points during the workshop, which is reported in Section 5.3.3.

5.3.1 Initial Interactions

After welcoming the participants, Sarah talked briefly about the study they were taking part in, and asked them what they thought PCK meant. Nick responded:

PCK refers to knowing how to teach.

(Nick, first CoRe design workshop)

Building on Nick's response, Sarah identified PCK as an outcome the work by Lee Shulman to do with professionalising teachers in the 1980s, and how it was identified as one of seven professional knowledge categories that teachers possess. In addition to Nick's comment, Sarah stressed that PCK distinguishes teachers from other professions, using the example of a chemist versus a chemistry teacher. After this initial PCK discussion, Sarah turned the focus onto capturing and representing PCK, and CoRe design (field notes, first CoRe design workshop).

Using her PowerPoint presentation, Sarah talked to the participants about the development of CoRes as a tool to represent expert teachers' PCK in a way that would be practical and useful for new/inexperienced teachers. Sarah also talked briefly about pedagogical and professional experience repertoires (PaP-eRs), but added that they are not part of this study. At this point in the workshop, Sarah gave the participants a blank CoRe template and a completed CoRe as an exemplar (see Appendices E2 and E3). Using these handouts and the PowerPoint, Sarah facilitated a discussion about each pedagogical prompt to ensure participants understood their meaning and intent. She also highlighted the use of CoRe design by other researchers in science education, the impact that it can have on developing teacher knowledge, and how CoRe design is situated in this study. After approximately 30 minutes of discussion around PCK and CoRe design, the workshop focus shifted to the context of the nature of science and scientific inquiry as a unit of work for junior science (field notes, first CoRe design workshop).

Using the article that the participants were asked to read prior to the workshop as a reference (i.e., N. G. Lederman et al., 2014), Sarah explained that the nature of science refers to knowledge in science, and scientific inquiry refers to processes in science. After giving the teachers some further information about these terms, the participants were then asked to complete the Views about Scientific Inquiry (VASI)

questionnaire (see Appendix E4) to promote further thinking and discussion. After 10 minutes, Sarah facilitated a discussion about the different questions, where participants offered their ideas and debated others. For example, there was lively debate about using empirical data to make conclusions when addressing question six of the questionnaire about plant growth and sunlight, and the difference between evidence and data (field notes, first CoRe design workshop).

The next stage of the workshop involved participants working collaboratively to identify the big ideas that students should learn, and then completing the CoRe document. For this process, Sarah organised the participants into their three Working Groups.

5.3.2 Completing the Process

In their individual Working Groups, Sarah asked the participants to brainstorm concepts and skills that they thought were important for Year 9 students to learn about the nature of science and scientific inquiry. All Working Groups were provided with relevant information from the New Zealand Curriculum (NZC) document (Ministry of Education, 2007) and information from the school's current unit plan that specifically focused on the nature of science and scientific inquiry (see Appendices E5 and E6). While the participants worked to identify relevant ideas, Sarah moved around the room and assisted participants when required (field notes, first CoRe design workshop).

During this task, participants found it difficult to identify key concepts and ideas about the nature of science and scientific inquiry for teaching students. They had confused the task that Sarah had given them with other CoRe prompts, such as discussing *how* they would teach students about the nature of science and scientific inquiry rather than identifying content (field notes, first CoRe design workshop). However, Sarah was able to effectively guide discussions to encourage participants to write down some concepts and skills that they saw as being important.

For example, as part of their concepts and skills they wanted students to learn about, the Working Groups identified:

Be able to scientifically discuss what they observe.

Explain their observations.

Science is a way of explaining the world.

(Alan's Working Group, first CoRe design workshop)

Develop questions, data collection methods, and collect data.

Identify variables in an experiment.

Research information and judge the quality of information.

Scientific knowledge has changed over time.

(Tony's Working Group, first CoRe design workshop)

Identify relationships between variables.

Make observations, gather data, and process data.

Develop conclusions from their experiments and incorporate science ideas.

Critically analyse information.

(David's Working Group, first CoRe design workshop)

Once participants had discussed and identified what they saw as some important concepts and skills, Sarah facilitated a whole group discussion. To support this discussion, she made available relevant sections from the NZC on the screen for all participants to see. She read through each nature of science Achievement Objective and discussed its purpose. Included in this discussion was the need for scientifically literate citizens, not necessarily scientists, but people who can make informed decisions about issues that are scientifically related or informed by science. The discussion concluded with Sarah asking the participants (after teaching a unit based

on the nature of science and scientific inquiry) what knowledge and skills they wanted the students to walk away with (field notes, first CoRe design workshop).

For the sake of efficiency, so each Working Group was able to experience filling in the CoRe template, Sarah modelled, with the assistance of the participants, the construction of the big ideas. Using the concepts that the participants had identified as a basis, Sarah carefully and purposefully used probing questions to help the group arrive at five big ideas:

1. *Scientific knowledge changes over time.*
2. *Scientific knowledge is useful/essential for our continued existence.*
3. *Science makes the natural and man-made world understandable.*
4. *Scientists use systematic approaches to scientific inquiry using a variety of methods.*
5. *Scientists use specialised language/terms to describe ideas, objects, and processes.*

(Collective big ideas, first CoRe design workshop)

As individual Working Groups, participants started completing their CoRes using these big ideas. During this phase of the workshop, Sarah moved around the different groups to guide discussions and assist with addressing the CoRe prompts. Filling in the CoRe continued for approximately 30 minutes, then Sarah asked for participants to share their work and their experiences with CoRe design in the whole group forum (field notes, first CoRe design workshop).

Since there were discussions at the beginning of the workshop about PCK, CoRe design, the nature of science, and scientific inquiry, the time allowance for actually completing the CoRe was limited. Thus, the Working Groups were only able to partially fill in their templates. These partially filled templates were submitted to the researcher who collated them and distributed the copy to participants to ensure accuracy. This collated CoRe can be found in Appendix G1.

Throughout the three-hour workshop there were many discussions and exchanges between participants as they worked collaboratively; both within their own Working Group and as a whole group. The following section identifies themes that were apparent during these conversations.

5.3.3 Emergent Themes from Workshop Discussions

When reviewing the transcripts of the discussions, there were two overarching themes that became apparent over the entirety of the workshop. The first was *teaching concepts that are relevant to students' lives*, while the second was *how the contextual influences of the school impacts teaching students about the nature of science and scientific inquiry*. There were also smaller themes that characterised each individual Workshop Group discussion, which are also described below.

Relevance was discussed separately within all three Working Groups, and also together as the larger group. The theme centres on how students need to have an understanding of the nature of science and scientific inquiry in order to make informed decisions about issues that may affect them. For instance, William said:

It would be good if people were more scientific, in my opinion. For example, vaccinations. You've got people who have got no understanding whatsoever of the concept that, if there is 95% coverage of the population, that particular microbe won't take off. So that 5% who don't get inoculated, they think whatever system they've got is working. They've got no scientific understanding of that.

(William, first CoRe design workshop)

Vaccines, as an example of making informed decision, was frequently used throughout the workshop by Sarah and the participants.

Expanding on this theme, participants advocated that students had an understanding about the tentative nature of scientific knowledge, and that it can change as new discoveries are made, especially with the input of new technology. For example, in his Working Group, David expressed the view that this concept is particularly important so people can feel comfortable with scientific knowledge, and that it can change. He reasoned:

I think that is important [that students recognise scientific knowledge can change] because they are going to strike that. They are going to be reading the newspaper, or trying to understand something, they are going to find that scientific knowledge has changed. If they haven't

already seen that acceptable, that it is not dangerous or a problem, then it is much easier to cope with: one, the fact that there is new stuff; two, this may not be the final answer... As adults, they will be exposed to a lot of science, if they're comfortable... If they have a little understanding of what is going on, they don't have to be doing it specifically, but they have to live with it.

(David, first CoRe design workshop)

A specific instructional strategy that was raised independently by all three Working Groups for teaching students the concept of tentative knowledge was the development of the atomic model (e.g., Thomson's Plum Pudding model compared to Rutherford's model). In their Working Group discussion, Nick also mentioned that scientific laws are better described as being approximations, and used the example of Newton's Laws. He explained:

They're an approximation. When you do relativity, they don't work.

(Nick, first CoRe design workshop)

The second theme that emerged from the transcripts was the influence of the school context, particularly assessment, on their teaching. Again, this theme was apparent in most of the discussions. However, in the transcript from David's Working Group discussion, there is no explicit mention of context as they were more focused on the concepts and skills to teach students, and how to teach them. Nevertheless, the issue of context was raised by Kate during the whole group discussion when the participants were talking about how science courses had been developed.

This theme highlights that the teachers acknowledge there are a lot of relevant and useful concepts to teach students about the nature of science or scientific inquiry, as discussed within the earlier theme, however, the consensus from the group was that actually teaching students these concepts was unachievable. For example, at River High School, junior science is only taught three times per week (Harry, first CoRe design workshop). The participants explained while some concepts such as the tentative nature of scientific knowledge or skills for carrying out experiments

were important, they did not have time to teach it. Although, during their discussion about this contention, when Chris stated that he “just teaches his field” rather than teaching about the nature of science or scientific inquiry, Lucas was quick to comment “teaching some of these concepts just comes out naturally during the lesson, whether it is planned for or not” (Chris and Lucas, first CoRe design workshop).

During the discussion about junior science classes only occurring three times per week, Harry said that issue was raised by a former senior manager whose position was overseeing the teaching and learning in the school. Harry recounted the specific comment made by this manager as “how you can do all the quality teaching required in only three periods?” In response, Harry explained that changing the structure had been discussed at a senior management level within the school but commented “it is not going to happen” (Harry, first CoRe design workshop).

Discussing the influence of assessment on teaching, Nick described how it influenced his practice:

You end up just banging through the content as fast as you can to get through the test. Then onto the next topic, and same again.

(Nick, first CoRe design workshop)

The influence of assessment also featured when the whole group was discussing how to teach the big ideas. When they were first brought together to share concepts and skills, Chris immediately highlighted this influence, saying:

I think when we are looking at a junior curriculum, we always keep NCEA Level One in mind. We are driven by assessment. Not that I think it is the right thing, but we are driven by assessment.

(Chris, first CoRe design workshop)

This comment led to a discussion of how the junior science programme at River High School was created. Kate commented:

The courses seem to be set on looking at Level Two [NCEA] and then going back to Level One.

(Kate, first CoRe design workshop)

Harry responded:

When the Level One course was first designed, that's how it was done. They looked backwards rather than forwards.

(Harry, first CoRe design workshop)

The participants went on to discuss how there are NCEA assessments which could be related to aspects of the nature of science or scientific inquiry, such as those where students can carry out research and write an informed response to address a socio-scientific issue, or carry out practical investigations. However, Nick said that many of these assessments were not used in the senior school because it would mean “more internal NCEA assessments”, and he indicated the school did not want to do more of these (Nick, first CoRe design workshop).

In addition to these two main themes from the workshop, each Working Group had their own theme that guided their individual discussions. Below are descriptions of these.

Working Group One's conversation was guided by the theme of *students' prior knowledge and possible misconceptions they might have*. Alan stated that all students “have limited prior knowledge” and Lucas added that teachers need to “access that information”. Within this discussion, Alan also talked about identifying misconceptions, which Lucas followed up with “acknowledging and utilising prior knowledge” and then “correcting misconceptions” (Alan and Lucas, first CoRe design workshop). Chris observed that sometimes teachers intentionally use misconceptions to explain difficult concepts, which then need to be corrected later on when they become senior students.

Working Group Two's conversation was somewhat guided by *the influence of popular media on students* (e.g., television or the internet). In relation to the theme of relevance, their thinking centred on the idea that if students did not have the skills to think critically and could not make informed decisions, then the media heavily guided their understanding. During these interactions, the ideas of controlling variables and ensuring the data was valid and reliable were discussed. For example, Nick talked about "headline grabbing" articles in the media where they "haven't controlled their variables" (Nick, first CoRe design workshop). Tony responded:

[Students need to] *critically analyse to see if it's true or not. The media is so powerful. If they want something to be in the news, it will be.*

(Tony, first CoRe design workshop)

Harry offered the following example:

They were talking about wind propellers in America and that 36,000 birds died as a direct result of them. What they didn't tell you is that one billion birds get eaten by cats. 36,000 sounds like a lot, but in context, it's not that many at all.

(Harry, first CoRe design workshop)

Tony mentioned out that students can also have views and opinions shaped by their parents:

Students come in with preconceptions that their parents have as well. You know, if Dad says something, junior believes it.

(Tony, first CoRe design workshop)

Working Group Three's conversation revolved around the idea of *engaging students in science, particularly using more practical work*. During their discussion, William offered detailed explanations, and often used examples and experiences from his extensive teaching career. For example, on the topic of teaching scientific inquiry, William argued that first and foremost students need "to enjoy it", which

he felt could be achieved by “using simple experiments” (William, first CoRe design workshop). Reflecting on his experience, William said:

We used to get students to do about half a dozen simple experiments; like investigations. They had to write down what they observed. The students loved doing it. Just heating things, they loved it... What you want is a series of simple experiments designed to just test how good they are at observing... So number one, there should be an experiment designed to allow people to do simple experiments, and at the same time they enjoy them.

(William, first CoRe design workshop)

David and Kate both agreed with William’s points about students enjoying science and doing practical work.

5.4 Electricity and Magnetism CoRe Design Workshop

The Year 10 *Electricity and Magnetism* CoRe design workshop was held one week later. Again, Sarah had information prepared for the workshop. However, this workshop was now more focused on producing a CoRe rather than providing participants with extensive information about CoRe design and the nature of science and scientific inquiry. So, brief instructions were written on the whiteboard rather than using another PowerPoint presentation. The handouts were similar to those from the previous workshop, with the addition of topic specific information such as River High School’s current *Electricity and Magnetism* unit plan, and the NCEA Level 1 Achievement Standard for Year 11 *Electricity and Magnetism* (see Appendix F).

Analysis of this workshop was done in a similar way to the first. The initial stages of analysis involved describing and narrating the initial interactions that took place between participants and how the process was completed. An inductive approach was utilised again to highlight themes via recurring ideas and discussion points in the data. Further to this analysis, a deductive approach was also used to highlight instances of PCK development for Year 10 *Electricity and Magnetism*. For this

deductive analysis, the themes identified earlier from the RCM of PCK were used. The following sections provide information from the initial interactions, how the process was completed, themes that emerged from the data, and evidence of PCK development.

5.4.1 Initial Interactions

Like the first workshop, Sarah started the proceedings by asking a question: Can anyone explain what they think PCK is, based on what was discussed last week? Initially the participants were quiet, but Tony offered a response:

Knowing the subject, and how best to teach it.

(Tony, second CoRe design workshop)

Sarah asked Tony to elaborate further and he explained:

Knowing different topics and different approaches, such as: students, content, and where they 'fall down'.

(Tony, second CoRe design workshop)

Sarah built upon this response by establishing that PCK is unique and different for each teacher. She then linked this PCK discussion back to CoRe design by expressing that a CoRe is an attempt to capture collective PCK (cPCK) of a group, which may be different from another group. She also reiterated the powerful nature of collaborative CoRe design in that it brings together professional knowledge, and identified some of the positive outcomes of CoRe design research to date.

Sarah directed the participants' attention to the whiteboard where she had written some points for them to consider, which is shown on the following page.

CoRe Design – Year 10 Electricity and Magnetism

Intent today: To collaboratively build topic specific professional knowledge for Year 10 *Electricity and Magnetism*.

- Possible resources? What resources would be useful?
- Brainstorm appropriate concepts and skills.
- Establish big ideas.
- Complete CoRe – share professional knowledge (at the end).

(Field notes, second CoRe design workshop)

After addressing the whiteboard, participants were tasked with working collaboratively within their Working Groups (which were the same as the previous workshop) to identify the concepts, ideas, and skills they wanted students to learn. This phase of the workshop started much earlier than the pilot workshop (field notes, second CoRe design workshop).

5.4.2 Completing the Process

Working Groups began writing their thoughts on small pieces of card that could be collated with those from the other groups at a later time. While attempting this task, participants identified the vague nature of the phrasing used in the NZC as problematic. For example, in their Working Group, Harry read the Achievement Object aloud and Nick commented “yeah, it’s general” (Nick, second CoRe design workshop). As Sarah assisted groups individually, she reiterated that one of the purposes of using CoRe design in this way was to unpack the Achievement Objective and identify specific concepts and skills they wanted students to learn. During this identification of concepts phase, Group Three teachers were observed to lead the discussions in all three Working Groups (field notes, second CoRe design workshop).

After 20 minutes, Sarah called for participants' attention to explore what concepts, ideas, and skills they had identified. Each Working Group was asked to share some of their thoughts with the goal of identifying common ideas. During this part of the workshop, David commented:

In our discussion, we brought up there are some things to include because these kids are going to be confronted with them at Year 11, and having a bit of a primer the year before gives them an advantage. But, there are other things that we discussed that may in fact do the opposite. That having them brings in some confusion and some unintended learnings in Year 10. We may be doing more harm than good in some areas.

(David, second CoRe design workshop)

Segueing from David's comment, Sarah decided to read each piece of card aloud and participants discussed and voted whether they saw it as being appropriate for Year 10 students. This technique generated plentiful discussion around what each participant saw as being important. Once arriving at a consensus about concepts to be included, Sarah modelled for the participants how to construct their big ideas as a propositional statement (i.e., a statement with a *noun* and a *verb*). She used the example of: *matter is made of tiny particles*. Each Working Group was then tasked with identifying what they saw as the big ideas for teaching Year 10 *Electricity and Magnetism* (field notes, second CoRe design workshop).

Working Groups wrote their big ideas on small pieces of card. This technique was employed again so they could be collated with the other groups when they had all finished this task. In this manner, participants could discuss each big idea to ensure a consensus was obtained.

The big ideas that Working Group One, Two, and Three identified respectively were:

1. *Electric current is the flow of charge from high energy to low energy.*
2. *Voltage is the difference that causes electrons to flow.*
3. *Ohm's law is the relationship that exists between current, voltage, and resistance.*
4. *Resistance is a measure of how easy/hard for electrons to flow through a conductor.*
5. *The current flowing through a wire produces a magnetic field.*
6. *Magnets – the magnetic field for a bar magnet and for Earth.*
7. *Static electricity is the separation of charge through friction.*

(Alan's Working Group's big ideas, second CoRe design workshop)

1. *Voltage is the difference in energy between two points.*
2. *Magnets produce magnetic fields which exert a force on other magnets.*
3. *Rubbing materials together can lead to separation of charge.*
4. *Current is the flow of charge.*
5. *Wires are full of charges and they all move, or none move.*
6. *Charges produce electric fields which exert a force on other charges.*

(Tony's Working Group's big ideas, second CoRe design workshop)

1. *Electric current is the flow of electrons in a circuit.*
2. *Make practical applications of simple circuits.*
3. *Voltage is the potential difference.*
4. *Able to build simple electrical circuits.*

(David's Working Group's big ideas, second CoRe design workshop)

Each Working Group shared their big ideas in the whole group setting with the goal of identifying between five and seven big ideas that reflected the whole group's

collective thoughts. Using this information, and input from the participants during the discussion, Sarah helped them to construct seven big ideas to be used for completing the CoRe design process:

1. *Charges produce electric fields which exert a force on other charges.*
2. *Current is the flow of charge.*
3. *Voltage is the difference in electrical energy between two points.*
4. *Ohm's law is the relationship between current, voltage, and resistance in a closed circuit.*
5. *Circuit diagrams are representations of electrical circuits.*
6. *Electrical circuits can be constructed to solve problems*
7. *Magnetism is another effect of moving charge.*

(Collective big ideas, second CoRe design workshop)

A goal of this study was to investigate the usability of CoRe design as a PLD intervention with practising teachers. So when the participants suggested to Sarah that the most efficient way to complete the process was to share the addressing of the seven big ideas amongst the three Working Groups, she acknowledged the suggestion and the design process went in this direction (field notes, second CoRe design workshop). The seven big ideas were shared amongst the groups as following:

- Tony's Working Group: Big Ideas 1, 2, and 3
- Alan's Working Group: Big Ideas 4 and 5
- David's Working Group: Big Ideas 6 and 7

The Working Groups then began completing their CoRes. Throughout this phase there were many discussions and again, there was significant input from the Group Three teachers. To exemplify this finding, in Alan's Working Group, Chris (Group Three Teacher) had to leave for a brief period of time (five minutes). During this period, there were many awkward pauses between Lucas and Alan as they tried to address different prompts, and Lucas took the lead in the conversation until Chris

returned. On re-joining the Working Group, Chris again took the lead in guiding their discussion (field notes, second CoRe design workshop).

After approximately one hour of addressing the CoRe prompts for their particular big ideas, the Working Groups were asked to share extracts from their CoRe documents with the others. The three partially-completed CoRe documents were then submitted to the researcher who collated the information and distributed copies to each participant to ensure accurate collation and so that the Group One teachers had a copy for planning purposes. The completed CoRe document can be seen in Appendix G2.

Like the first CoRe design workshop, there was much discussion and exchanging of ideas between participants as they worked collaboratively; both within their own Working Group and as a whole group. The following section identifies themes that became apparent during these conversations.

5.4.3 Emergent Themes from Workshop Discussions

The transcript data from the workshop revealed three emergent themes: *how to explain concepts and phenomenon to students; which concepts should be prioritised; and, the influence of school context, including assessment*. Each of these themes is now discussed in more detail.

As an emergent theme, explaining concepts and phenomenon to students, encompassed three sub-themes: *accuracy of explanations; teaching students underlying principles as opposed to definitions and rules; and, simplifying complex concepts, but not to the point where they are wrong*.

Firstly as a sub-theme, all the Group Three teachers promoted accuracy in how physical phenomenon should be explained. For example, during their discussion about static electricity, Lucas referred to “isolating charges”, to which Chris emphasised to Lucas and Alan that rather than isolating charges, you in fact “separate charges”. When challenged by Lucas about there being no difference in the phrasing of these descriptions, Chris explained that using charge separation is more accurate and it also helps with explaining voltage. Lucas accepted this clarification and indicated that he would change his explanation in the future (Lucas and Chris, second CoRe workshop). Similar examples of the Group Three teachers

inputting their expertise on this sub-theme were seen in the other discussions such as William addressing voltage sharing in circuits, or Nick discussing flow of charge.

As a second sub-theme, Group Three teachers also promoted to others the value of teaching students about the underlying principles of the concept, rather than just simply teaching students definitions or rules. For example, early in their discussion about what concepts to teach students, Tony suggested “definitions of current and voltage”, to which Nick replied “it’s not definitions. It’s understanding of what it actually is” (Tony and Nick, second CoRe design workshop). Later in their group discussion, Nick used the example of teaching students about the conservation of energy to explain voltage and current in a circuit, rather than simply rote learning voltage and current rules for series and parallel circuits (this information is reported in more detailed in Section 5.4.4.1). Other examples of this focus on underlying principles from different groups include Chris discussing how to teach the principles of resistance, or William discussing why multimeters are connected in different ways according to what they are measuring, rather than just giving a set of rules to memorise.

The third sub-theme, which is related to the previous two, was an agreement amongst all participants that all science teachers should strive to explain difficult concepts in a simplified way, rather than a ‘wrong’ way which may cause issues later in their education. For example, the participating teachers discussed teaching voltage to Year 10 students. All of the Group Three teachers acknowledged that voltage is a difficult concept to explain to junior students, which then turned into a debate during the whole group discussion about how to actually approach it. All of the Group Three participants contributed to this discussion and offered their approaches and rationales for teaching in this way. The following exchange between Chris and Nick, which occurred during the whole group discussion, illustrates this type of contribution.

Nick: *The voltage difference doesn't make electrons flow. It's the electric field that you get from the separated charges that makes them flow.*

Chris: *For Year 10, Nick?*

Nick: *Yeah I know.*

Chris: *What do you want them to know?*

Nick: *What I am trying to say is, what I am always conscious of is trying to teach a simplified version, not a wrong version. I remember when I was at school, and being taught this is how atoms are in Year 9, then is Year 10, no that was wrong, this is how they are. Then in senior chemistry, actually that was wrong, this is how they are. So I am always teaching my kids this is a simplified version of the thing. It is more complicated than this. But, I am not saying this is how it is, and next year actually that's not how it is, it is more complicated. Because I do not believe in lying to them.*

(Chris and Nick, second CoRe design workshop)

The outcome of debating exactly what voltage means resulted in five ideas, including voltage is: a push, energy per unit of charge, work done per unit of charge, a result of separated charges, and the energy difference between two points. This discussion concluded in that teaching voltage in a simplified way is recommended such it can be built on in subsequent years.

Kate added that a difficulty with teaching this concept lies in terminology. She explained:

The problem that I have is that the terminology changes. So then you get to potential difference versus voltage, and I struggle with that. Here I've taught them something about voltage, then here I really want them to understand potential difference.

(Kate, second CoRe design workshop)

Nick asked Kate what her understanding of the difference was between these two terms, which she did not answer. Then, William explained that they can mean the same thing, or they can mean different things, depending on the situation. To further his explanation, he drew some diagrams on the whiteboard to show how he teaches voltage to his students (this event is reported in more detailed in Section 5.4.4.2). Later, in their Working Group, William reiterated to Kate and David that the term

voltage can be interpreted in more than one way, and it is the context that determines the correct interpretation.

The consensus after the ‘best way to explain voltage’ discussion (voltage was one of their big ideas for the CoRe for Year 10 students), was that voltage is the difference in electrical potential energy between two points.

Another means of explaining information in an understandable way, is through the use of analogies and models. While analogies and models are useful for representing difficult and abstract information to students (see Chapter Two, Section 2.3.3), all Group Three teachers were quick to comment that their use can cause issues when the students take senior physics. For example, when Tony suggested using an analogy for teaching electrical current, Nick stated:

There is danger in using analogies. It is very easy to create strong misconceptions when you use analogies. Very easy.

(Nick, second Core design workshop)

To emphasise his point, Nick used an example from his own teaching practice where a student failed to make the link between the analogy (trucks carrying coal) and the principle being taught (voltage: energy per unit of charge). As a result, the student referred to voltage as dumping coal in an assessment (Nick, second CoRe design workshop). Similarly, Chris told his group that models can cause misconceptions and that it’s the teacher’s role to “choose models carefully” to aid with their understanding now, but not create issues for their education later on (Chris, second CoRe design workshop).

The second of the three themes to emerge from the data concerned which concepts and ideas should be prioritised. This theme also encompassed three sub-themes which are all very closely related: *make the learning relevant to students’ lives*; *teaching concepts so they can be built on in following years*; and, *teaching less content, but more thoroughly*.

The first sub-theme, making concepts relevant to students’ lives, highlighted participants’ personal philosophy for teaching science, and it was mostly raised by the Group One teachers. For example, when discussing which concepts should be

taught to Year 10 students in this unit of work, one of Alan's first comments was "I do a lot of everyday situations" (Alan, second CoRe design workshop). Similarly, David wanted to include concepts of societal and political interest into the unit, saying:

It doesn't relate to the Achievement Standards [for NCEA], but I want to see more emphasis on alternative generation and see our students develop ideas with regards to alternate sources of electricity. I think it is important politically and socially. It is not obviously important in terms of them passing Achievement Standards... It's an interesting one.

(David, second CoRe design workshop)

Tony's thinking about which concepts should be taught was influenced by assessment, as shown by this exchange in his Working Group:

Nick: *Should we teach electricity generation?*

Tony: *But there is nothing on the test.*

Nick: *But do you think you should do it? Do you think it would be useful for the kids?*

Tony: *I think it would be useful to spend a lesson on it.*

Harry: *I think so. It is a large part of our everyday lives.*

(Nick, Tony, and Harry, second CoRe design workshop)

While relevance was emphasised by Group One teachers, there was also mention of this sub-theme from the others. For example, Chris and Lucas offered practical applications of variable resistor use that students can relate to (dimming lights and volume control), and Kate talked about applications of series and parallel circuits in homes. However, the input from the Group Three teachers was more focused on concepts that can be built on in future years, which was identified as the second sub-theme within this theme.

Examples from the data to support this second sub-theme include Nick wanting to introduce electric fields, in a simplified way, to Year 10 students. While he

acknowledged that it was a difficult concept, he expressed that it was crucial to have some understanding of electric fields at this stage, particularly for senior physics. Likewise, Chris wanted to include teaching students about metallic lattice structures. Again, he acknowledged that it was a difficult and abstract concept, but if students were able to understand it then it helps with teaching concepts such as conduction, resistance, and conventional current at later levels of schooling. In another group, William discussed teaching students particular concepts in a particular way so when they arrived in senior physics, some concepts “could be assumed” without having to spend time recapping what they are and correcting misunderstandings (William, second CoRe design workshop). To illustrate his argument, William posed a circuit diagram question to both Kate and David. While both of these teachers provided the correct answer, William reported that when he asks his senior students the same question it often polarises the class into two groups.

At the conclusion of their Working Group discussion, Lucas commented about the Group Three participants’ perspective during workshop activities. There was no elaboration from other group members after Lucas made this comment as they departed the venue.

It is the luxury of having a physics background. What they [Group Three participants] are doing, they've got their extensive Level Two and Level Three [NCEA] knowledge that they are bringing down to this, and they're simplifying that in a way that... They're thinking about building on ideas for Year 12 and 13 physics, so the seed is being planted.

(Lucas, second CoRe design workshop)

This second theme also encompasses the suggestion to reduce the number of concepts in the junior science programme. Initially William suggested:

All I would want for my Year 10s is for them to learn certain things well, as opposed to trying to learn too much. All of this is what they need ultimately, but in the time space that you have to teach Year 10, they don't get it.

(William, second CoRe design workshop)

His comment became a crucial discussion point as the participants debated appropriate concepts as a group, facilitated by Sarah. For example, David argued that some concepts can act as a “primer” for later years, while others have the opposite effect and bring about “confusion and unintended learning” which actually does “more harm than good” in some cases (David, second CoRe design workshop). This comment prompted Sarah to employ the technique of voting for the inclusion or not of different concepts, which was described in Section 5.4.2.

The third emergent theme featured how the school context affected which concepts should be taught, and how they are delivered. This theme encompassed two sub-themes: *the influence of assessment*, and *the administration of junior science*.

When identifying skills and concepts to be included in the Year 10 *Electricity and Magnetism* topic, participants referred to the NCEA Achievement Standard more than the NZC (field notes, second CoRe design workshop). Each Working Group concurrently discussed how assessment in Year 11 actually governed which concepts were taught. For example, following on from earlier comments about teaching students about generating electricity, Tony told his group:

I find myself spending a lot of time on Ohm's law and going over how to calculate current or resistance, or voltage using those rules... If we are going to have something on it in the test then I would do it. But, there is nothing to do with generation in Level One as well. So I am not saying it's not good, it would be nice to have.

(Tony, second CoRe design workshop)

Similarly, Chris commented in his group that one of the issues with teaching this topic at his school is a short amount of time available before a test:

It would be nice to have a little programme where they can pick components and make circuits, and if they did it right the little light comes on or something, stuff like that. There is some good stuff, but time is difficult. It is one of the worst things in terms of teaching this, the fact that you are constricted by time. You have to finish it, then sit a test.

(Chris, second CoRe design workshop)

In another instance, William and Kate had a wider discussion about the value of doing practical work with students, but how it is often overlooked because it is not assessed. Kate used an example from her senior chemistry classes where “in chemistry, we don’t do practicals, and even if you do, you don’t have time to discuss it” (Kate, second CoRe design workshop). William added:

I have colleagues, who will say to themselves, who will say that the most important thing for them to do is to get students through the exams, because that is what they are judged by. Therefore, they put an emphasis on finishing the course [rather than practical work].

(William, second CoRe design workshop)

This sub-theme of assessment influencing the teaching of science links closely to the other sub-theme of the administration of junior science.

The earlier issue of science at River High School being taught only three periods per week was raised again in discussion. In addition, the size of the school roll was mentioned, and how class sizes can be large and some science classes ‘miss out’ on being timetabled to an appropriate science laboratory because there are not enough available. When reviewing all of these discussions from the workshop, the overarching idea was that these teachers expressed the administration of junior science meant they did not have enough time to teach concepts effectively. For example, when Sarah first brought the participants together to discuss appropriate concepts to teach, Chris said:

Time will determine. It is always the big thing, how many periods we see them. It is determined by time. When we get down to the specific learning outcomes that cannot be an infinite list. It has got to be related to the time to teach this programme.

(Chris, second CoRe design workshop)

On another occasion, when discussing how to teach students to make circuits, Lucas and Chris agreed the science department was sufficiently resourced. However, it was not easy to engage with their students effectively when making circuits because

their time was spent troubleshooting mundane issues (e.g., equipment not working) or students misbehaving. Similar conversations about time constraints were had by the others.

The themes and sub-themes identified in this section emerged from the data. The data was also analysed deductively using RCM of PCK as an analytical lens to identify evidence of PCK development which is reported in the following section.

5.4.4 Evidence of PCK Development

For this deductive analysis, the five themes from the RCM of PCK identified in Chapter Three were used to highlight instances of PCK development. These themes are: subject matter knowledge, knowledge of curriculum, knowledge of students' understanding and learning, knowledge of topic-specific instructional strategies, and knowledge of assessment strategies. The other two themes, that is, personal philosophy for teaching science and self-efficacy, used earlier in analysis, act as amplifiers and filters on those knowledge forms, so they were not considered relevant for this analysis as they are not forms of knowledge, per se. When instances in the data related to these themes, data was coded appropriately, as shown by the coding structure in Figure 5.1 on the following page. During these instances, there were situations where a particular piece of data represented two codes, for example, when subject matter knowledge was discussed, which may also include knowledge about topic-specific instructional strategies. Following the advice of Bryman (2016) and L. Cohen et al. (2011), when these instances occurred that piece of data was coded to all appropriate themes.

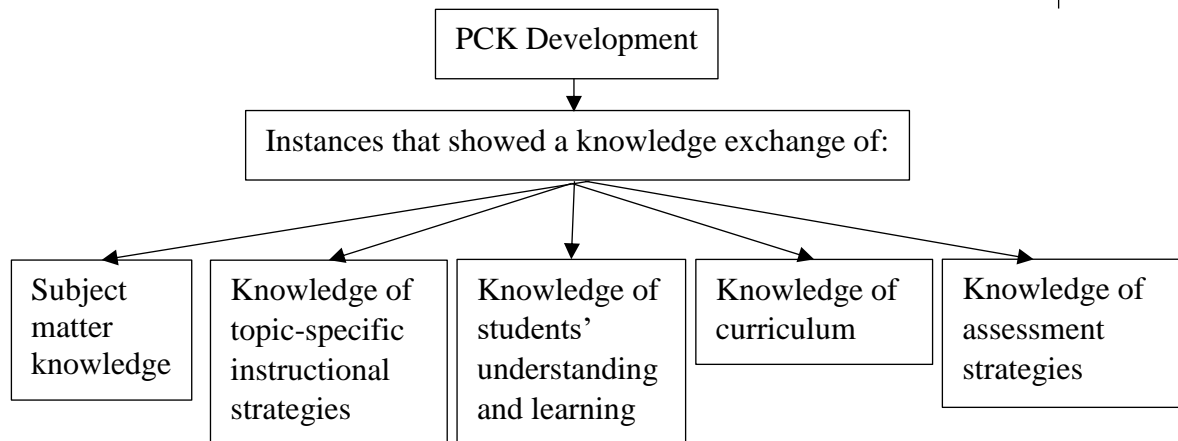


Figure 5.1: Coding structure for analysing instances of PCK development during the Year 10 *Electricity and Magnetism* CoRe design workshop.

When this indexed information was reviewed, there were many instances in discussions between different participants that showed where PCK development was taking place. Predominately, these exchanges occurred during the individual Working Group discussions, but there was also evidence of PCK enhancement during the whole group discussions. By and large, the PCK development was driven by the Group Three teachers.

Of the five themes used for deductive analysis, the exchanges mostly represented developments in subject matter knowledge and knowledge of topic-specific instructional strategies. In the first half of the workshop, there were also conversations about which concepts, skills, and ideas were appropriate, which can be attributed to knowledge of curriculum. There were also some instances that indicated knowledge exchanges about students' understanding and learning. These four themes are explored in the sections below. As for knowledge of assessment strategies, there were few data that represented any knowledge exchanges between participants concerning this theme. Data that referred to assessment in any way during the workshop was about its influence on teaching (i.e., ensuring concepts are covered in preparation for a test, as previously discussed). In other instances, groups talked about ways to ascertain student understanding, such as asking them questions about their circuits, but these conversations did not reveal any evidence that would suggest PCK development.

5.4.4.1 Subject Matter Knowledge

Knowledge exchanges regarding subject matter knowledge were the most frequent type of exchange during the workshop. This theme directly relates to two sub-themes identified earlier under emergent themes: *explaining concepts accurately*, and *teaching students' principles rather than memorising information*. Different types of discussions represented a knowledge exchange of subject matter knowledge, and although they were all driven by the Group Three teachers, they were not always initiated by them. Types of discussions included: the Group Three teacher explained concepts in detail and provided information to the others; one of the other participants asked the Group Three teacher a direct question about some concept that they were unsure of; or, a combination of these two where an explanation incurred questioning.

Within Tony's Working Group, Nick focused primarily on how electric fields cause charged particles to move, and the conservation of charge and energy within a circuit. An example showing a knowledge exchange of subject matter knowledge occurred when Nick explained these ideas to Harry and Tony to enhance their understanding of voltage differences in series and parallel circuits:

Nick: *Electric fields cause charges to move. The big idea with circuits, is actually conservation of charge. You can't make the charges out of nothing, and you can't destroy them. So, in a series circuit, there is only one way for them to go. All the ones that go in have to come out. So, the current has to be same all the way around. Otherwise if you had more going into your lamp than coming out, then the lamp must be destroying electrons.*

Tony: *See that is why having a physics specialist is good, because you actually understand the big ideas.*

Nick: *Or, if you have more current coming out of your device, it must be making more charge. Whereas in parallel, the reason that it splits is, you have got a certain amount of charge, so amount going in has to equal amount coming out, so it splits. Because you can't make charge out of nothing. And the voltage, the reason why the voltage rules happen, is conservation of energy. Because if the charge goes*

around, it goes through the battery and gains some energy. In a series circuit, it loses its energy at the devices – I mean voltage is energy change. So, the amount it gains must equal the amount it loses, so the supply voltage must get split over all the components. They have to add up. If it was losing less, it would get more and more, and you would wind up with an infinite amount of energy.

Tony: *So, explain a parallel circuit, what is going on there?*

Nick: *So, with parallel, again your charge is going around and it gains energy. Now because it is either going through that or through there, it going to lose its energy, isn't it? So that one will lose all their energy, so it will have the same voltage. If that is +12, that will be -12. Or if they go through that way, they also lose their energy, so that is also that one. Does that make sense?*

Tony: *Yeah.*

(Nick and Tony, second CoRe design workshop)

In David's group discussion, similar exchanges were taking place. Throughout their time in the workshop, one of William's techniques for engaging David and Kate was to ask them questions about certain concepts (which William often said were the same questions that he asks students). During these moments, William was then able to offer explanations and address questions that they may have. For example, when addressing the big idea of magnetism, William explained that the whole idea of magnetism is 'aligned electrons', which can be achieved by passing a current through a conductor. He gave them the following example (which could also be analysed as an example of a topic-specific instructional strategy):

Did you know for instance, that when they make ships, the continued tapping from where they put the rivets in will shake the little poles inside the steel? The Earth's magnetic field is in a certain direction. If it is lining up with the ship, the ship will become magnetic.

(William, second CoRe design workshop)

He elaborated on the concept, explaining when permanent magnets are dropped or handled poorly, their electrons can become misaligned, thus losing their magnetic properties. David asked a question about the direction of magnetic fields as he had been confused by how a textbook had portrayed it, which William clarified for him. Kate asked a question about using other magnets to align electrons which William also addressed. After explaining magnetism and addressing their questions, William then continued his questioning to probe his colleagues' understanding which revealed they were still unsure:

Kate: *Why can some metals be magnetised, and others can't?*

William: *This one is subtle. I will ask a trick question; can aluminium be magnetised?*

Kate: [Laughter]. *No.*

William: *Yes, it can. Just pass current through it.*

David: *Oh, okay. So, if you were to use... Use it as the core in an electromagnet?*

William: *You are thinking along the right thing. What is the metal inside conductors? The common metal.*

David: *Copper is our common one.*

William: *So, if you pass current through copper, does it become magnetised?*

David: [Pause]. *Uh...*

William: *That's the whole point of what we are teaching the students!*

(William, Kate, and David, second CoRe design workshop)

Noticing that his colleagues were unsure about magnetism from his questions, William used equipment available in the workshop to show them some magnetism phenomena to supplement his explanations and help their understanding. He also offered to explain anything that they had discussed in more depth in the future, or give them practical ways of teaching concepts.

Similar knowledge exchanges took place in Alan's group discussions, although as group, they concentrated on the CoRe design process and focused on following instructions and completing the tasks, meaning they had less discussions about teaching concepts than the other groups (field notes, second CoRe design workshop). In comparison, the other two Working Groups frequently had philosophical discussions about what to teach and why, and the explanations about underlying principles. Nevertheless, there were still instances in Alan's group discussions where Chris took the opportunity to further the others' knowledge. For example, his explanation to Lucas and Alan about the correct terminology when working with static charge, as reported earlier (i.e., isolate charges versus separate charges). Other instances include Chris explaining to the others the relationship between atomic structure and metallic lattice structures, and how "teaching the lattice structure helps with teaching resistance" (Chris, second CoRe design workshop). After an explanation about voltage, Chris also asked the others whether or not that had made it clearer for them, Alan responded "yeah" and Lucas responded "yeah, I am getting more clarity with things. Not only with the terms, but how to teach it a little better" (Alan and Lucas, second CoRe design workshop). In the larger group discussion, instances of subject matter knowledge exchange could be seen when the Group Three teachers shared and discussed their ideas about teaching certain concepts in front of the other participants. The most notable example (already described in this chapter), focused on the concept of voltage. During this discussion, when William used the whiteboard, it was evident that the other participants became attentive (field notes, second CoRe design workshop). He used his questioning technique here too, and called on various participants to answer, which he often used as a starting point for his explanations. For example, the following exchange occurred after William began drawing his diagram:

William: *Lucas, what is the voltage at this point?*

Lucas: *Zero.*

William: *True. But I could see you were unsure.*

Lucas: [Laughter].

William: *Alan, what is the voltage here?*

Alan: *12V.*

William: *Good. That's good, now I think we should get the staff [in the science department] together so we all agree.*

(William, Lucas, and Alan, second CoRe design workshop)

William continued with his explanation about how to each voltage using diagrams. These diagrams are reported in the following section about knowledge of topic-specific instructional strategies.

5.4.4.2 Knowledge of Topic-Specific Instructional Strategies

Knowledge exchanges regarding topic-specific instructional strategies often accompanied the subject matter knowledge exchanges. Once the experienced physics teacher had imparted some knowledge, the discussion naturally flowed into strategies for teaching and communicating that concept to students. Although, there were also times when a topic-specific strategy was discussed without the direct lead-in from a subject matter knowledge discussion. As in the previous section, data is presented here by identifying knowledge exchanges within each individual Working Group and in the whole group discussion.

As reported earlier, Nick focused on teaching students about electric fields and energy conservation. When he explained the underlying principles of these concepts, he also offered ideas about teaching these abstract ideas to students. For example, during the subject matter knowledge exchange reported earlier, Nick drew some diagrams for Tony and Harry allowing them to further their own understanding, and providing them with a way to explain these concepts to students. The main diagrams that Nick drew are shown in Figure 5.2 where the numbers are used to represent an overall conservation of charge, independent of current pathway. Note that these diagrams were redrawn by the researcher from material obtained from Nick.

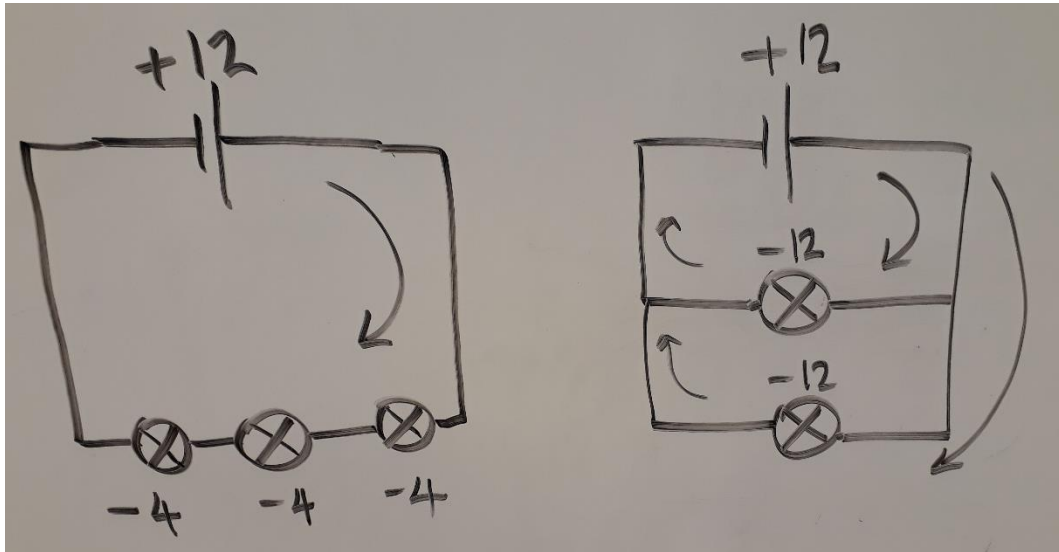


Figure 5.2: Nick's diagrams for explaining voltage, as conservation of charge, for series and parallel circuits.

Another instance during their discussion about electric fields indicating a topic-specific knowledge exchange involved Nick telling Tony and Harry how he teaches flow of charge (as in electrons) to students using an analogy: 'if one moves, then they all move'. He explained:

Electrons move when there is an electric field exerting a force on them. But, only if they can all move. If you don't have a complete circuit, you have a force on them still, but it is like a traffic jam, which is how I teach the kids. The guys at the front have got nowhere to go, no one gets to move.

(Nick, second CoRe design workshop)

Utilising his pPCK for topic-specific instructional strategies again, Nick told the others to relate electric fields to gravitational fields; gravitational fields exert forces on 'things' with mass, while electric fields exert forces on 'things' that have charge. He explicitly advocated not using a water pressure analogy, reasoning:

Water models break down pretty quickly. I don't use that one personally. You've got that, with the pump at the bottom... Yeah, I am

not a fan of that one. People talk about voltage being the pressure, but it is more. I would rather do it as a vertical thing and the pump gives it energy. It lifts it up, to compare it with gravitational energy. You have to do the same with electrical energy fields, you can relate back to gravitational fields quite easily. The kids understand gravity, well relate to it better.

(Nick, second CoRe design workshop)

There was one instance of a whole group knowledge exchange about topic-specific instructional strategies, which instigated David's group discussion about topic-specific instructional strategies. The instance (reported earlier on Page 240) occurred when William took to the whiteboard to explain how he teaches voltage, specifically to identify the voltage across components in series and parallel circuits by rotating the circuit to give the students a sense of a vertical scale; akin to height. In this strategy, anything connected to the top rail is '12' and anything to the bottom rail is '0', and the voltage, therefore, is the difference between the two. If there are two identical components in series, which is appropriate for this level, then it is halved (i.e., 6). The diagrams he used are shown in Figure 5.4. (Note that these diagrams were reproduced by the researcher based on field notes taken during the workshop.)

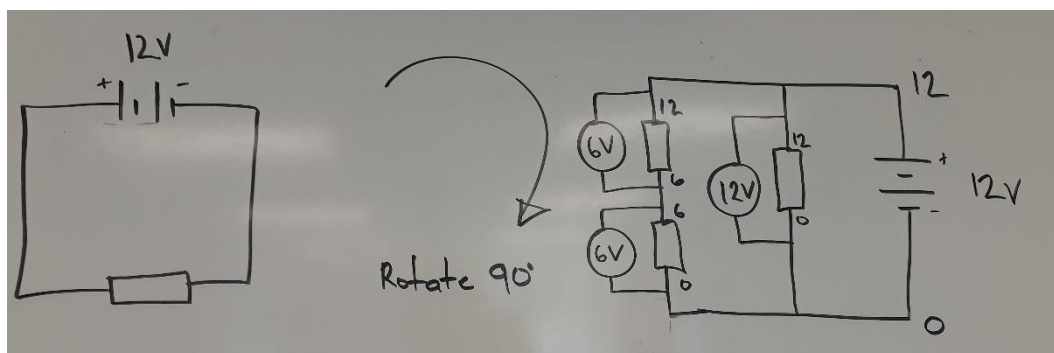


Figure 5.4: William's diagrams for identifying voltage as a difference between two points for series and parallel circuits.

As reported earlier, the other participants engaged with his explanations and when William asked questions of other participants, they also asked him to clarify parts of his strategy (field notes, second Core design workshop). During this interchange, Alan quietly whispered to his Working Group that he would use this technique to teach series and parallel circuits, which they then quietly talked about as William finished his explanation:

Alan: *I would probably use that to teach series and parallel circuits.*

Chris: *Anything that is connected to zero is relative to zero. Once you get that it makes it easier.*

Lucas: *It explains your supply and your zero is coming back to the supply.*

Chris: *And the supply re-energizes the electrons from zero energy to 12.*

(Alan, Chris, and Lucas, second CoRe design Workshop)

When William returned to his Working Group, Kate asked him how his method explained potential difference. William commented that he felt he rushed his explanation at the whiteboard and did not do a great job. However, Kate's question allowed for him to elaborate within their group.

When William discussed his teaching of voltage, he encouraged David and Kate to relate voltage to height, and use that analogy to explain the two interpretations of voltage. William reasoned:

If you think of it as height, you can have height in absolute terms. Like that point is 2m off the ground, so it's got a height of 2m, but off the ground. So, the difference in height is 2m. Or you could say two points, that point has an absolute height of 1.5m and that point has an absolute height of 2m, so the difference in height is 0.5m. So, voltage can mean the absolute voltage at a point, so the height of the point, or it can mean the difference in voltages.

(William, second CoRe design workshop)

When Kate and David asked William which interpretation of voltage is more useful for students (i.e., as the difference between two points on a circuit or an absolute value), William replied:

The point is, at the moment, the majority of students think that voltage flows. They have got no idea what the voltage is, so whatever we do, it can't be worse than what is being done.

(William, second CoRe design workshop)

On a connected concept of circuitry, William explained how he teaches students to use multimeters for measuring current and voltage. He talked about students using meters incorrectly when they try to measure current through a lamp, but accidentally the multimeter is set to measure voltage. He offered some useful information about the functioning of multimeters on this setting to explain why the above practice hinders learning. William explained that on this setting the multimeter has a resistance of approximately $11\text{M}\Omega$, which essentially means no current will flow through it. If students place a multimeter set to measure voltage in their circuit to try and measure current, the lamp stops glowing. William's technique for eliciting student metacognition in this situation is to short circuit the multimeter with a conductor, and have students explain what is happening. Likewise, he talked about how students try and measure voltage but have the multimeter set on current, which also makes the lamp stop glowing and burns out the fuse in the multimeter. Utilising his pPCK, particularly experiences from his teaching practice and from the information he had provided, William recommended to the others that they should start teaching students voltage, then current. He rationalised there is a smaller chance of damaging equipment, and measuring voltage is easier to understand than measuring current. William's advice was noted in their group's CoRe, and he expressed that the science department at River High meet at least annually to discuss and practise using multimeters.

As reported earlier, William also offered Kate and David strategies for teaching magnetism, particularly using practical equipment.

Alan's group also discussed topic-specific instructional strategies, particularly after Chris provided informative subject matter knowledge. However, the strategies that

Chris talked about were not as detailed as the other Group Three teachers, as he explained “I don’t really think about these things [instructional strategies] anymore when I am teaching, I just teach” (Chris, second CoRe design workshop). Nevertheless, Chris did suggest that the others teach students a simplified version of metallic bonding to help them understand resistance and current flow, and explained how he facilitated a useful practical lesson to highlight the Ohm’s law relationship. When he recounted this practical lesson, Chris explained that he always asks his students to take multimeter readings when the power supply has a voltage output of zero, so his students can see no current is flowing. Two other discussion points reveal potential knowledge transfers.

Like the other Group Three teachers, Chris offered an analogy that he uses when teaching students about circuits, which was a water-based model. When Lucas asked him to explain it further, he stated:

Your energy source, or your battery, is a pump that pumps water around a closed circuit. It has got to be closed otherwise the water escapes. Then valves in that circuit represent the resistors. The more resistors, the more you close the valve or the tap, the less water can flow, and that is your current. So in series it will limit the current more than in parallel, because you add all of the currents together in parallel. So a little bit goes through the top valve, a little goes through the bottom valve, and they join together again, so it gives a bigger current than in series.

(Chris, second CoRe design workshop)

This group also discussed the use of simulations for explaining concepts to students, particularly the use of Physics Education Technology (PhET) interactive simulations (see PhET Interactive Simulations, 2017). It was Lucas who raised the use of PhET interactive simulations in the conversation about teaching current, and Chris reinforced their use, affirming “computer simulations are great for teaching this. Animations, the flow of charge as an animation is a great tool. It makes it visual” (Chris, second CoRe design workshop). For example, Figure 5.5 on the following page shows a screenshot of how these simulations can be used to show

electrons flowing a closed circuit, and how lamps in series are not as bright as one in parallel.

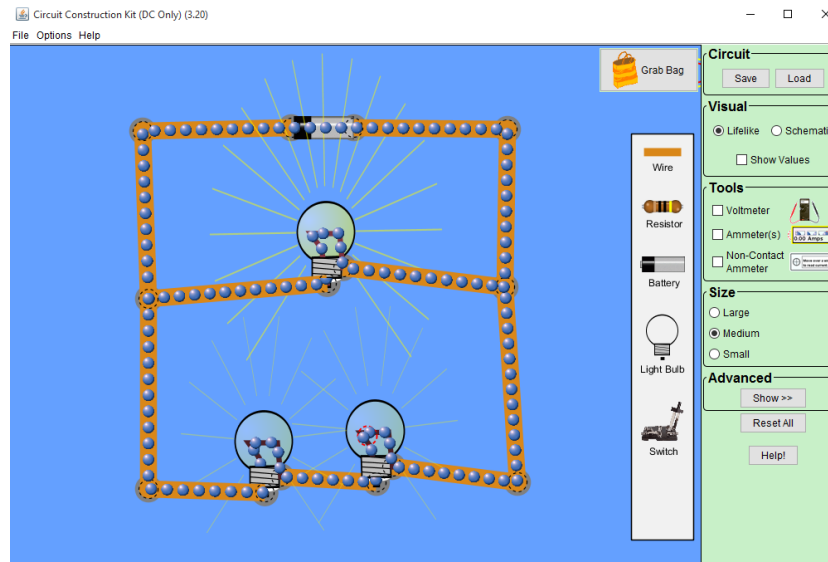


Figure 5.5: Screenshot of a PhET interactive simulation showing movement of charged particles in a closed circuit and brightness of lamps in different configurations.

The following section reports on knowledge exchange instances during the workshop with regards to knowledge of curriculum.

5.4.4.3 Knowledge of Curriculum

Knowledge exchanges between participants regarding knowledge of curriculum were not as plentiful as the previous two forms of knowledge. However, occurrences that showed insights into participants' knowledge of curriculum were seen at the beginning of the workshop when they were discussing and debating appropriate concepts and big ideas for teaching *Electricity and Magnetism* to Year 10 students. Again, Group Three teachers were the major contributors to these discussions, both within their own Working Group and in the whole group discussions. While each group had a NZC document, the Achievement Standard for Year 11 had a significant influence on their choice of appropriate concepts (field notes, second CoRe design workshop).

These conversations and interactions have already been extensively covered in this chapter, although one point worth reinforcing here, is the emphasis the Group Three teachers placed on aligning concepts for subsequent physics learning. They maintained throughout the workshop that it was important not only to teach students concepts that are important in terms of their everyday lives, but also to ensure that if they took physics later in their schooling they would have sufficient understanding of certain concepts which could be developed.

After completing their CoRe document, Tony's group talked candidly about the process before departing. During the conversation, Tony asked Nick if they did CoRe design in the future, would it be better to just have the specialist teachers. For example, if another CoRe was made for Year 10 *Forces and Motion*, would it be better if it was just the physics teachers. Nick replied that it is actually useful having "a mix" of teachers, otherwise there is a danger of pitching concepts at a level which is too difficult; rather, the specialists need to be "shot down a bit" (Nick, second CoRe design workshop).

The following section reports on knowledge exchange instances during the workshop with regards to knowledge of students' understanding and learning.

5.4.4.4 Knowledge of Students' Understanding and Learning

Throughout the Working Group discussions, there were a few instances showing knowledge exchanges about Year 10 students' understanding and learning with regards to *Electricity and Magnetism*. Again, most of these came from the Group Three teachers, who drew on their experiences of teaching this topic. They identified some of the difficulties that they have seen when teaching these abstract concepts before, and offered ways to overcome these problems to the other members of their group. Some examples from each Working Group are reported below.

In Tony's group, Nick recounted how students think about charges in wires, and how they behave in electrical circuits, which followed his earlier discussion points about electric fields exerting forces on charges. He explained to Tony and Harry that students often see an electrical circuit as a situation where the battery is producing a charge that "goes around and around, and then the next ones goes"

(Nick, second CoRe design workshop). He argued teachers need to ensure that students have an understanding about this situation and teach them that the wires are full of charges, and the whole thing is continuous. Tony acknowledged these suggestions, stating “oh, I see”, (Tony, second CoRe design workshop) after Nick’s explanation, but did not elaborate.

A similar account about students’ understanding and learning was offered in David’s group. Using his experience, William identified a misconception that he had commonly seen, related to how students think about open circuits. The excerpt below indicates some possible knowledge exchange.

William: What they get wrong is they think current can flow up to an open switch. Then then they think it doesn't flow on the other side. But they think it flows up to there. So, if one lamp blows in the circuit, they think that the current continues to flow up to the first lamp, but can't flow to the second because the circuit has been broken.

David: So, if it was the second one that blew, would the first one go?

William: That is what they imply, despite what they see with their own eyes that it doesn't, they still say that.

(William and David, second CoRe design workshop)

The conversation above had initially begun with the group talking about the prior knowledge students have when they begin this unit of work. David indicated that students have some knowledge because they have “played with electrical things” before (David, second CoRe design workshop). Directly after the conversation in the excerpt above, Sarah joined the group and asked William how he would address the misconception. William explained that the best approach, in his opinion, was for students to experience plenty of practise building electrical circuits: starting with basic circuits containing one lamp to more complex circuits with components in both series and parallel.

In Alan’s Working Group, the discussions around the difficulty of teaching concepts to students were of a different nature to the others. Rather than talking about student thinking, their conversations focused on practical issues. For

example, Chris stated that the difficulty with students making circuits is their inability as teachers to interact with all of them within the timeframe, and there were sometimes classroom management issues. Nevertheless, there were instances of potential knowledge exchanges linked to students' understanding and learning. For example, when talking about multimeters, Chris indicated that students have real difficulty using them and need careful guidance and instructions. Also, when they were discussing the idea of electrical current being a flow of charge, Chris was clear about keeping the term as 'charge' rather than 'electrons' or 'protons'. He reasoned it can open a "dark horse in terms of conventional current" (Chris, second CoRe design workshop). He argued it is better for students to learn the concept of flow of charge first, which can then be built on later.

5.5 Chapter Summary

This chapter has presented the analysed data from Phase Two of this study where CoRe design workshops were used as PLD interventions to promote professional learning. During this phase, two CoRe design workshops were held, with the first as a pilot so participants could become familiar with the process. This pilot workshop featured the nature of science and scientific inquiry as the focus for CoRe design. The second workshop was the main focus for this study about enhancing teachers' PCK for Year 10 *Electricity and Magnetism*.

To facilitate the reader's understanding of the participant interactions that took place, the process in both CoRe design workshops has been narrated. The emergent themes from each workshop have also been identified. In the first workshop, the two emergent themes were: ensuring concepts are relevant to students' lives, and how contextual influences of the school impact the teaching of the nature of science and scientific inquiry. There were three themes that emerged in the second workshop, which were: how concepts and phenomena should be explained to students, which concepts should be prioritised in junior science, and how the school context influences classroom practice.

As this study centres around the impact of CoRe design on practising teachers' PCK development, evidence of PCK development from the second workshop was also identified. This analysis revealed many occurrences where knowledge was

exchanged in the workshop. There were frequent exchanges regarding subject matter knowledge and knowledge of topic-specific strategies, and some regarding knowledge of students' understanding and learning. At the beginning of the workshop, discussions and debates about appropriate concepts showed knowledge exchanges regarding knowledge of curriculum. There were no occurrences that indicated any knowledge of assessment exchanges.

The following chapter presents the findings from Phase Three of this study which evaluates the impact of the knowledge exchanges during CoRe design on the Group One participants' knowledge and practice.

Chapter Six

Phase Three Findings: Evaluating CoRe Design

6.1 Overview

This chapter contains the information obtained from Phase Three of the study to evaluate content representation (CoRe) design for enhancing pedagogical content knowledge (PCK). The evaluation of the effectiveness and worth of CoRe design as a professional learning development (PLD) intervention for practising teachers was done using two sets of data: Section 6.2 presents the observational data collected from the Group One teachers' Year 10 *Electricity and Magnetism* lessons post-CoRe design to gain insights into ePCK development; and, Section 6.3 presents the interview and focus group discussion data from all participants as they evaluated CoRe design as a professional development intervention for enhancing PCK. Lastly, there is a summary of this chapter.

6.2 Observing Group One Teachers (Post-CoRe Design)

The analysis and presentation of observational data here is similar to Phase One (see Chapter Four, Section 4.4). Four lessons from each participant were used for this analysis, which included: the introductory lesson; a lesson where students were carrying out practical work; and two other lessons that reflected concepts that each Group One teacher encountered and discussed during the CoRe design workshop. Observational data was analysed using the observational protocol (see Appendix D).

The data related to each Group One teacher has been separated and treated independently as individual cases to allow for cross case comparisons. Contextual information about each teacher's class is provided, followed by a series of tables detailing the data analysis. One table represents one lesson and the same abbreviations from Chapter Four have been used (see Table 4.2 on Page 195).

6.2.1 Tony's Post-CoRe Design Observations

6.2.1.1 Contextual Information

Tony's four post-CoRe design lessons selected for analysis included his: introductory lesson; second lesson, featuring explanations about charged particles, voltage, and current; third lesson, where students explored differences between

series and parallel circuits, and the Ohm's law relationship; and, fifth lesson, where students made simple circuits and took measurements.

There were 30 students on the roll in Tony's post-CoRe design class (school records) and they were mostly well-behaved in class; Tony only dealt with students being off-task or disruptive a few times. Students were engaged in the lessons, particularly during practical work (observational protocol).

Tony's teaching style was identified as teacher-centered, with a focus on students taking notes. However, there were also times during his lessons where Tony engaged with students and challenged their thinking; particularly to probe why they thought in a particular way (observational protocol). Prior to teaching this second class, Tony and David worked together with the completed Year 10 *Electricity and Magnetism* CoRe produced in the second workshop to plan their lessons. Again, Tony had a PowerPoint for this class, but it was different to that used previously.

6.2.1.2 Tables of Observational Analysis

The four tables for Tony's post-CoRe design lessons are on the following six pages.

Table 6.1: Tony's first post-CoRe design lesson. The concepts covered were current and conductors, and energy and voltage.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the New Zealand Curriculum (NZC).
Accuracy	A	All of the explanations that Tony offered in this lesson were accurate and addressed the concepts.
Concept links	A	Tony made many links and connections between different concepts throughout this lesson, and provided suitable explanations of these connections. For example, offering a detailed explanation about the link between voltage, energy, and electrons as charged particles.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	P	Tony explored student prior knowledge by talking with students, allowing students to ask questions and make comments, or asking students questions. He often related their responses to key words. For example, when students asked about electric fences and receiving shocks, Tony used this prior knowledge by linking it to concepts that was being taught in the lesson (i.e., conductors and insulators).
Variations in understanding	B	While Tony recognised variations in student understanding at times, these instances were not used to guide the lesson.
Questions used	B	Tony rarely used questions, and when he did, there was little variety with students only needing to offer a one-word response. For example, asking what charge electrons have. He did also ask them about energy types, but that formed only a very brief part of the lesson.
Knowledge of Instructional Strategies		
Sequencing of concepts	A	There was clear flow between concepts. Tony started with basic principles of voltage, current, and resistance, and explained the relationship between them in detail. This explanation allowed him to then use these terms when talking about conductors and insulators. The flow to static electricity was also clear from the explanations about conductors and insulators.
Examples and representations	A	Tony used many different relevant examples for explaining his concepts, which appeared to be effective as students were engaging with his explanations. He also used a few representations to aid his explanations, including Williams's example from the CoRe workshop (see Figure 5.4 on Page 254).
Metacognitive strategies	B	There were two instances of a strategy which promoted some metacognition. One comprised questioning students about energy types, which was followed by an explanation. The other involved exploring voltages in a series circuit, using his CoRe design strategy.

Table 6.2: Tony's second post-CoRe design lesson. The concepts covered were charged particles, voltage, and current.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were considered to be in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that Tony offered in this lesson were accurate and addressed the concepts.
Concept links	A	Tony made many links between different concepts and explained the relationship between them. For example, he offered a detailed explanation about what voltage represents (in terms of energy) and how a multimeter is used to measure it.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	B	Tony only briefly referred to, and explored, the learning that they had done in previous lessons. However, there were more opportunities for him to strengthen this ePCK component. For example, further exploring students' conception of voltage, and acknowledging the difficulty in understanding what voltage represents.
Variations in understanding	P	Tony did try to use student ideas, via their questions, to inform this lesson. For example, when it became clear that a student was misinformed about the meaning of neutral (in terms of static electricity), Tony diverted attention away from his PowerPoint and drew diagrams to explain the concept in greater depth and detail.
Questions used	B	Tony only used two questions. One asked what particle had a negative charge and the other question asked what charge does an un-charged object have. When no one immediately answered, he provided the answer.
Please see following page for Knowledge of Instructional Strategies		

Table 6.2 Continued.

Knowledge of Instructional Strategies		
Sequencing of concepts	B	There was some flow between the concepts that Tony was covering, but the explanation about the concept links was lacking. For example, when the concept he was teaching changed from static electricity to current electricity, the shift lacked an explicit or insightful explanation to why or how these concepts are related. A link here from Tony would help students develop their understanding.
Examples and representations	P	Tony used some examples that were effective. For instance, the reason why dust particles stick to computer screens. However, there were also examples that he used that needed development. For example, Maglev trains to highlight charged particles repelling, which is actually about magnetic poles rather than different charges. Similarly, he used an example of fuses in homes, which he discussed in detail. However, his explanation was actually about circuit breakers.
Metacognitive strategies	B	There was limited use of strategies that allowed students to challenge their own thinking. These included Tony trying to engage students in a discussion about the attraction between charged particles, and how fuses work in homes.

Table 6.3: Tony's third post-CoRe design lesson. The concepts covered were differences between series and parallel circuits, and the Ohm's law relationship.

Subject Matter Knowledge		
Appropriateness	P	Tony asked students to calculate the total resistance of a parallel circuit. This concept could be argued to be more appropriate for Level 6 or 7 of the NZC. Although, the method he was trying to get them to use was appropriate for Level 5. Tony also showed the YouTube video that he used in his pre-CoRe design class of a person generating a high voltage spark using capacitors, transformers, and an alternating current voltage supply. It could be argued that these concepts are better suited to Level 8 of the NZC.
Accuracy	A	All of the explanations that Tony offered in this lesson were accurate and addressed the concepts.
Concept links	A	Tony frequently expressed the relationships between voltage and current, and resistance and current, by talking about them, drawing diagrams, and doing practical demonstrations.
NoS/SI links	B	There were some implicit links to the nature of science about using correct symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	P	Tony explored student prior knowledge by talking with students and asking them questions, and allowing students to ask questions and make comments. As for misconceptions, there was an opportunity that was simply overlooked. Tony was corrected by a student for leaving a wire off a circuit diagram, and he could have used that as a useful example for a misconception about a complete circuit.
Variations in understanding	A	When Tony talked about differences in voltage and current with respect to parallel and series circuits, he could quickly tell that his students were unsure. Tony left his PowerPoint and opted to draw diagrams on the whiteboard instead, and used the explanation about conservation of energy from Nick (see Figure 5.2 on Page 253). Also, after teaching his students about the Ohm's law relationship, he asked his students to complete a task on it. However, upon realising they were unsure, he changed tack completely and opted to step them through it, and then allow them to complete another task individually.
Questions used	P	Tony used some questions during the lesson, which seemed to be more varied than his previous lessons. For example, he asked students to explain voltage and current rules in terms of series and parallel circuit.

Please see following page for Knowledge of Instructional Strategies

Table 6.3 Continued.

Knowledge of Instructional Strategies	
Sequencing of concepts	P The flow between concepts was suitable to allow concept building on behalf of the students, but there were instances that could have been strengthened. For example, only briefly mentioning relationships between voltage, current, and resistance; although, he did talk about relationship in depth in previous lessons.
Examples and representations	A Tony used no examples during this lesson, but represented some abstract ideas in ways that the students could understand. These representations appeared to be effective with students readily engaging with him. For example, Nick's representations of voltage and conservation of energy that he learned during the CoRe design workshop.
Metacognitive strategies	B There were two instances during the lesson where students were prompted to challenge their own thinking. Both of these instances were when Tony was asking questions and offering explanations to get students thinking about their own conception of voltage and current in series and parallel circuits.

Table 6.4: Tony's fifth post-CoRe design lesson. The concepts covered were making simple circuits and taking measurements.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that Tony offered in this lesson were accurate and addressed the concepts.
Concept links	P	Tony made many links during the lesson and explained key connections well, such as the current and resistance relationship. Although there were two key links that he overlooked: voltage across the bulbs with both voltage of power supply, and brightness of bulbs.
NoS/SI links	P	There were some implicit links to the nature of science about using correct symbols and conventions. Also, implicit links to scientific inquiry about gathering data and exploring trends. However, there were other links that could have been made.
Knowledge of Student Understanding		
Prior knowledge	P	Tony used questions at times to recognise students' prior knowledge and he used that information in the lesson. While there were opportunities to talk about the difficulty of using multimeters and common errors, this was not done. However, compared to the first time he did the same practical (pre-CoRe design), it was done in a much clearer way with more explanation.
Variations in understanding	P	There were some instances where Tony acknowledged student understanding and used that to guide further instruction. This seemed to be effective. For example, when students were unsure about what would happen to current when he changed a circuit, Tony practically demonstrated his question to aid their understanding.
Questions used	A	Tony used many questions during the lesson and he used a variety of styles. This included asking students how to connect components, what terms meant, and to explain their predictions when making circuits. These questions occurred in both the whole class setting and when the students were working in groups.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequence and flow of concepts was suitable. However, the transition to calculating resistance was overlooked. While it was touched on in the beginning of the lesson, it would have been useful to then revisit that again before asking students to solve problems.
Examples and representations	P	Tony did a demonstration of what to do for this lesson. It was somewhat effective with students stating they knew what to do, but then needing some help. A parallel circuit example/representation would have been useful here too, rather than only a series circuit.
Metacognitive strategies	P	Tony seemed to adequately use metacognition strategies and asked students to predict what might happen and why. This was followed up by a practical representation to aid with their knowledge development.

6.2.2 David's Post-CoRe Design Observations

6.2.2.1 Contextual Information

David's four post-CoRe design lessons included his: introductory lesson, second lesson, where students made simple circuits and measured voltage; fourth lesson, where students made simple circuits and measured current; and, fifth lesson, featuring explanations around voltage sharing across components, and the Ohm's law relationship.

There were 28 students on the roll in David's post-CoRe design class (school records) and they were well-behaved some of the time. David had to deal with students not engaging in activities, talking, or being disruptive frequently during his lessons. However, during the practical lessons, his students were interested and engaged, and followed instructions (observational protocol).

Prior to teaching this second class, David and Tony worked together with the completed Year 10 *Electricity and Magnetism* CoRe produced in the second workshop to plan their lessons. In his lessons, David used the whiteboard to write notes and used plentiful practical equipment (observational protocol).

The first two lessons used for analysis were before a two-week break, and the following two occurred when students returned to school after the break. David's teaching style for the first two lessons was classified as student-centered, where he encouraged students to play with equipment and make discoveries. The second two lessons were identified as more teacher-centered, where practical work was heavily structured and David focused on students taking notes from the whiteboard (observational protocol).

One of the concepts that David's Working Group explored in-depth during the CoRe design workshop was magnetism. However, when David taught his first Year 10 class (i.e., pre-CoRe design), it was in the last week of the school term and Ryan (video camera operator) was unable to make recordings as the equipment was unavailable that week. When this situation was relayed to the researcher at the time, a suitable replacement was not able to be organised quickly enough. So while there were magnetism lessons covered in his post-CoRe design class, classroom teaching comparisons could not be made about potential PCK development as a result of the workshop. David was contacted during the analysis to see whether or not he had

made any significant changes to his instruction, as a result of CoRe design. His response was that by the time he reached the magnetism portion of his unit, he felt under pressure to get the topic finished and students ready for the assessments. Thus, he attributed no significant changes to his instruction regarding magnetism compared to his first pre-CoRe design class (personal communication with David, during data analysis).

6.2.2.2 Tables for Observational Analysis

The four tables for David's post-CoRe design lessons are on the following eight pages.

Table 6.5: David's first post-CoRe design lesson. The concepts covered were differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts.
Concept links	P	David made some important links between concepts, but the connection could have been significantly strengthened with a more insightful explanation. For example, during that lesson he made the link between voltage and brightness of lamps for his students, but an explanation about why that occurs in terms of energy would have been useful for developing their understanding.
NoS/SI links	P	David made some of the possible implicit links to the nature of science and scientific inquiry. For example, showing students correct conventions for this topic and explaining why that standardisation is important. Similarly, he talked to his students about the idea of doing an investigation to gather data, and then explore trends in the data.
Knowledge of Student Understanding		
Prior knowledge	P	David explored what students had already learnt about electricity in terms of series and parallel circuits. He called on those students that had some prior knowledge to share their ideas with the class. During this lesson, while he did not explicitly state it was a misconception, he also talked about the issue of open and short circuits.
Variations in understanding	P	There were times where David became aware that students were unsure about the concept he was trying to teach them. For example, David identified a lack of understanding and learning about current pathways in series and parallel circuits. After explanations, he tried a different approach to explain the concept using practical equipment, which seemed to be effective.
Questions used	B	David used a few questions to probe student understanding during the lesson. However, there were also other instances where a question would have been effective, but David opted for an explanation. It appeared as though this decision was driven by time constraints.

Please see following page for Knowledge of Instructional Strategies

Table 6.5 Continued.

Knowledge of Instructional Strategies	
Sequencing of concepts	P The flow between concepts was suitable, but there were times when further explanations during the sequencing may have enhanced students' understanding. For example, he would stop the class mid-activity and tell them what he wanted them to do next. Careful explanation about the concept transition at that point would have helped the students to understand the actual links between concepts.
Examples and representations	A David used clearly constructed circuit diagrams to represent circuits during the lesson, and at times, modelled what the circuit looked like in 'real' terms by making it. There were also times that David used examples to explain points. For instance, using different types of common batteries to explain differences between batteries and cells to students.
Metacognitive strategies	B The only instance that showed metacognition was when David asked students to think about what was happening when they took a wire out of the series circuit, compared to parallel, and to explain it, which was followed up with an explanation by David.

Table 6.6: David's second post-CoRe design lesson. The concepts covered were voltage, and voltage differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts.
Concept links	A	David made many of the possible links between concepts in this lesson and explained how they were related. For example, he made clear links between energy, voltage, and the brightness of lightbulbs, and he explained the relationships well.
NoS/SI links	P	David made some of the possible implicit links to the nature of science and scientific inquiry. For example, reiterating correct conventions for this topic. He also talked to his students about the idea of doing an investigation to gather data, and then explore trends in the data.
Knowledge of Student Understanding		
Prior knowledge	B	David acknowledged student prior knowledge from previous lessons by recapping previously taught concepts and asking some questions about those. However, the information that he gathered was not used in a meaningful way in the lesson.
Variations in understanding	L	There were no instances that could be attributed to this indicator.
Questions used	P	David asked an adequate range of a questions to explore student understanding about various concepts. During these instances, if a particular student was not able to offer an answer, or their answer was incomplete, David called on someone else in an attempt to develop a coherent and full answer before explaining it himself.

Please see following page for Knowledge of Instructional Strategies

Table 6.6 Continued.

Knowledge of Instructional Strategies	
Sequencing of concepts	A <p>The sequencing between different concepts was appropriate and clear to the students. Of particular note was the different sequence or approach that David used when making simple circuits with his students. He appeared to have followed William's instructional strategy advice, which he described in their CoRe design workshop, of making series circuits first, and then measuring voltage, because that is the easiest arrangement to make and understand.</p>
Examples and representations	A <p>David used clearly constructed circuit diagrams to represent circuits during the lesson, and at times, modelled what the circuit looked like in 'real' terms by making it. Also, David used a representation when he first introducing the idea of what voltage meant and how to measure it. His explanation placed emphasis on voltage being an energy difference between two points, which was stressed by William at various times during the CoRe design workshop. As for the actual representation, David used the example that William offered during the CoRe workshop, which was to relate measuring voltage and energy difference to different heights, as students will connect better with that idea.</p>
Metacognitive strategies	B <p>It appeared as though David was trying to get his students to undergo a metacognitive process, but the strategy was not as effective as he may have hoped. David was trying to support students to interpret and explain trends in data from measured voltage. However, the explanation phase required further consideration as David was quick to offer the explanation without allowing students to fully espouse their ideas.</p>

Table 6.7: David's fourth post-CoRe design lesson. The concepts current, and current differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts.
Concept links	A	David made many of the possible links between concepts in this lesson and explained how they were related. For example, he made clear links between electrons moving, current, current pathways, resistance, and brightness of bulbs.
NoS/SI links	B	Some implicit links to the nature of science in terms of using symbols and conventions. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	B	David acknowledged student prior knowledge from previous lessons by recapping previous concepts and asking some questions about those concepts – particularly since this was their first lesson after the term break. However, the information that he gathered was not used in a meaningful way in the lesson.
Variations in understanding	P	There was some acknowledgement of student understanding which guided instruction. Notable examples were when students asked David a question, clearly showing him they did not understand something. Both times when students asked these types of questions David used practical equipment to allow them to come to the answer. For example, what a variable resistor does in a circuit, or how current is affected by multiple components.
Questions used	A	David asked multiple and varied questions of his students. During these questions, he would often get various responses from students and he was effective at trying to address different answers. For example, asking students about applications of variable resistors and then explaining each of the examples they offered fully.

Please see following page for Knowledge of Instructional Strategies

Table 6.7 Continued.

Knowledge of Instructional Strategies		
Sequencing of concepts	P	The flow between concepts was suitable. The shift from series to parallel circuits could have done with more explanation, but it was clear that David was wanting to move through the lesson quickly.
Examples and representations	A	David used many examples and representations in this lesson which appeared to be effective. Representations included his carefully constructed diagrams to represent circuits, and his analogy of how more bulbs in a series circuit will affect current. Examples included the various household appliance that use variable resistors, and how that affects current and energy output (e.g., brightness or loudness).
Metacognitive strategies	P	It appeared as though David was trying to get his students to undergo a metacognitive process. Throughout the lesson he was calling on students to offer their ideas and share their thinking with the class. He tried to use that information when constructing explanations about the concept they were working with.

Table 6.8: David's fifth post-CoRe design lesson. The concepts were voltage sharing across components, and the Ohm's law relationship.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that David offered in this lesson were accurate and addressed the concepts.
Concept links	A	David made many of the possible links in this lesson and explained the relationships well. For example, explaining the interconnectedness of current, resistance and voltage in detail. He also demonstrated this interconnectedness using practical circuits.
NoS/SI links	B	There were many possible links to the nature of science and scientific inquiry in this lesson, but they were rarely made. The only links seen were implicit links to the nature of science in terms of symbols and conventions, and implicit links to scientific inquiry in terms of making observations and exploring patterns in different types of circuits.
Knowledge of Student Understanding		
Prior knowledge	P	David acknowledged and recognised student prior knowledge in terms of recapping work they had previously done. He also showed insight to difficult concepts by acknowledging his explanations of voltage and current were simplified versions, but adequate for what they needed.
Variations in understanding	P	There were some instances where it became clear to David that students were unsure about what he was meaning, so he deviated away from his intended next move to try and remedy the issue. For example, he deviated to further explore the concept of voltage sharing in a series circuit in a completely different way. Similarly, David had written some notes, and after a student-led question and the discussion that followed, he adjusted the information he was giving to the students.
Questions used	P	David asked an adequate range of questions to explore student understanding about various concepts. During these instances, if a particular student was not able to offer an answer, or their answer was incomplete, David called on someone else in an attempt to develop a coherent and full answer before explaining it himself.

Please see following page for Knowledge of Instructional Strategies

Table 6.8 Continued.

Knowledge of Instructional Strategies	
Sequencing of concepts	P The sequence of the concepts was suitable to allow for conceptual development. However, there were times when a better explanation to why the concept was changing would have been useful. For example, when the lesson shifted between the concepts of current and voltage.
Examples and representations	A David used multiple representations in his lessons and relevant examples. These appeared to be effective at portraying the idea he was trying to teach. For example, some representations included carefully constructed circuit diagrams, demonstration circuits, and analogies. Similarly, some examples included electricity in homes, wiring in houses, and how appliances use electrical energy.
Metacognitive strategies	P It appeared at times that David was trying to get his students to undergo a metacognitive process. For example, when demonstrating the sharing of voltage using the meters, or the current and resistance relationship, he was trying to get his students to think about what was happening and then he wanted them to explain it. However, it may not have been as effective as he hoped as students became disruptive.

6.2.3 Alan's Post-CoRe Design Observations

6.2.3.1 Contextual Information

Alan's four post-CoRe design lessons included his: introductory lesson; second lesson, featuring explanations about charge separation and static electricity; third lesson, where students made simple circuits and explored differences between series and parallel circuits; and, fourth lesson, where students made simple circuits and measured current and voltage in series and parallel circuits.

There were 26 students on the roll in Alan's post-CoRe design class (school records) and they were well-behaved most of the time. There were only a few instances where Alan had to deal with students being off-task or disruptive. Students were interested and engaged in the lessons, and enjoyed working with the practical equipment (observational protocol).

Alan's teaching style was identified as student-centered, where he tried to make links between concepts and relate concepts to everyday situations that were familiar to students. Alan wrote information on the whiteboard, and he had often written some of this information before students arrived to class (observational protocol).

6.2.3.2 Tables for Observational Analysis

The four tables for Alan's post-CoRe design lessons are on the following six pages.

Table 6.9: Alan's first post-CoRe design lesson. The concept covered was current, as the movement of charged particles.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	P	Alan's explanations were mostly accurate during the lesson. However, he did talk about current flowing up to an open switch, and then not being able to go past, which is inaccurate and may contribute to students developing misconceptions.
Concept links	A	Alan made many of the possible links between concepts and explained them well. For example, he offered an in-depth explanation about the relationship between charge, sub-atomic particles and atoms, and current flow.
NoS/SI links	B	Alan made some implicit links to the nature of science in terms of conventions and language. No scientific inquiry links.
Knowledge of Student Understanding		
Prior knowledge	P	Alan started the lesson by trying to explore student understanding from the previous week through a range of questions. This part of the lesson was useful as it allowed him to transition to the next phase using their knowledge as a base.
Variations in understanding	P	There were times when Alan recognised students were having difficulty in understanding a concept, and he altered that part of the lesson to ensure they understood the concept. For example, when he was discussing atomic structure and charged particles, he noticed students were having difficulty and changed tack.
Questions used	A	Alan used multiple and varied questions throughout the lesson to explore student understanding. For example, asking them to explain what electricity was in terms of charged particles. These mostly occurred in the first half of the lesson.
Please see following page for Knowledge of Instructional Strategies		

Table 6.9 Continued.

Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequence at the beginning of the lesson was clear and allowed for conceptual development from the students. The transition into making the circuit on the physics education technology (PhET) simulator was not as clear, which was impeded by technical difficulties.
Examples and representations	P	Alan used many representations to help students understand the targeted concept. These seemed to be mostly effective and accurate. He also used PhET simulations, which he learnt about in the CoRe design workshop – although he did have some technical issues with it.
Metacognitive strategies	P	Alan used some strategies to get students to think about their own understanding. Once at the beginning during a brainstorming activity where students had to combine and debate their understanding in a group setting. Later in the lesson, students were tasked with using their understanding of circuits to make a particular type of circuit on the PhET simulator. It also seemed as though Alan was going to follow the PhET activity up with something else, but he ran out of time due to technical difficulties.

Table 6.10: Alan's second post-CoRe design lesson. The concepts covered were charge separation and static electricity.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	A	All of the explanations that Alan offered in this lesson were accurate and addressed the concepts.
Concept links	A	Alan made many of the possible links and explained the connections in detail. For example, explaining charge separation, discharge of energy, and the Earth being neutral, in detail.
NoS/SI links	L	There were no instances that could be attributed to this indicator.
Knowledge of Student Understanding		
Prior knowledge	P	Alan referenced student prior knowledge a few times, particularly as he was trying to get students to tap into their knowledge of charged particles, which was covered in previous lessons. No indication of misconceptions or difficult concepts.
Variations in understanding	A	There were many instances that showed Alan trying to get students to understand an idea, or carry out a task, and he could tell they were having difficulty. In these instances he changed his tack to allow them to develop their understanding.
Questions used	A	Alan used many questions to probe and extend understanding. For example, exploring their knowledge of charged particles, and trying to get them to use that knowledge to explain phenomena.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequencing of concepts within the lesson was appropriate. In the second half of the lesson, he wanted students to carry out tasks with the Van der Graaf. While he intended that activity to be student-led, it ended up being more of a teacher-led demonstration, as students were unsure about using it. This part of the lesson confused students; a detailed explanation beforehand would have been beneficial
Examples and representations	A	Alan used many examples and representations in this lesson which appeared to be quite effective at helping to explain the point he was making. For example, his detailed explanation and diagrams about lightning and how that is a useful example for static electricity.
Metacognitive strategies	P	Alan used an adequate range of strategies to get students to think about their own understanding. For example, questioning students about their understanding and then offering them explanations in order to scaffold and develop their understanding.

Table 6.11: Alan's third post-CoRe design lesson. The concepts covered were exploring differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	B	Some explanations were accurate, whilst others were not. Of particular importance was how Alan kept referring to voltage as "flowing through the circuit". When measuring voltage, he also instructed his students to use the multimeter function for measuring AC voltage, not DC voltage, which yields incorrect data.
Concept links	P	Alan explored some of the possible links between concepts and the explanations of how they are linked. For example, linking how a circuit is constructed to what type it is, and how current and voltage are different, and why.
NoS/SI links	P	Alan made some implicit links to both the nature of science and scientific inquiry. For example, talking about conventions and symbols, and gathering data to explore relationships.
Knowledge of Student Understanding		
Prior knowledge	B	Alan perpetuated a misconception that was mentioned during CoRe workshop; voltage flowing. Alan referenced the difficulty of using multimeters and how to connect them. At the beginning of the lesson, he briefly touched on student prior knowledge from before the term break, but this was not used in the lesson.
Variations in understanding	P	Alan noticed that students were having difficulty and changed his tack a few times during the lesson. It occurred both in small groups and as a whole class. For example, recognising students understanding around using multimeters and explaining how to use them correctly to measure voltage (both in small groups and as a whole class).
Questions used	B	Alan only used a few questions in this lesson to probe student understanding. For example, asking students about the difference between series and parallel circuits.

Please see following page for Knowledge of Instructional Strategies

Table 6.11 Continued.

Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequence itself was appropriate. However, the enactment needed some attention in the form of careful explanations during the lesson to ensure students actually know what they are doing and what data they are looking for. These explanations would allow students to make links between concepts and develop their conceptual understanding.
Examples and representations	P	Alan used a number of examples and representations during the lesson. While they appeared to be suitable, they also seemed to require some further development to make them more effective. For instance, when he used Christmas tree lights as an example for series circuits, a more insightful explanation would strengthen that example.
Metacognitive strategies	P	Alan's primary strategy in the lesson was for students to explore voltage and current differences in different circuits and explain why that was occurring. This strategy was seen as an adequate use of a metacognitive strategy.

Table 6.12: Alan's fourth post-CoRe design lesson. The concepts covered were current and voltage differences in series and parallel circuits.

Subject Matter Knowledge		
Appropriateness	A	All of the concepts in this lesson were in close alignment with Level 5 of the NZC.
Accuracy	L	Alan made numerous errors during the explanations during this lesson. He told students to measure voltage using the AC function on the multimeter. Then, at the end of the lesson during his wrap up of the practical work, Alan used theoretical data that was completely inaccurate. It appeared that he had confused the voltage and current rules of parallel and series circuits. He also stated that voltage flows.
Concept links	B	Alan made a number of links during the lesson and explained them. For example, brightness and voltage across the lamps, or current and resistance. However, other links could have been made, but weren't. Most notably, the link between current in series and parallel.
NoS/SI links	P	Alan made some implicit links to both the nature of science and scientific inquiry. For example, talking about conventions and symbols, and gathering data to explore relationships.
Knowledge of Student Understanding		
Prior knowledge	P	Alan referenced student prior knowledge a few times about series and parallel circuits, and using multimeters. He appeared to try and use that information to inform his lesson.
Variations in understanding	P	This whole lesson was based on Alan's previous lesson; students missed the point in the previous lesson and misunderstood the concepts. Since the whole lesson was based on this indicator, it has been deemed proficient
Questions used	B	Alan used a few questions during the lesson, but towards the end he started to answer them himself as he began to rush.
Knowledge of Instructional Strategies		
Sequencing of concepts	P	The sequence was appropriate, and the enactment was suitable. However, many students were still unsure. Breaking the lesson up further and explaining concept transitions would allow students to develop their conceptual understanding.
Examples and representations	P	Alan used many examples and representations during the lesson. Most of these were effective. For example, using the example of a dimmer switch to explain the link between resistance and current.
Metacognitive strategies	B	The strategy of having students explore trends in data and explain what was happening was seen as a metacognitive strategy. However, it was used in a limited way, particularly as inaccurate data was used by Alan.

6.3 Evaluating CoRe Design

The evaluation of CoRe design presented here is from the participants' perspective. Data was gathered after both CoRe design workshops through participant interviews: Group One teachers individually; and, Group Two and Three teachers in focus groups. The first evaluation interview focused primarily on CoRe design as a process and participants' experiences during that process. The second evaluation interview focused primarily on CoRe design as a PLD intervention for enhancing PCK. However, there were instances in each interview that could be attributed to CoRe design as a process or PCK development (see Appendices C2 and C3 for guiding questions). Also, after teaching Year 10 *Electricity and Magnetism* to their post-CoRe design class, Group One teachers were interviewed one final time to explore their thoughts of the entire study and PCK development as a result of CoRe design (see Appendix C4 for guiding questions).

Analysis of these data sets was done inductively by identifying recurring themes throughout the interview data within two broad categories: collaborative CoRe design experiences; and, potential for, and espoused, PCK development.

6.3.1 Tony's Evaluation

6.3.1.1 Collaborative CoRe Design Experiences

When Tony was first asked about his experience with CoRe design he reported that it was a useful process as it allows a large unit of work to be unpacked into manageable pieces:

It was good... A CoRe enables you to break a topic into smaller bits, so it seems less overwhelming... So, breaking it up into the big ideas, and then from there it's a good way of putting it all together.

(Tony, first CoRe design evaluation interview)

However, Tony expressed that the initial workshop was challenging as understanding the nature of science is complex, but he appreciated that it was intended to teach participants about the process. He indicated that the Year 10 *Electricity and Magnetism* workshop would be more applicable. Tony explained:

The nature of science is a hard one... That reading that you gave, half of it was defining what it actually is... It was good because it gave us an idea on how to build one [a CoRe]... I think that next week will be better because it will be something concrete that I will be able to apply to my teaching.

(Tony, first CoRe design evaluation interview)

When asked about useful aspects of CoRe design, Tony felt the collaboration between participants was the most important feature, as it allows participants to share their ideas and pedagogical approaches. He reported:

The collaborative aspect of it... Getting different heads together and talking about how different people approach things, I think that is pretty valuable.

(Tony, first CoRe design evaluation interview)

Tony identified time as being the only limitation with CoRe design. Nevertheless, he indicated that it would be useful to develop a CoRe for each topic, and suggested using times during the year when teachers may be able to work in this way:

It takes time. I mean, it would be quite good to develop a CoRe for every single topic that we do. But to develop a CoRe, from start to finish, you are looking at a number of hours... So that would be the main issue, finding time to do it... If you used teacher only days, or Term 4 can be a bit less busy.

(Tony, first CoRe design evaluation interview)

After the first workshop, Tony reported that he thought the process was beneficial and he was interested in taking part in CoRe design in the future:

Definitely. For junior science, or for Level One [NCEA], I think it would be a good thing to do. I think it would be a useful tool.

(Tony, first CoRe design evaluation interview)

During Tony's second evaluation interview (after the second CoRe design workshop), he was asked about working collaboratively again. He talked about how useful it was because he could learn from the experienced physics teachers. Tony added that as a department, they already collaborate. He explained:

Yeah, it's good. I like that. Having a guy who knows what he's doing, and then you can just get clarification and confirmation, or if you have a question you can ask straight away... I've asked Nick and William for help in the past... If you want to know about physics, go and talk to a physics guy... We sort of do this a little bit anyway, I think. As a department, we're quite open to talking to each other, no one is too shy to ask for help if they need it.

(Tony, second CoRe design evaluation interview)

To illustrate the usefulness of working with experienced teachers, Tony used the example of getting confirmation from Nick about his subject matter knowledge and instructional strategies:

I think sitting down with someone like Nick who knows what he's doing, I was actually able to get clarification of my own ideas and just check that the knowledge was sort of correct... How I've been teaching it, I haven't totally been leading my students down the wrong way... I found it quite good, because he was like "yeah, I do it like that", so I was like okay. I got a bit of confirmation.

(Tony, second CoRe design evaluation interview)

When asked if he thought CoRe design would be worthwhile to assist his department by helping them to frame and organise their collaborative efforts, Tony responded “yeah, definitely” (Tony, second CoRe design evaluation interview).

In his final interview, Tony talked about how CoRe design was useful because it offered new ideas. While he felt that teachers could always develop their teaching capabilities, he thought that CoRe design would not completely change their practice:

It is not like CoRe design is going to change everything in your practice... But, there were definitely some ideas that I came away with that I made use of. So I think everyone can get a little bit better.

(Tony, final interview)

To conclude his final interview, Tony reiterated some of his earlier points such as CoRe design being useful, wanting to take part in it again, and using time at the end of the year. He also suggested targeting a particular topic that may be troublesome, and ensuring that those teachers who were going to be teaching the unit were involved with the process, rather than just being given a completed CoRe:

Yeah, it was good. I would like to do it. I think it is good to do those for every topic that we do, especially Level One [NCEA] science... Maybe topics that are problematic, or ones where we are the weakest. What topic is worst in terms of kid's results, then let's develop a CoRe. I think that everyone who is teaching it needs to be involved. It is no good just getting three people, and saying okay, you guys sort out a CoRe for genetics, or something. You've got to involve everyone that is teaching it, so they can all get something from it. There is no point in just going, here you go... This time of year would be the time to do it, where the pressure is off. You could sort out some CoRes with different groups.

(Tony, final interview)

The following section reports on aspects of his PCK development that Tony espoused after his CoRe design workshop experiences.

6.3.1.2 Potential for, and Espoused, PCK Development

In the first evaluation interview, Tony was asked how he thought CoRe design might develop a teachers' PCK. He felt argued the process allowed teachers to learn about different teaching ideas and methods that they may have overlooked:

I think CoRe design will give people different ideas about doing stuff. I think that is quite good. There might be other ways of doing things that I haven't thought about.

(Tony, first CoRe design evaluation interview)

After the first workshop though, he thought that his PCK was not really affected. However, he did indicate that he would like to make some changes to his practice after taking part in CoRe design. Although, he identified there were time restraints, meaning that teaching students about the nature of science or scientific inquiry would not become a priority. Tony expressed:

[Pause]. Probably not. You have these ideals of the nature of science and it would be cool to do these things... You might say, how does a car work? You could have all these groups going and finding out about a how a certain part worked, and then present back to the class. That would be a cool thing. But are we going to do that? Probably not because we don't have the time. I like the idea of all of that, and I can definitely see how you could apply it.

(Tony, first CoRe design evaluation interview)

However, after the second workshop, Tony reported that he had enhanced his PCK:

Well yeah, I think I can explain voltage and current better.

(Tony, second CoRe design evaluation interview)

When asked about specific examples of what he had learnt during the workshop, Tony talked about how Nick's explanation and representation of voltage and energy (including the diagrams) had helped his understanding:

Nick talked to me about how to explain the concept of voltage... Why voltage is the same in a parallel circuit and different in a series circuit. He explained it in quite a good way. He drew a series and parallel circuit and explained how the voltage is shared. [Tony re-drew Nick's diagrams]. So he said like here is 12V, and this is zero. That was quite an important thing, I've never looked at the zero thing before. So to me, that made sense.

(Tony, second CoRe design evaluation interview)

Tony indicated that he would use Nick's explanation in the future with his students as the explanation and the diagrammatic representation made the concept of voltage easier to comprehend. He reasoned:

It makes sense like that... The energy that's been carried has not been used before when it gets here. And the same with here. [Tony referred to his diagrams]. So yeah, it makes sense to me... I think putting a zero there to visualise it. That has made a big difference.

(Tony, second CoRe design evaluation interview)

When asked about anything else he remembered learning in the workshop, Tony recalled Nick talking about issues when using analogies. However, he referred to Nick's diagrams and indicated that learning about the interconnectedness of voltage and current was the most important event:

Nick was talking about analogies being troublesome. But I think for me, it was these diagrams... You have to understand the difference between voltage and current, and how it all fits in together. I think that is pretty important. That was probably the thing that helped me the most.

(Tony, second CoRe design evaluation interview)

Concerning his sequencing of concepts, Tony indicated that he would probably use the same order that he had done in the past. However, he talked about making adjustments to practical lessons after talking with Nick:

Not really, I don't think so. I am probably going to stay with static first because it is kind of fun and it is relatively easy to do. Nick did talk to me about when he does the circuit stuff, he spends a whole period getting students to constructing circuits, so I would probably do that differently.... So getting them to think about the structure of the circuit that will be something I will do differently.

(Tony, second CoRe design evaluation interview)

In his final interview after teaching his post-CoRe design class, Tony stated that his PCK had been enhanced as a result of CoRe design, particularly as he was given new ideas and approaches:

Yeah, definitely. I think you can always get some new ideas of how to do things... Things like that are good.

(Tony, final interview)

Tony also realised he became more aware of students' understanding after being involved, but did not provide any specific examples:

[Pause]. I suppose so. I think so.

(Tony, final interview)

When asked about any developments or changes to the way he would monitor or assess students' knowledge, Tony recalled their Working Group discussions around the CoRe being focused on teaching concepts, rather than assessing them:

I think the CoRe was more about how to deliver the lessons, so we didn't talk about how to assess it. We talked more about ideas and things that we need to get across to the kids... I think that's the value of CoRe, the experienced teachers saying we've been doing this, it works for us, and it's a good idea. I think it is more beneficial for the teacher than the kids.

(Tony, final interview)

6.3.2 David's Evaluation

6.3.2.1 Collaborative CoRe Design Experiences

When David was first asked about his CoRe design experience, he indicated that the process was useful and he saw potential in using it:

I was quite impressed with the process. It seems to be a very sensible and productive way about going about things... I think it has got potential and it is very sensible. I think we have some issues in that regard, but I suspect most schools do. So having a system that people are going to be prepared to buy into and that they see value in, that is a good idea.

(David, first CoRe design evaluation interview)

David was asked whether he thought the staff within his department would buy into this process. He responded:

Yeah, I think so.

(David, first CoRe design evaluation interview)

Regarding useful aspects of CoRe design, David recognised that the pedagogical prompts made teachers think about what they were actually doing in the classroom and why, which could be overlooked sometimes. He reasoned:

I think that there is a tendency to not think through what we actually want to achieve, and why we want to do it... Over time, as you modify schemes, thinking gets lost. So having a formal set up whereby you can't avoid doing that, without intentionally avoiding doing that... That is where the real value lies. Just having things to prompt you, to prime you to think about what we are trying to achieve and why; that sort of thing.

(David, first CoRe design evaluation interview)

David reported that working collaboratively with his colleagues was positive as it allows for knowledge and ideas to be shared:

It is useful because we bring different experiences and content knowledge to the group... One of the strengths of teachers is that they are not generally competitive with each other.

(David, first CoRe design evaluation interview)

When asked about possible limitations with using CoRe design, David identified the time that it takes, but felt using CoRe design as an ongoing process would be a way to alleviate that issue:

Time. I think that if we were going to do that more effectively we need more time... I am sure it can be overcome. Maybe if you have an ongoing programme of reviewing schemes and things like that. Maybe once a month we sat down, and you didn't have to achieve anything today, we we've got an hour or two to sit down. So it's not like we have to finish it on the day, you just address each unit on a continual basis and review it. If that was an ongoing continual process, that would take away a lot of the time pressure.

(David, first CoRe design evaluation interview)

After the first workshop, David was interested in taking part in collaborative CoRe design in the future. While he expressed his particular area of expertise (horticulture) did not align with concepts in the junior science programme, he was interested in sharing his experiences:

Yeah, I think so. I don't feel that I have any great expertise in most of what we do in junior science. But, I have got a reasonable length of experience, and I would be quite happy to be involved in this sort of thing.

(David, first CoRe design evaluation interview)

David was asked about working collaboratively again after the second workshop. He reiterated his earlier comment about it being good, and also offered further insights about how it compares to other professional development opportunities at his school. In particular, he felt it would enhance teachers' pedagogical skills at the same time as reviewing schemes of work. David maintained:

Yeah, I think that it is great... I don't think we do enough of it now... I think it would be more productive for us to pick a unit and go through it, and have a regular programme of reviewing them. Not only would that develop PCK, but also review units to make sure we are still doing what is relevant. If we did it on a two or three year cycle, that would be a big improvement on what we do now... It would get you in regular contact with people so you could develop your pedagogy; you would be in the habit of consulting and sharing... I think a programme of this nature encourages that, and that is a good thing.

(David, second CoRe design evaluation interview)

David did identify a potential issue with working collaboratively; the possibility of teachers' ideas being overlooked. While he said it did not happen to him, he argued that it could be a possibility:

There is always the possibility of some peoples' ideas getting brushed over... There is always that potential. But, I think the benefits still far

outweigh the potential problems... In that situation, if you think people are not taking you seriously, you can always jump up and down a bit louder.

(David, second CoRe design evaluation interview)

In his final interview, David revealed he was apprehensive about taking part in CoRe design at first, but actually found it to be a positive experience, and wanted his department to consider CoRe design as a worthwhile process. David stated:

I was a little unsure about it before I was involved. Having been involved, I really enjoyed it. I felt like that it was a useful and really positive experience... I would like our faculty to sit down and talk about whether the idea is a good one, because I think it is. I think there is real value for kids there.

(David, final interview)

The following section reports on aspects of PCK development that David espoused after his CoRe design workshop experiences.

6.3.2.2 Potential for, and Espoused, PCK Development

In the first evaluation interview, David was asked about how he thought CoRe design might develop a teachers' PCK. He decided that the process highlighted particular knowledge areas where a teacher may need further development:

In terms of your ability to teach a topic, I think it is probably best at highlighting or informing the areas that are lacking. Thereby making it obvious where you need to do a bit of sorting out before teaching. I think that is where the main value lies.

(David, first CoRe design evaluation interview)

As for his personal PCK (pPCK) development after the first workshop, David judged there were no significant changes. However, he did mention how it made him think about the purpose of science and that made him see potential with CoRe design:

I don't think it has greatly at the moment, except that it reminded me why we are actually doing things [teaching science]. However, as a process, it looks like quite a good system. If we were to adopt that as a group process, I think that it would be good for everyone.

(David, first CoRe design evaluation interview)

David was asked if it might change his approach to teaching science, and/or whether he learnt new things about the nature of science and scientific inquiry. He reflected that it was not going to change his practice, but it did make him think more philosophically about science:

Probably not greatly at the moment... I did think about some of the definitions a bit more. So yeah, I did spend some time afterwards thinking about what people and why people do it, some of the terms, and why those are important. So it is a useful thing to do.

(David, first CoRe design evaluation interview)

However, after the second CoRe design workshop, David perceived his pPCK had developed as it gave him new ideas about teaching Year 10 *Electricity and Magnetism*. He stated:

Yes, I guess sharing ideas, picking up new ideas, and evaluating ways of doing things. Evaluating what I am doing now and sorting out what's good and what is less effective than it could be.

(David, second CoRe design evaluation interview)

To emphasise the value of sharing knowledge, and how that makes teachers more effective, David talked about how he learnt about PhET simulations as a result of

the workshop. He also used the example of working with Tony after the workshop as they discussed the actual CoRe, saying:

Tony asked if I had used those online simulations before, I thought no, I don't know about them. So he pulled them up and we had a look. So I could see those would be really useful and I hadn't used those before. So just sharing, getting a group together is really good because everyone has got different ideas, and you can pick the best ones. It makes life easier for us, and makes it more effective for the kids.

(David, second CoRe design evaluation interview)

David quoted other examples of what he had learnt from the workshop including clarifying his understanding of magnetic field lines with William and using computer-based methods of representing concepts. He said:

I was confused about magnetic field lines. I thought I knew what was going on, but when I looked in the book, I found what appeared to me, to be contradictory, and I wasn't quite sure. I thought what should I be teaching? I am better off now... Also, generally in my teaching, I probably don't use enough things like YouTube and simulations and things like that.

(David, second CoRe design evaluation interview)

Since the use of practical work was discussed in detail in David's Working Group, he was asked how that might affect future lessons. He talked about using more practical work in the future, but also ensuring it was appropriately structured to keep students on task:

I would do more practicals. I am inclined to do a lot more practical, and a lot more controlled practical next time... The equipment is interesting and exciting for the kids, which is great, there is a lot of potential there. But there's also the potential for kids to go astray and get very little out of it... So I think it needs to be teacher-directed.

(David, second CoRe design evaluation interview)

In his final interview, David was asked again about PCK development as a result of CoRe design. In contrast to his earlier comments, he described the changes as small, citing the contextual restraints of the school.

Probably not greatly at the moment... When we went through it as a group of teachers, I was actually quite excited. I thought this looks really good, I can see a lot of good stuff here. I like being able to sit down with other teachers and be able to say, you know, this stuff is really important, and this stuff, maybe not so much. I liked that approach, and there was a lot of that. I felt like I was getting a lot out of it. When I went to start applying that, I did fall straight back to the idea that these kids are going to have to do the same test as the other guys. They are doing to be doing the same exam as the other guys. So I can't afford to leave anything out that might have otherwise done. I did feel very constrained by the structure that we have, that we work under.

(David, final interview)

When asked about what changes in his teaching did occur as a result of CoRe design, David talked about the process making him more receptive to student ideas because he recognised that would help their conceptual development. He explained:

I tried to be more responsive to what the kids were saying about things... I thought that would be more effective in terms of their learning. If they had put something into it in the first place, then they are much more likely to get something out of it.

(David, final interview)

David was also asked about if he used different formative assessments with his second class as a result of CoRe design. He answered:

Not formally. I think I tried to informally. How effective I was, I am not sure.

(David, final interview)

6.3.3 Alan's Evaluation

6.3.3.1 Collaborative CoRe Design Experiences

During his first evaluation interview, Alan reported that it was a positive experience and a valuable process, particularly as the pedagogical prompts provide useful direction. He explained:

It was a positive experience. Once you establish your big ideas, the questions... The information that you have to put in is thorough, and it gives you an idea of the direction that you should be going. How to check for understanding, it takes into consideration teaching and pedagogy. If you can adapt it as you go along and take into account your teaching style and the groups you are working with, it is extremely useful.

(Alan, first CoRe design evaluation interview)

He identified other useful aspects, including how the process unpacks a unit and displays everything on one page, and how the pedagogical prompts address student prior knowledge, which can be overlooked:

I think the whole planning approach is useful. It makes you cover all of the bases and gives you an idea of where you are going, which I think is important. Also, you're not going through a booklet, it is all on one page... and the fact that it takes into account what students already know, which can be overlooked if you are comparing it say, with a scheme of work.

(Alan, first CoRe design evaluation interview)

Alan also revealed that he enjoyed working collaboratively and sharing ideas. While other participants had greater teaching experience and content expertise, he believed his recent teaching qualification at university gave him an advantage when talking about the nature of science and scientific inquiry:

I always enjoy that [working collaboratively], especially the situation that I am in compared to the others because they have got their experience; or more experience than I have on their content knowledge. I would say that the group I was in, I was a little more recent; I remember a lot from university. A lot of the key words and key questions were covered at university.

(Alan, first CoRe design evaluation interview)

Alan identified time as being the issue when developing a CoRe, but recognised that it could be adapted to use as a long-term PLD intervention, and that the CoRes produced would become the schemes of work:

It is quite time consuming initially. But I suppose it is like anything; once you get it going, it is something that could be easy to monitor, adapt, and change, depending on the class. But initially, it is extremely time consuming... I think if you put a few of them together, it would replace our schemes of work.

(Alan, first CoRe design evaluation interview)

Further to the time issue, Alan also suggested that identifying students' prior knowledge and possible misconceptions may be difficult, but that information can be adapted and changed:

Knowing prior knowledge and any misconceptions that students have might be a guess at this stage, rather than a solid statement. But it lends itself to be adapted and changed anyway.

(Alan, first CoRe design evaluation interview)

At the conclusion of his first interview, when asked about taking part in CoRe design in the future, he responded:

Yeah, definitely.

(Alan, first CoRe design evaluation interview)

During his second evaluation interview, Alan reported that the CoRe design process was worthwhile for him as he was able to learn from the others. He also indicated he was going to continue doing professional development with other participants in the immediate future. Alan said:

I think if anything, it is important for me personally to learn off everybody and their knowledge. And take what everyone has to offer and then create something. As opposed to just one way of doing things. I thought it was quite good. It was very worthwhile for me. In fact, I know with a couple of them, I am going to continue doing some PD [professional development] for electricity.

(Alan, second CoRe design evaluation interview)

Alan reiterated that working collaboratively was useful after the second workshop. Although, he did suggest that some teachers were so passionate that they could go off topic, in turn making the process longer:

Working collaboratively was really good. Anything like this is useful for me, which is why I am going to continue a little PD [professional development] around it myself... I think that sometimes people are so passionate about it, that we could have done what we did in half the time. I think we got off topic a little bit. There was a lot of individual celebrating of what they know, which is great, but if it can be condensed it could be a little more efficient.

(Alan, second CoRe design evaluation interview)

Alan was asked how he thought CoRe design could be used at his school. He suggested utilising their faculty members and addressing multiple topics at the end of the year, ready for the following year:

I think it is an end of year thing we can do. Because then we'd be set up and ready for the start of the year. You can get going straight away. Whereas at the moment, everyone is at different stages... I think it would be easy enough to address the Year 10 course. You don't need the whole faculty working on one topic, you can spread them around. If it is something that could be a living document from year to year, then it doesn't take much time at the end of the year to change and adapt.

(Alan, second CoRe design evaluation interview)

In his final interview, Alan expressed how being involved was good for him, and while he explored CoRe design at university, he now understood its purpose and how it could be used. He stated:

It has been good for me, it has been really good. I know about CoRe design, I did it at university, but it makes more sense now. I can see the bigger picture now instead of it just being a piece of paper in front of you... [At university] it was just used for an assignment. So that is why this has been useful because I can actually see how it could be used, and also the barriers that you might come up against, like assessments.

(Alan, final interview)

The following section reports on aspects of PCK development that Alan espoused after his CoRe design workshop experiences.

6.3.3.2 Potential for, and Espoused, PCK Development

During his first evaluation interview, Alan was asked about the potential of CoRe design to develop teachers' PCK. He reasoned that working through the process essentially plans a unit, and it teases out important pedagogical considerations:

I think it is in the planning. It makes the teacher aware of not only what to teach, but how to teach it. It gives you the space to fill it in and to actually think about it.

(Alan, first CoRe design evaluation interview)

Alan indicated that his pPCK had not developed as a result of the first workshop, particularly as he was aware of many of the concepts from university. Nonetheless, he talked about it being a useful exercise to refresh his knowledge:

Not really, because I think it is only something that I've known for less than 12 months anyway. It is something that I spent a lot of time looking at I try and put it into my teaching at this stage anyway... I didn't learn anything new, but it was a really good refresher. It made me aware of things that I had forgotten.

(Alan, first CoRe design evaluation interview)

During his second interview, when he was asked about PCK development, Alan indicated that it was too early to see changes, particularly as he was conscious of the assessment that his students had to complete. However, he did think it would impact his PCK for future classes. He said:

[Pause]. At the moment, it is difficult to judge. I know it will next year. The assessment has to change. Going through what we did, and reading through all of that... our schemes are still assessment driven. I feel that you have to tick the boxes, and I think that the assessment has got to align with what we did... The assessment should be updated in line with what the unit we did.

(Alan, second CoRe design evaluation interview)

When asked about changes to starting the topic, or instructional strategies, Alan talked about being more aware of the topic as a whole; but assessments would still influence his practice:

I am more aware of it. But again, I have always got in the back of my mind, you've got this assessment that you need to teach to. Whether that is a good or a bad thing, at the moment it feels like bad thing. Because it strays away from what we did... but there are bits in the assessment that I will change how I teach because of what I learnt.

(Alan, second CoRe design evaluation interview)

Alan was asked for specific examples of change in his teaching and he identified using PhET simulations and trying to incorporate what he had learnt about voltage and current. Although, he reiterated that these would be more influential if the assessment was changed:

So we talked about as an introduction, trying to explain current using the PhET website and simulations. I got that through talking with a couple of people about what they use. I have also taken into consideration a lot more of what people in the group perceived as being issues with misunderstanding with regards to voltage and current. There are a few things that I will change, but I think that change will come more next year if we realign the assessment.

(Alan, second CoRe design evaluation interview)

Alan was asked if there were concepts that he had learnt from the workshop. He said that he had, which would influence his pPCK, but there were too many to talk about:

Yeah, probably too many to go into. Like I've said before, I am learning all the time so anything new for me is a different approach I can use. Sometimes it works and sometimes it does, but that develops my PCK.

(Alan, second CoRe design evaluation interview)

In his final interview, Alan agreed the workshop had influenced his planning for his post-CoRe design class, but the assessment still had a large effect:

Initially, yeah. It didn't last long though, because of time and what they needed to know for their assessment.

(Alan, final interview)

When asked about his teaching with his post-CoRe design class, he talked about the intent of changing his practice, such as making concepts more relevant to students' lives, but requirements of the assessment negated too much change:

I think again, the plan was to have a different approach. I feel the direction the lessons went was better. It opened itself up more, it was more flexible to not only... Not necessarily what they need to know for the exam, but it was more relevant in my opinion for what they need to know when they are relating science to the outside world. But again, it ended up eating too much time with what they needed to know for their assessment. In fact, everything we teach is assessment driven at the moment... So I think, perhaps, the assessment needs to be changed. The CoRe is modern and relevant, and it's exciting. It will be motivating for the students as well. It's almost like a square peg trying to go into a round hole because the assessment is still quite traditional.

(Alan, final interview)

Regarding his PCK enhancement for teaching Year 10 *Electricity and Magnetism*, Alan acknowledged he had learned subject matter knowledge, which combined with his pre-existing pedagogical knowledge, strengthened his PCK:

Yeah, I think it was good. In a sense, I am not as experienced at teaching science as some other people in the department. But, I am experienced at teaching. So I can use... I am learning the content knowledge and can see what I know and see the pedagogy that I know, and see how I can put them together.

(Alan, final interview)

Alan recognised CoRe design had made him more aware of students' understanding, particularly that students find it difficult to understand the concept(s) explaining phenomena. He reasoned:

Yeah, definitely. Just their whole understanding of how electricity works or what it is. I think a lot of them almost take it for granted that you press a switch and the light goes on. They have got no idea how... static electricity, again, they know what it does, but not what it is. So I think I have got an appreciation. I already had, but even more so after CoRe design.

(Alan, final interview)

Alan indicated that taking part in the CoRe design process promotes teachers to monitor student understanding by using more questions:

It [CoRe design] opens itself up a lot more for questions and answering type of assessment, as opposed to over the shoulder workbook assessment... So you can expand a bit more on questioning and answering.

(Alan, final interview)

The following section reports the Group Two participants' evaluation of CoRe design as a PLD intervention for enhancing PCK.

6.3.4 Group Two Teachers' Evaluation

The focus group interviews with Group Two teachers that evaluated CoRe design for enhancing PCK yielded significantly less data than that obtained from the Group One participants. While a reason for using focus groups was to allow for ideas to be shared and elaborated on, more often than not, one Group Two participant would offer a succinct response and others would agree. Also, these participants were not interviewed a third time. Nonetheless, these teachers offered useful insights about their CoRe design experiences and how PCK may be developed.

6.3.4.1 Collaborative CoRe Design Experiences

These teachers indicated CoRe design was useful as it allows units of work to be unpacked. They explained:

Harry: *I think that it teases out the concepts that you want to teach quite well.*

Lucas: *Yeah, I agree with that.*

Kate: *It also established what you want to teach. It enables you to think outside of the square. Throw everything out there and then go, well this is what we want to do.*

Harry: *It makes you think about what the key things that students need to know, or learn about, in a topic.*

(Group Two, first CoRe design evaluation focus group interview)

Kate led the discussion about possible limitations with CoRe design while both Harry and Lucas nodded in agreement. She identified having to learn the process, and then getting practising teachers to think beyond what they are currently doing, as important limitations:

I think there is two. One is actually teaching people and getting them to understanding it, so that is what we did. Secondly, getting people to think beyond what they're doing; to think outside of what you are doing and, don't revert back to what we've always done. Because we are not after that. We are after, let's open it up for discussion.

(Kate, first CoRe design evaluation focus group discussion)

The group agreed future involvement with CoRe design was worthwhile, and offered their insights on how they saw it being used:

Lucas: *Well it would be valuable to change a unit, or to tweak a unit.*

Kate: *I think if we were going to look at changing the content of the programmes that we have, or aspects of it, then I think it would be a valuable tool.*

Harry: *I think it has got some use outside of what we did. I think it could be used in many situations, or at any level.*

(Group Two, first CoRe design evaluation focus group interview)

During their second evaluation focus group interview, these teachers were asked how they found working collaboratively and they all indicated that they would work in that away again:

Kate: *It was good.*

Harry: *Yeah I thought it was all good, it was well worth the exercise.*

Lucas: *I think if you didn't worry about marking, and put aside those other school influences, and became involved and integrated in the process, then it was quite good to talk about those things.*

Harry: *It was a good focus session.*

(Group Two, second CoRe design evaluation focus group interview)

Again, Kate led a discussion about the worth of CoRe design. She focused on CoRe design helping teachers with their own understanding, but felt the impact might be limited, reasoning:

I think it helped with clarity. It brought up discussion about peoples own misunderstandings and own misconceptions about things, and I think those discussions were really beneficial. But I don't think anyone went away and revisited their plan of how they deliver it.

(Kate, second CoRe design evaluation focus group interview)

Harry and Lucas agreed with her.

The researcher shared with these participants that the Group One teachers had used the workshop to influence their future lessons. Lucas responded:

But we are not teaching it. So, [for us], that thinking is on the backburner.

(Lucas, second CoRe design evaluation focus group interview)

The following section reports on aspects of PCK development that the Group Two teachers espoused after their CoRe design experience.

6.3.4.2 Potential for, and Espoused, PCK Development

When the Group Two participants were asked about the potential of CoRe design to develop teachers' PCK during their first evaluation focus group interview, Kate focused on how it would particularly help inexperienced teachers:

I think some aspects, where it says the things that we know, but we don't want the students to know, I think if you particularly have a teacher that hasn't taught it before, some of that information is really useful to them. Because it is hard to define for somebody, or for them themselves when they do their prep to work out what they teach and what they don't teach, but I don't need to teach that yet. I think that would really help.

(Kate, first CoRe design evaluation focus group interview)

Harry and Lucas agreed with her.

When asked about their own PCK development after the first workshop, there was a long pause. Harry and Lucas then identified no pPCK development, saying:

Harry: *Not for me personally.*

Lucas: *Not for me. Only because I think I incorporate a lot what was said anyway.*

(Group Two, first CoRe design evaluation focus group interview)

In their second focus group interview after the Year 10 *Electricity and Magnetism* workshop, these teachers were asked how the CoRe design process may have influenced their PCK. After a pause, only Lucas responded where he talked about using that information in the future. Both Kate and Harry nodded while Lucas said:

If there was written documentations to look at or glance at, I would look at it before going into the unit. I would touch base with it again.

(Lucas, second CoRe design evaluation focus group interview)

6.3.5 Group Three Teachers' Evaluation

The Group Three teachers' focus group evaluation interviews yielded more data than the Group Two teachers, but less than Group One's. These teachers embraced the focus group interview format, and would often build on each other's ideas. At times, they became so engrossed in their discussions that they would go off topic and the researcher had to redirect focus. This change in focus was particularly evident when William engaged in the discussion, as he often reflected on his extensive career and offered detailed insights into professional development and teaching physics. Their experiences with CoRe design and their views on how it can develop PCK is now reported.

6.3.5.1 Collaborative CoRe Design Experiences

William and Chris found the initial CoRe design process challenging, and wanted more direction:

Chris: *I found it really hard with the group I was in. We were all thinking in different directions... It was good, but it was hard. I would ask a question and their answers were way out; I struggled.*

William: *I think it was hard for me because I want a practical solution. That is how I think... When we started the CoRe, Sarah said we were not doing right – we were one step ahead. It was hard to interpret what was wanted.*

(Group Three, first CoRe design evaluation focus group interview)

When asked what aspects of CoRe design were useful, Nick led the discussion while William and Chris agreed with him. Nick focused on how the process makes teachers think about what they are teaching and why:

I think it is really good to be thinking about why we are teaching these particular bits, and what we should be teaching – why are we doing that. And things like, what are the bits that the kids are going struggle with, and sharing that.

(Nick, first CoRe design evaluation focus group interview)

When identifying limitations of CoRe design, these teachers unanimously talked about the time it takes, and felt it would be overcome if school management saw it as being worthwhile:

Nick: *The downside is the time that it takes to share everything.*

Chris: *I think finding the time to sit down and do it properly... There is a way to overcome that. You could use a teacher's only day to do something like that.*

Nick: *If they [school management] decide it's important enough, then they will make time.*

(Group Three, first CoRe design evaluation focus group interview)

There were divergent responses about being involved with CoRe design in the future. Chris was only interested in taking part if it was focused on a topic he was more comfortable with, while Nick suggested he could be interested, and William talked about his career stage:

Chris: *No thank you. It's not my strength.*

William: *At my stage in my career... [Near retirement].*

Nick: *Possibly. I am more theoretical than these guys.*

Chris: *When it comes to the practical bit, then I would be able to contribute to it. When it is philosophy, no. When it goes, how are we going to teach magnetism? Then I would be comfortable.*

(Group Three, first CoRe design evaluation focus group interview)

During their second evaluation focus group interview, these participants reported that they enjoyed the collaborative nature of CoRe design, particularly as they were comfortable talking about teaching physics concepts. They stated:

William: *I found it quite interesting to see the point of view of the non-physics teachers...*

Chris: *Yeah...*

Nick: *Yeah...*

William: *It was an eye opener seeing Alan's eyes light up when I turned around and said what was the voltage at that point?*

Nick: *It would be interesting to be on the other side of that as well. We went in as the people who knew what we were talking about. But doing a biology one, I don't think we would be as comfortable in that environment.*

Chris: *No, we wouldn't.*

(Group Three, second CoRe design evaluation focus group interview)

Building on that conversation, William reflected on why he drew diagrams on the board and asked questions. Essentially, he was trying to highlight how teachers without a physics background don't understand many physics concepts, which puts them at a disadvantage when teaching it, and students at a disadvantage if they choose to study senior physics. William explained:

What was going through my mind was to try and point out that non-physics teachers don't really understand it, and they are teaching at a disadvantage. I mean, honestly, just last week a teacher asked me to remind them which way voltmeters are connected. Now if they're going

in, feeling that way, they can't be all that comfortable... We want our students to do well in Level Two and Three, even if another teacher takes them. How can they possibly do that?

(William, second CoRe design evaluation focus group interview)

All three teachers saw collaborative CoRe design as an effective PLD intervention, and were interested in seeing it adopted to their faculty, although again the time required is an issue:

William: *Yes!*

Chris: *It's a time issue.*

Nick: *Yes, it's just a time thing, because you can't really do a CoRe in less than two or three hours.*

William: *I think also, some staff might not like it. They might think it's just the physics teachers trying to show off. As long as it is seen as trying to help people and they took it in that vein, it could be really useful.*

(Group Three, second CoRe design evaluation focus group interview)

When asked if there were any issues working collaboratively, they talked about how different teachers will have different opinions on the best approach for teaching concepts:

Nick: *You have to realise that you are not all going to necessarily agree on the best way to do it. I mean, me and William get on, so we can have an argument and not get upset, and we did. We disagreed on the best way to do it, so that is going to happen, and you just have to deal with it.*

Chris: *You just need to be grown up enough to realise his way is best for him, and your way is best for you.*

(Group Three, second CoRe design evaluation focus group interview)

The following section reports on aspects of PCK development that the Group Three teachers espoused after their CoRe design experience.

6.3.5.2 Potential for, and Espoused, PCK Development

When asked about the potential of CoRe design for developing PCK during their first evaluation focus group interview, these participants indicated it was worthwhile, particularly, as it allows for knowledge and ideas about teaching to be shared:

Chris: *I think it is a useful process.*

Nick: *I think just talking about these pitfalls and things, and to address them and teaching ideas. They are very beneficial. It is very useful.*

Chris: *If you are not experienced, it is a really good exercise.*

Nick: *It is a knowledge sharing tool... Putting together the ideas in a way to teach and misconceptions for people who haven't had that experience.*

(Group Three, first CoRe design evaluation focus group interview)

Regarding their own PCK development, they indicated that little change had occurred. Nick said he would not include more nature of science or scientific inquiry context in his lessons, and both William and Chris remarked there was too little direction to change their practice. After an initial pause, they expressed:

William: *It got me thinking, what is the point of science? But I want some directive.*

Chris: *If it was a specific topic, it would give me more directive... I think it will make me a little more effective in getting it over to the students.*

Nick: *I don't think it will make me do any more than I am doing now.*

(Group Three, first CoRe design evaluation focus group interview)

When asked about how worthwhile the Year 10 *Electricity and Magnetism* CoRe design workshop was for professional learning, these participants indicated that it had done little for them, but was beneficial for others; particularly Group One teachers. In terms of benefit to them, they stated:

Nick: *Chucking ideas around, and just seeing different ways of coming at things. And William and I arguing about things.*

Chris: *Just re-thinking the whole thing.*

(Group Three, second CoRe design evaluation focus group interview)

Whereas, the benefit to the other participants was significant in their view:

Nick: *Well, some of it was just even learning the basic principles. Like I was able explain to Tony, why does current in a parallel circuit divide? He knew the rule, but he had no idea why. So, I mean, that deepened his understanding, so I think he will be able to explain things better to his class.*

Chris: *I was with Alan, and he found that very useful as well. In terms of learning to understand those concepts a lot better.*

Nick: *And it is all very well, you can sit down and say okay, ask me some questions about electricity, for people who don't know electricity. But in some ways, they don't know what they don't know. But when you sit down and do a CoRe, it triggers off conversations about things, about the necessary content.*

William: *I also noticed that Alan, when I started to talk about the voltage, he was actually looking like he wanted to learn. Lucas was looking a bit defensive, but Alan looked like he wanted to learn.*

(Group Three, second CoRe design evaluation focus group interview)

After talking about the benefit to Group One participants, Nick said “presumably, you are going to ask them as well. But my impression was that it was good” (Nick, second CoRe design evaluation focus group interview). It was disclosed to these

participants that two of the Group One participants had already been interviewed, and how they talked about the process being beneficial as they saw how physics teachers approached physics concepts. Nick elegantly summarised the outcome, saying:

Yeah, that's pedagogical content knowledge. That's not just understanding the concept, but how to hook it into the kids, and how to get it to the kids.

(Nick, second CoRe design evaluation focus group interview)

When asked if they would change how they might approach junior science concepts in the future as a result of CoRe design, Nick and William talked about making the content more appropriate:

Nick: *Yeah, I possibly go in at too high of a level sometimes... Sometimes I am going conceptually beyond what the kids are capable of.*

William: *Yeah, I do the same thing as well. I think we are driven by time constraints.*

(Group Three, first CoRe design evaluation focus group interview)

The following section presents the inductive themes from Phase Three, that is, themes arising from the data.

6.4 Inductive Themes from Phase Three

6.4.1 Inductive Themes from Group One Participant's Data

In Chapter Four, the data from the three Group One participants were separated when reviewing for emergent themes. The rationale being that different themes can become apparent, which are unique to each teacher. However, when reviewing their Phase Three data, there was significant overlap or similarity in the emergent themes. Hence, rather than reporting the same findings three times, they have been combined here.

When reviewing the Phase Three data obtained from the Group One participants, one overarching theme became quite apparent. All of the Group One participants saw CoRe design as an effective PLD intervention that influenced their pPCK and ePCK. Evidence for that finding was apparent in all aspects of the data; both from observing changes in lessons, and in how the participants reported knowledge sharing and enhancements during the workshop. However, the learning context they were immersed within still significantly governed their teaching.

The influence of context, particularly assessment, was evident in all of the lesson observations. For example, Tony ensuring students copied definitions and underlined key words since they were to be examined (lessons one, two, and three, post-CoRe design), and both David and Alan moving through content much faster after the term break as they approached the end-of-year examination, which assesses the entire year's work (David: lessons four and five, Alan: lessons three and four, post-CoRe design). Furthermore, all three participants made reference to this theme during their interviews by acknowledging that the CoRe design process was useful, but they still felt limited by the assessments. Thus, the teachers indicated they did not utilise their knowledge developments fully, and that that if CoRe design is used in the future, assessments need to be changed.

6.4.2 Inductive Themes from Group Two and Three's Data

These two data sets are much smaller than those obtained from the Group One participants, so the decision was made to combine them.

When combining and reviewing their evaluation data, there was one theme that became obvious. All these teachers saw real value in CoRe design and thought it was a useful PLD intervention for developing teachers' PCK. They viewed it as a valuable mechanism for sharing knowledge and discussing different ways of conceptualising and teaching concepts. However, they strongly were of the view that CoRe design would only have impact on teachers' knowledge and practice if they were of direct use. For example, to get the most benefit from the process, teachers would need to either be: teaching those particular big ideas in the near future; or, have a limited knowledge base, in terms of subject matter knowledge and topic-specific instructional strategies around the big ideas.

6.5 Chapter Summary

This chapter has presented the research findings from Phase Three of this study to evaluate collaborative CoRe design workshops as professional development interventions to enhance PCK. During this phase, Group One teachers were observed again as they taught their second Year 10 science class. These observations were analysed using the same observational protocol as those in Phase One. All nine participants were interviewed to gain insights into their experiences from involvement in the workshops and to explore their PCK development. Group One teachers took part in individual interviews, while Group Two and Three teachers took part in focus group discussions. Group One teachers were also interviewed a final time after they had finished teaching the unit to explore what changes occurred in their classroom practise as a result of CoRe design (Group Two and Three teachers did not have this final interview).

The analysis of lesson observations revealed changes to different enacted PCK (ePCK) indicators for the Group One teachers after taking part in CoRe design. These findings are compared to the ones presented in Chapter Four in the following chapter to highlight ePCK enhancements.

Interviews and focus group discussions revealed that all of the participants saw value in collaborative CoRe design and thought it was a worthwhile PLD intervention. While there were some limitations identified, there were also solutions offered to overcome those. Similarly, all participants talked about how collaborative CoRe design can enhance a teacher's PCK. However, only the Group One teachers indicated they have developed their PCK.

An inductive analysis of the Group One participants' data revealed the degree to which their PCK was enhanced was influenced by the school context and assessments. Combining the Group Two and Three's Phase Three data revealed collaborative CoRe design was only going to have great impact on teacher knowledge if the focus of the workshop aligned with the participants' goals.

The following chapter used a cross-case analysis approach to interpret and discuss the findings presented in the three Findings Chapters in relation to the research questions.

Chapter Seven

Interpreting and Discussing the Findings

7.1 Overview

This chapter interprets, discusses, and evaluates findings presented in Chapters Four, Five, and Six in relation to the research questions guiding this study and the literature reviewed in Chapter Two. The three research questions guiding this study were:

1. In the New Zealand context, what does the personal and enacted pedagogical content knowledge (pPCK and ePCK) of junior science teachers with a limited physics background look like for the Year 10 topic *Electricity and Magnetism*?
2. What impact does collaborative CoRe design have on the pPCK and ePCK development of junior science teachers with a limited physics background for the New Zealand Year 10 topic *Electricity and Magnetism*, when working collaboratively with experienced physics and junior science teachers?
3. What are teachers' experiences and perceptions of collaborative CoRe design as a professional learning and development (PLD) intervention for enhancing pPCK and ePCK?

Each of these research questions frames the following sections in this chapter: Section 7.2 discusses the initial pPCK and ePCK of Group One before they took part in collaborative CoRe design; Section 7.3 discusses the impact of collaborative CoRe design on Group One teachers' pPCK and ePCK development; and, Section 7.4 discusses all participants' experiences and perceptions of collaborative CoRe design as a professional development intervention for enhancing PCK. Each section reiterates the research question and the findings used to answer that question. A cross-case analysis (Yin, 2014) of the findings from the three case studies has been conducted to highlight similarities and differences. Links to relevant literature are also made, and each section concludes with a summary to answer the research question. There is also a chapter summary.

7.2 Group One Teachers' Initial pPCK and ePCK

This section addresses the first research question:

In the New Zealand context, what does the personal and enacted pedagogical content knowledge (pPCK and ePCK) of junior science teachers with a limited physics background look like for the Year 10 topic *Electricity and Magnetism*?

This research question is answered using a cross-case analysis of the findings reported in Chapter Four. This cross-case analysis focuses on the pPCK and ePCK of each Group One teacher determined from data collected prior to the participants taking part in collaborative CoRe design, using the Refined Consensus Model of PCK (RCM of PCK) as an analytical framework.

7.2.1 Cross-Case Analysis of Group One Participants' Initial pPCK

To facilitate the cross-case analysis, comparisons across the case studies are made using the same pPCK components from the RCM of PCK that were used in Chapter Four. In the following sub-sections, the case study findings for each pPCK component are dealt with in turn. For example, the first subsection compares and contrasts findings about the case study teachers' personal philosophies for teaching science to identify similarities and/or differences in that component of their baseline pPCK. These cross-case findings are then linked to existing literature and discussed in light of their contribution to the field. The subsequent sub-sections follow a similar pattern.

7.2.1.1 Personal Philosophy for Teaching Science

All three participants affirmed that science education is important and valuable. They reasoned that science allows students to understand phenomenon in the world around them. Tony and Alan's thoughts on why science is included as one of the learning areas in the New Zealand Curriculum (NZC) (Ministry of Education, 2007) reflect their personal teaching philosophies. For example, Tony believed that the

government shared his view on science education, while Alan reiterated his personal philosophy as a rationale for the inclusion of science in the NZC. David, on the other hand, maintained that the government sees science as a priority because it allows students to advance their knowledge through investigating, which he thought was an important consideration for functioning in a modern society that is reliant on scientific knowledge.

However, when identifying goals for their classroom teaching of Year 10 *Electricity and Magnetism*, not all the teachers' views reflected their personal philosophies. David and Alan did aspire to their students making sense of their world and understanding every day phenomenon, using *Electricity and Magnetism* as the context. In contrast, Tony's teaching goal was not influenced by his stated teaching philosophy. Rather, his goal was to ensure students were ready for the test that was prescribed and administered by his school.

Similarities in pedagogical approaches were identified when comparing Tony and David's views about students acting as scientists in their classroom. They explained that such pedagogy could be achieved by students investigating questions or problems, carrying out their own research, and critically discussing what they had found out. However, they both maintained that realistically, such pedagogy was not achievable in their classrooms as contextual restraints (e.g., class size, student behaviour, or limited time allowances) were too influential. In contrast, Alan's view on students acting as scientists differed from Tony and David's perceptions. While he expects his students to act as scientists, he also challenged what 'acting as a scientist' means. Alan argued that when students are learning about science in his classes they are working as scientists. He believed his pedagogy naturally encourages students to be inquisitive about phenomena and evidence driven when making claims.

When comparing Tony, David, and Alan's responses about the nature of science and scientific inquiry, and their pedagogical strategies for teaching these aspects of science, their views were markedly different. Tony viewed the nature of science as a process for discovering knowledge, which he promoted in his lessons by encouraging students to be curious and interested, and to seek answers when they have questions. Despite his advocacy for this approach, on probing he was unable to articulate in depth what scientific inquiry involved, choosing to reiterate

comments about students acting as scientists and focusing on the use of an overarching question, which he felt would be difficult to achieve in practice.

David's detailed view on the nature of science focused on students' attitudes towards understanding scientific knowledge. He stated that he was not good at incorporating this dimension into his lessons, but tried to encourage students to recognise there are alternate ways of explaining phenomena. David argued that scientific inquiry involves controlling variables and being analytical. Like Tony, David repeated his earlier comments about students working as scientists, including how he felt it was unachievable in current classroom practice.

Alan was unable to explain what the nature of science meant in much detail, although when prompted during the interview, he recognised that his close following of the detailed departmental schemes in his teaching meant he actually did teach students aspects of the nature of science. When explaining his view about scientific inquiry, Alan talked about being evidence driven and adhering to a scientific method, which he indicated is a set procedure to be followed.

The personal philosophies of Tony, David, and Alan towards teaching science show some alignment with the international science education curriculum goal of becoming scientifically literate. For example, their commonly shared focus on students learning science so they can understand the world around them is recognised internationally as a component of being scientifically literate (NRC, 2012). Students learning about science to understand their world is also emphasised in the NZC (see Ministry of Education, 2007, p. 28). However, while these teachers had this focus, they did not elaborate why their students learning to understand their world was important. In particular, there was no mention of their students learning science to make informed decisions about socio-scientific issues in their lives, which is a quality N. G. Lederman et al. (2014) identifies as a fundamental aspect of being scientifically literate.

Similarly, teaching students about the epistemological underpinning of science and scientific processes are considered key for developing scientific literacy in the literature (e.g., Fives et al., 2014; N. G. Lederman et al., 2014). Interpreting evidence from the case study teachers' dialogue on epistemic awareness, it suggests they have naïve views about the nature of science and scientific inquiry. The NRC

(2012) and N. G. Lederman et al. (2014) identify a number of key nature of science and scientific inquiry understandings that students need to develop for scientific literacy, namely: scientists seek explanations about phenomena, both new and existing; data collection methods should be critiqued for their effectiveness; and, students should appreciate the subjective and tentative nature of scientific knowledge. None of the case study teachers mentioned such understandings in their responses; instead two made fleeting references to developing knowledge via investigations and the third made no links.

In terms of scientific inquiry and students acting like scientists, Tony and David's views aligned with developing scientific inquiry skills promoted by Jadrich and Bruxvoort (2011), Lederman and Lederman (2012), and N. G. Lederman et al. (2014). These teachers thought that students should be engaging in authentic inquiry experiences by approaching a question or problem from a scientific point of view. In reality though, both teachers felt using this pedagogical approach would be too challenging because of contextual restraints, such as the time available or classroom management issues. This finding is similar to those Staer et al. (1998) reported when they researched science inquiry lessons in secondary schools. These authors note that teachers had great difficulty implementing authentic inquiry into their science lessons because of the learning context. For example, it was noted that available class time and student behaviour were two factors that greatly impeded this pedagogical approach. The third teacher, Alan, advocated for learning being evidence driven, which is a key part of scientific inquiry (NRC, 2012). Although, he also indicated that scientific inquiry refers to following a scientific method, which is a naïve view (Hume & Coll, 2008; N. G. Lederman et al., 2014) as there is no singular method (NRC, 2012).

In this study, participant's personal philosophy for teaching science has been conceptualised as having an amplifier or filter effect on knowledge, rather than being a form of knowledge in its own right. Although, in their PCK research, Gardner and Gess-Newsome (2011) saw knowledge of the nature of science as an important component of PCK for teaching science. When comparing the case study teachers' responses in this study with the work of Gardner and Gess-Newsome (2011), a limited to basic level of understanding about the nature of science is seen.

7.2.1.2 Knowledge of Curriculum

When talking about teaching of Year 10 *Electricity and Magnetism*, all three teachers spoke of their reliance on the specific learning outcomes (SLOs) in the school's scheme. These SLOs were developed as an interpretation of the NZC by the head of junior science. Their goal was to ensure each outcome had been covered in their teaching and they did not teach beyond the scope of these SLOs. In other words, the SLOs formed the curriculum that they endeavoured to teach.

As for particular concepts that they thought should be included, their unanimous belief was that concepts should be relevant to the students' everyday lives to ensure they had an understanding of the world around them. These findings reflect their personal philosophies for teaching science, as reported earlier. Tony also stated that concepts that aligned with the following year's programme, to prepare students for their Level One National Certificate of Educational Achievement (NCEA) examinations, ought to be taught.

Identifying core ideas and concepts to teach (Park & Oliver, 2008) and being aware of specific curriculum programmes (Magnusson et al., 1999) are important considerations for PCK. However, these teachers were unable to identify the key concepts for this topic were, rather, it was clear that they were influenced by their school's interpreted science curriculum as opposed to the NZC. Interestingly, Tony's response about preparing students for the following year partially links to what Magnusson et al. (1999) identify as understanding curriculum goals and objectives, as he was aware of the learning required in subsequent years.

7.2.1.3 Knowledge of Students' Understanding and Learning

Tony, David, and Alan expected students to have some prior knowledge of *Electricity and Magnetism* before starting this unit of work, albeit at a basic level (e.g., knowing some electrical components from everyday experiences). Despite this recognition of their students' prior knowledge, they did not elaborate on how it would influence their pedagogy.

Similarly, all three participants recognised that students have different learning needs and styles, and offered suggestions for accommodating these needs. For example, while their responses were brief, Tony and Alan emphasised using

practical work with their students. David wanted to use a pedagogical approach where students could self-direct their own learning within set boundaries. Although he felt there would be issues when students were learning about interesting concepts that were not going to be assessed or reported to parents.

As opposed to misconceptions per se, all teachers spoke of their students having difficulties understanding particular concepts. David identified specific concepts that caused difficulty (e.g., conceptualising voltage and current), while Tony spoke of an overall lack of understanding. Alan felt that the term misconception was not correct, rather, students found it difficult to make the conceptual link between scientific theory and their experiences.

Having a well-developed pPCK, with respect to the component of knowledge of students' understanding and learning, includes having an appreciation for students' prior knowledge (including misconceptions) and their learning needs, and being able to vary lessons to ensure students' needs are met (Gardner & Gess-Newsome, 2011; Lee et al., 2007; Magnusson et al., 1999; Park & Oliver, 2008). While these participants recognised that students would have prior knowledge, they did not elaborate on how that might influence or inform their classroom practice. Similarly, their responses about students having varied learning needs did not show insights about how they might be pedagogically responsive in practice. Furthermore, while David's comments about students' difficulties with certain concepts reflect findings from the literature about common misconceptions students have about the same concepts (e.g., Bauman & Adams, 1990; Johsua, 1984; Tasker & Osborne, 1985), Tony and Alan's responses showed little insights or knowledge about documented student misconceptions for the *Electricity and Magnetism* topic. Although, Alan's comments about misconceptions arising from not making conceptual links is a similar viewpoint to Leach and Scott (2003), who suggest misconceptions may arise from the misalignment between terms used within a scientific and an everyday context.

When these findings are compared to the research by Lee et al. (2007), who critically examined this component of PCK when analysing beginning science teachers' PCK using interviews and observations, a limited or basic level of this component of pPCK is identified.

7.2.1.4 Knowledge of Topic-Specific Instructional Strategies

There was little similarity amongst the Group One participants' knowledge of topic-specific instructional strategies. All, for example, had different ideas about starting the unit: Tony wanted to do a fun activity, David used the SLOs to guide him and started this unit by explaining the first SLO before moving down the list, and Alan wanted to explore student prior knowledge by asking questions. Again, after their first lessons, all three teachers offered different ideas about proceeding forward. Tony wanted to give students notes and definitions, and to cement their own knowledge by having them make circuits; David continued down the list of SLOs while trying to relate concepts to students' lives and having students make their own discoveries through practical work; and, Alan wanted to use student ideas and continue to develop their understanding, particularly in relation to everyday experiences, although he did not talk about how he tried to achieve this aim. When asked about a particular instructional strategy they use, all three talked about guided-exploration practical lessons.

Within their responses about particular strategies they use, there was no mention of using representations to make complex ideas more comprehensible for students, which Nilsson (2014) argues is a key requirement of this PCK component. Using models or analogies to represent complex ideas and concepts are examples of instructional strategies that can mediate their understanding for learners (e.g., Coll, 2006; Harrison & Treagust, 2006).

While there was no mention of representing complex ideas, when reviewing their ideas for practical lessons to seek what Magnusson et al. (1999) describe as subject specific strategies, it appears that each teacher addresses some of the points from the 5Es Learning Model, as illustrated by Hume (2013) (see Table 2.6 on Page 60). For example, they all wanted students to explore concepts and then develop explanations. Alan's response also aligned with engaging students, as he wanted to explore prior knowledge. Interestingly, David's pedagogical approach suggested a discovery orientation towards learning (Magnusson et al., 1999), where students make their own discoveries and develop their own explanations.

It is difficult to compare these responses to existing PCK research, because while their responses did not show an indication about their knowledge of representing

complex physics ideas, they did describe actual strategies they use. So, when comparing these findings to the PCK research by Gardner and Gess-Newsome (2011), Alonzo et al. (2012), and Lee et al. (2007), it appears that this component of pPCK, for each teacher, ranges from limited through to proficient, depending on which particular aspect of the component is being analysed. For example, in terms of representing concepts, a limited or basic level is identified. In comparison, their practical strategies partially align with subject specific strategies, which reflects a proficient level.

7.2.1.5 Knowledge of Assessment Strategies

Data to evaluate the assessment component of the Group One teachers' pPCK for the *Electricity and Magnetism* topic was sparse. The group briefly talked about what they did in the classroom and how assessment strategies they used influenced their practice, but there was little indication about specific assessment strategies they used for monitoring learning in the *Electricity and Magnetism* topic.

For example, both Tony and David shared common viewpoints on assessment, such as how school assessments (i.e., topic tests and examinations) affected their practice. For instance, these school assessments influenced their earlier comments about students acting as scientists in their classrooms; their self-perceived role was to ensure students were ready for the assessments as opposed to promoting students acting as scientists.

Both Tony and David also shared similar views on formative assessment; they use this strategy in a very informal and casual way to find out what students know so they can adjust their teaching accordingly. For example, asking students questions during the lesson to gauge understanding, but not recording any information.

In comparison to the others, Alan's viewpoint on assessment strategies primarily focused on formative assessment. He did not mention the school-based assessments, rather he sought to gauge student understanding through question-based tasks during his lessons.

7.2.1.6 Sense of Self-Efficacy

All three participants indicated that they felt capable when teaching this topic, but fell short of being experts. They all referenced their background experiences of developing their subject matter knowledge and teaching science, and indicated that there was room for PCK growth for this topic. Interestingly, both Tony and Alan indicated that they had a pedagogical advantage over other teachers because their level of understanding of concepts was closer to that the students had to know (versus a physics teacher, for example). They inferred this level of understanding enables them to explain concepts in ways that make them easier for students to comprehend.

In terms of their confidence using instructional strategies, all of them alluded to being confident with the strategies that they have in their current repertoire, although, they did ask for assistance from other teachers when required. They also stated that they would not use an activity if they were unsure about it, rather they would seek further clarification. For example, asking a physics teacher to explain a new activity that they had read or heard about in more detail before using it. There was a strong sense that they felt comfortable asking for assistance within their science department and they all talked about seeking assistance successfully in the past.

Like their personal philosophy for teaching science, participants' sense of self-efficacy is an important consideration for this study as it can have an amplifier or filter effect on their knowledge and practice (Gess-Newsome, 2015; Park & Oliver, 2008). These findings show that these teachers' sense of self-efficacy is relatively proficient for teaching this topic, and they were confident with their current level of knowledge and instructional strategies.

7.2.2 Cross-Case Analysis of Group One Participants' Initial ePCK

To facilitate the cross-case analysis, comparisons across the case studies are made using the same components from the ePCK rubrics used in Chapter Four. As in the previous section, the cross-case findings for each ePCK component are dealt with in turn, then linked to existing literature and discussed in relation to their contribution to the field.

7.2.2.1 Subject Matter Knowledge

The concepts that all three participants were teaching throughout this unit were mostly appropriate for this age group of students, which was determined by comparing concepts to information provided in the NZC (Ministry of Education, 2007). There were only small anomalies during lessons where a concept was in appropriate, for example, concepts that were too conceptually challenging for these students to understand. However, these were not the focus of the lesson. Similarly, their explanations were also mostly scientifically accurate – on a few occasions their explanations featured minor inaccuracies, or their explanations were too brief. These findings are not unsurprising, as all three indicated their reliance on the SLOs in the junior scheme, which were developed by the head of junior science. These SLOs are considered by this researcher to be appropriate interpretations of the NZC.

Tony and David's pre-CoRe design lessons observations showed their linking and connecting of concepts during lessons were similar. Both teachers made some links between concepts and offered explanations about the relationship, but there were often key links during the lesson that were overlooked. For example, not making a clear connection between voltage and energy, or energy and energy conservation in circuits. During his practical lessons, Alan also failed to make some important links and connections, although he made considerably more links between different concepts in his non-practical lessons compared to his colleagues Tony and David. Not only was Alan seen to make more links in those lessons, he also offered suitable explanations about how the concepts were related.

Links to the nature of science or scientific inquiry during lessons were rare for all participants. There were no explicit links at all but implicit links could be detected when lessons were reviewed by the researcher using an analytical lens informed by the nature of science information contained in the NZC (Ministry of Education, 2007). The most common links were promoting students' use of scientific conventions and language (although this could also be interpreted as a link to the key competencies in the NZC) and their gathering of data to explore trends.

Evaluations about the subject matter knowledge component of their ePCK were made by making comparisons to other PCK research (e.g., Alonzo et al., 2012; Gardner & Gess-Newsome, 2011), and reviewing discussions from the 2nd PCK

Summit. For the appropriateness and the scientific accuracy their explanations in their lessons, they demonstrated proficient to advanced levels for these indicators. In contrast, while linking concepts during lessons is an important indicator of a teacher's ePCK, this indicator was judged to be at a lower level for all three teachers. With the exception of Alan's non-practical lessons, where he made multiple links and connected concepts well, all other observed lessons from the participants demonstrated a basic level for this indicator. Similarly, the lack of links to the nature of science or scientific inquiry being made by teachers in the lessons suggests a limited to basic knowledge about this aspect of science education for all three teachers.

7.2.2.2 Knowledge of Student Understanding

All three participants acknowledged and explored students' prior knowledge in their lessons, but the information they gathered was either used in a limited way in the lesson or not used at all. Similarly, there were few instances across all observations that showed these teachers being pedagogically responsive to students' needs and varying their approaches or tack during lessons. Their acknowledgement of possible misconceptions or difficult to comprehend concepts was also rare in their lessons.

These findings about accessing student prior knowledge and using that information (i.e., being pedagogical responsive to students' learning needs) suggests a limited to basic level of attainment of these ePCK indicators (Alonzo et al., 2012; Gardner & Gess-Newsome, 2011; Lee et al., 2007).

Similarities were seen in the way that David and Alan used questions with their students. Both teachers asked multiple and varied questions throughout their lessons. For instance, both asked factual questions requiring a one-word answer, and also posed questions that required students to predict what might happen and explain their thinking. However, Tony rarely questioned students in his lessons, and when he did, they were often superficial requiring a one-word answer or he addressed his own questions.

David and Alan's use of questions reflects a proficient level in regards to that indicator, while Tony's use of questions shows a limited to basic level (Gardner & Gess-Newsome, 2011).

7.2.2.3 Knowledge of Instructional Strategies

The sequencing of concepts by all three teachers in their teaching of the *Electricity and Magnetism* topic was similar. At times, the flow between concepts was suitable for promoting understanding, but there were many instances where further explanations were needed when concepts transitioned to another. There were also instances in their lessons where this indicator was overlooked, resulting in student confusion as they were unsure about what they were learning and why.

Alonzo et al. (2012) argue the need for teachers to appropriately sequence concepts so students can identify the connections and develop their understanding of those concepts, and their relationships with other concepts. The case study teachers' sequencing of concepts, while suitable some of the time, and requiring more forethought at other times, reflects a basic to proficient level of knowledge of instructional strategies (Alonzo et al., 2012; Gardner & Gess-Newsome, 2011).

All three teachers used examples and representations to aid student understanding with varying degrees of success, including times where they appeared to be ineffective. The use of examples and representations to aid with student understanding in science, and promoting metacognition are important indicators of a well-developed ePCK (Alonzo et al., 2012; Gardner & Gess-Newsome, 2011; Lee et al., 2007). While the use of examples and representations were analysed as basic, proficient, and advanced, the analysed data indicated a proficient level of knowledge of instructional strategies across all teachers (Gardner & Gess-Newsome, 2011; Lee et al., 2007).

Instructional strategies that promoted metacognition were rarely seen in any of the observed lessons. There were no instances in Tony's observed lessons where he tried to make students think about and challenge their own understanding. While there were some instances of such practises in the others' lessons, they proved limited in their effectiveness at activating students' metacognition. These findings

about teachers promoting metacognition indicated a limited to basic level for this ePCK indicator (Gardner & Gess-Newsome, 2011).

7.2.3 Research Question Summary

Since the inception and scrutiny of PCK over the last three decades, one aspect that researchers have agreed on is the individual and unique nature of this type of professional knowledge (e.g., Hume et al., 2013; Magnusson et al., 1999; van Driel et al., 1998). Thus, it is not surprising that the findings discussed here in this study reinforce this point, particularly as the participants all had markedly different backgrounds. Hence, summarising the findings to identify the nature of their pPCK and ePCK is a difficult task. However, the Group One participants were united by their limited physics background, and when reviewing the discussions around their pPCK and ePCK, four main findings became apparent. The first finding related to *what* they were teaching, while the other three related to *how* they were teaching.

Regarding *what* they were teaching, all participants talked about their reliance on the provided SLOs in the junior science scheme. These learning outcomes were seen as comprehensive and teachers perceived their role was to ensure the content outlined by the SLOs was covered adequately before assessments. Despite this information to guide them, links and connections to other concepts were often overlooked during their lessons. Furthermore, during lessons, when the teaching involved transitioning between concepts, the sequencing often required an insightful explanation about why the focus on concepts was changing and how concepts in the change were related to ensure students were developing their conceptual understanding.

As for *how* they were teaching these concepts, the three findings were: being pedagogically responsive to student's understanding and learning, promoting metacognition, and the influence of context.

Well-developed PCK allows a teacher to recognise students' learning and understanding, and then alter their teaching approach (Gardner & Gess-Newsome, 2011; Lee et al., 2007). Teachers need to be pedagogically responsive to student needs during lessons and adapt their pedagogical approach as required. However,

the case study teachers often had a rigid lesson focus resulting in them not adapting their teaching during lessons.

Similarly, teachers should facilitate the development of students' conceptual understanding (Başer & Geban, 2007; Bowe, 2007) by helping students to relate new knowledge to their existing understanding and think about their thinking. Strategies should be used that promote and elicit metacognition. However, it was apparent that during the observed lessons, teachers had set agendas based on the SLOs, and teachers transmitting information was a common thread in their pedagogy. Instances during observed lessons that showed teachers eliciting metacognition were limited, for example, there were only a few glimpses of such pedagogy during David and Alan's lessons.

The influence of 'context' on their instruction was apparent for all three teachers; although it manifested in different ways. The RCM of PCK (see Figure 2.7 on Page 76) predicts a 'learning context' affects teachers' pPCK and ePCK. That proved true for both David and Tony, as it was clear contextual constraints within their learning environment (i.e., influence of the school) influenced their teaching. Findings showed that assessment was an influencing factor for both these teachers as they wanted to ensure students were suitably prepared for tests and examinations. While they both talked about wanting students to have big overarching questions to seek answers to and carry out their own research to guide their learning, they felt these were not achievable. The influence of context on Alan was different to the others. It appeared that it was not the learning context that shaped his decision making, but his personal background. As noted in the contextual information, Alan had completed his New Zealand teaching qualification the year prior to this study, and science education was a key component. The influence of his university course on his teaching was apparent. Most notably, throughout his interview and in his lessons, Alan was adamant about making the science concepts relatable to students' lives. While he also campaigned for students to be evidence driven in their thinking, it was not evident in his lessons.

7.3 PCK Development as a Result of Collaborative CoRe design

This section addresses the second research question:

What impact does collaborative CoRe design have on the pPCK and ePCK development of junior science teachers with a limited physics background for the New Zealand Year 10 topic *Electricity and Magnetism*, when working collaboratively with experienced physics and junior science teachers?

Findings from all three research phases were used to address this question: PCK exchanges during the CoRe design workshops (Chapter Five); ePCK of Group One teachers' in their pre- and post-CoRe design lesson observations (Chapters Four and Six), which are compared here; and, participants' perceptions about how collaborative CoRe design enhanced their PCK (Chapter Six). To discuss the changes in ePCK seen in lesson observations and participants' perceptions of their own pPCK development, a cross-case analysis was conducted to highlight similarities and differences between the case study teachers.

7.3.1 PCK Exchanges during the Year 10 Electricity and Magnetism CoRe Design Workshop

During the Year 10 *Electricity and Magnetism* CoRe design workshop there were many instances where knowledge, regarding the teaching and learning of this topic, was being exchanged between the participants. This observation resonates with a finding that Hume and Berry (2013) reported from their CoRe design study, which showed when teachers with particular pedagogical expertise engage in CoRe design, their PCK were transferred to other participants. Within the RCM of PCK (Figure 2.7 on Page 76), these exchanges in the workshop are represented by the double-headed arrows between collective PCK (cPCK) and other forms of PCK, and as input from teacher contributors (shown as blue figures within pPCK).

Of the exchanges that took place, the most frequent were concerned with subject matter knowledge and knowledge of topic-specific instructional strategies. This finding links with content focus, a key characteristic of effective PLD interventions

(e.g., Desimone, 2009). Content focus is an important consideration for teachers' PLD as it focuses on what students are taught, and how to teach them (Desimone, 2009; Garet et al., 2001).

As for other knowledge transitions, the discussions at the beginning of the workshop which identified the relevant big ideas and key concepts were regarded as sharing knowledge of curriculum. There were also some instances where knowledge of students' understanding and learning was discussed and shared within the group. However, there were no instances that showed participants developing their knowledge of assessment strategies.

During these times of knowledge exchanges, the Group Three teachers were extremely influential in discussions. Whilst some significant discussions were not necessarily initiated by them, they guided them. To represent the knowledge transitions that took place, Figure 7.1 on the following page was developed. Each element of this diagram is subsequently addressed.

Dashed boxes within Figure 7.1 represent components of the teachers' PCK. Boxes with solid lines represent the knowledge form being discussed, while the arrows show the developmental progression of how the knowledge form transitioned to another. The labels associated to each of these boxes and arrows are now addressed.

Box 1 represents the identification of the big ideas during the workshop proceedings, which shows knowledge exchanges regarding curriculum knowledge. Here, participants shared their ideas about what *should* be taught in this unit. During this phase, Group Three teachers controlled the discussions as they offered their insights and debated with the others about what concepts are appropriate and why. These discussions included the alignment of concepts with the NZC, preparation for NCEA Level One, and ensuring that if students were to study physics in the future, they would have suitable foundational knowledge.

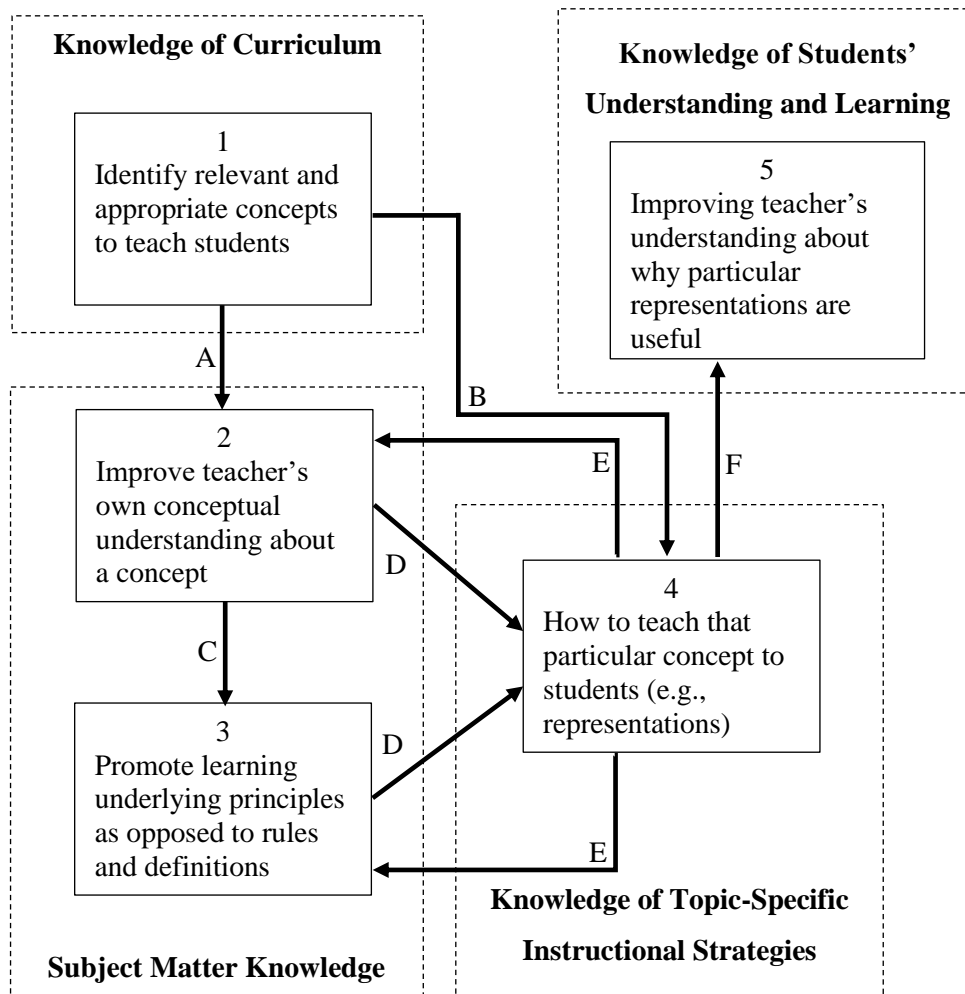


Figure 7.1: PCK transitions during collaborative CoRe design.

Via Arrow A, the identification of appropriate concepts often led into a discussion about what the concept actually meant, which again, was directed by the experienced physics teacher (e.g., what does voltage mean?). Box 2 represents the most frequent knowledge exchanges during the workshop. However, where there was a consensus in understanding about a concept within the Working Group, the discussion could also follow Arrow B, leading into a direct discussion about how to actually teach that concept to students.

In Box 2, knowledge exchanges that improved teachers' own conceptual understanding occurred (i.e., knowledge transformation occurred). These discussions were then seen to go one of two ways: either following Arrow C or D. When following Arrow C, Group Three teachers encouraged the others to teach

students to understand the underlying principle of the concept. They agreed this pedagogical goal was more important than teaching students to memorise rules and definitions. After these discussions, the natural progression in the discussion was to follow Arrow D.

Arrow D leads to another section where frequent knowledge exchanges were seen: how to teach a concept to students. Within Box 4, Group Three teachers offered new ways for the others to think about and conceptualise their understanding. For example, the drawing of diagrams or discussions about different representations to aid student understanding. These discussions often allowed for a feedback loop to Boxes 2 and 3 via Arrow E, or led into discussions that developed the teacher's knowledge about student understanding and learning.

Arrow E shows how discussions about how to teach concepts, as led by the physics teachers, inadvertently develops teachers' conceptual understanding further (i.e., knowledge transformation taking place), while also prompting the underlying principles. Arrow F shows how discussions around instructional strategies for a particular concept, and reasons for using those strategies, inform teacher's knowledge of students' understanding and learning (Box 5).

While there were many occurrences that showed PCK exchanges during the workshop, it is important to consider how these instances actually impacted the case study teachers' knowledge and actions. That is, did knowledge transformation take place? The following two sections address this question.

7.3.2 Cross-Case Analysis of Group One Teachers' Reflected pPCK Development

The three case study teachers indicated their PCK had not actually changed after the *Nature of Science and Scientific Inquiry* workshop. When asked about what they learned from the experience, their responses varied. Tony thought the ideas and concepts that were talked about were beneficial, and he could see how they could be applied to lessons. However, in reality, he thought that he did not have the time to implement those ideas in to his current practice. David enjoyed the CoRe design process, saw its potential, and expressed that talking about the nature of science and scientific inquiry had reminded him about the importance of teaching science. Since

Alan had recently done work on this topic at university, he had been trying to incorporate the concepts discussed before the intervention. The workshop served as a refresher for him and reminded him of aspects that he had forgotten.

In contrast, all three participants affirmed that the second collaborative CoRe design workshop did enhance their PCK for teaching Year 10 *Electricity and Magnetism*. Specific areas of PCK enhancement that these teachers identified included their subject matter knowledge, knowledge of topic-specific instructional strategies, and knowledge of students' learning and understanding. When discussing subject matter knowledge, Tony and David referred to concepts that were discussed during the workshop and how they had improved their own understanding. For example: Tony talked about Nick's voltage, current, and energy explanations; and, David his understanding of magnetism. Alan also indicated his understanding of concepts developed, improving his subject matter knowledge, but for him there were too many examples to talk about during the interview.

For topic-specific instructional strategies, all three participants mentioned new ideas they took away from the workshop. For example: Tony was going to use Nick's diagrams with his students in the future; David wanted to investigate the use of simulations to use in the future, and to use more structure and give more direction in his practical lessons; and, Alan talked about learning to use Physics Education Technology (PhET) simulations with his students to show them different features of circuits.

Participants' responses about the enhancement of their knowledge of students' understanding and learning were brief compared to previous responses. They were all in consensus about CoRe design making them more aware of student ideas, but they did not elaborate on their responses or offer any examples to provide evidence for their claim.

There were no findings that indicated these teachers had developed their knowledge of assessment strategies for monitoring student understanding. When asked about this area of pPCK, they all offered divergent responses: Tony thought the collaborative CoRe design process focused more on teaching than assessment; David indicated that he made some informal changes to his use of formative assessment, but was unsure if those changes had been effective; and, Alan's

perception was that the process promoted the use of more questions and answers during lessons.

While David and Alan identified areas of their own pPCK that developed as a result of CoRe design, both participants expressed that contextual restraints (particularly assessments) would impact negatively on any developments. They experienced pressure from the upcoming assessments (topic tests and formal examinations), and although they developed their pedagogies for this topic, they thought they reverted to old teaching habits and transmitted the ‘right’ information to students so they could pass. David commented that his school’s assessment structure restricted his ideal teaching style, while Alan thought the best approach forward is to use the CoRe produced as a unit plan and develop an assessment accordingly. These comments show that while their pPCK developed, the impact of this development on their ePCK was likely to be affected by the school context.

7.3.3 Comparing Group One Teachers’ Observations (Pre- and Post-CoRe Design)

To examine developments in the case study teacher’s ePCK, comparisons were made between their two sets of lesson observations (i.e., pre- and post-CoRe design findings presented in Chapters Four and Six). This comparison showed which ePCK indicators had been enhanced, allowing for a cross-case analysis to discuss similarities and differences in ePCK development.

To highlight where enhancement was seen in relation to the ePCK indicators used, and to compare the three case study teachers, Table 7.1 was constructed. The development for each indicator is addressed in more detail in the text following the table using cross-case analysis. Within the table, arrows (↑) indicate where enhancement was seen, and dashes (-) represent no obvious change to that indicator. To determine if there was change, as represented in the table, the detailed notes (e.g., see Appendix D2) were compared for pre- and post-CoRe design lessons. This review was done with respect to each ePCK quality indicator, and a judgement was made by the researcher about whether obvious enhancements had been observed or not. The same ePCK abbreviations that were used in Chapter Four and Six have been used here (see Table 4.2 on Page 195).

Table 7.1: ePCK indicators from the rubric, Group One teachers, and an indication of ePCK development.

ePCK Indicator	Tony	David	Alan
Subject Matter Knowledge			
Appropriateness	-	-	-
Accuracy	↑	-	-
Concept links	↑	↑	-
NoS/SI links	-	-	-
Knowledge of Student Understanding			
Prior knowledge	↑	↑	↑
Variations in understanding	↑	↑	↑
Questions	↑	-	↑
Knowledge of Instructional Strategies			
Sequencing of concepts	↑	↑	↑
Examples and representations	↑	↑	↑
Metacognitive strategies	↑	-	↑

7.3.3.1 Cross-Case Analysis of Subject Matter Knowledge

Across all case study teachers there were no apparent developments in the appropriateness indicator since the concepts that the teachers taught were (mostly) appropriate and aligned with Level 5 of the NZC (Ministry of Education, 2007). This finding is unsurprising given all three teachers talked about their use and

reliance on the SLOs that are provided for them. During the CoRe design workshop, an important step was to debate and agree upon appropriate concepts to inform the rest of the CoRe. These teachers then implemented this CoRe in tandem with the original unit scheme to plan and teach their lessons.

Only Tony appeared to make significant developments around scientific accuracy. Working with Nick during the CoRe design workshop influenced the way Tony explained concepts. His explanations were now more in-depth and he focused on the underlying principles as well as rules and definitions, a point that was stressed by Nick. In contrast, David spent additional time verbally explaining concepts to the class rather than focusing on students writing notes down. Alan's comparison of classroom teaching also showed no change to this indicator. After taking part in CoRe design he actually explained voltage and voltage sharing across resistors incorrectly to his students, indicating a weakness of his PCK for this indicator.

Both Tony and David developed in the area of making links and connections between concepts. While David made some links and explained them effectively in his pre-CoRe design class, there were many situations where a link would have been useful for student understanding, but it was overlooked. Similarly, Tony made some links in his pre-CoRe design class, but the explanation that linked the concepts was in need of further development. After taking part in the workshop, both of these teachers made more links between concepts, and offered students well thought-out explanations about the linkage. In comparison, there was only a slight difference seen between Alan's classes. In both sets of observations, Alan made many conceptual links and explained them well. However, he did make less links during his practical lessons. The only difference observed between his two classes for this indicator, was that Alan made greater conceptual links in his practical lesson after taking part in collaborative CoRe design.

Clear links to the nature of science and/or scientific inquiry were rarely seen in lessons, and there appeared to be no development of this indicator for any of the Group One teachers. Within both sets of observational data, there were no explicit links made. The implicit links that were observed, involved promoting the use of specialised symbols and conventions, and modelling circuits using diagrams. Using specialised symbols and language also features in the key competencies in the NZC

(Ministry of Education, 2007) (see Table 2.1 on Page 33). Gathering data to explore trends and relationships was also mentioned during some practical lessons.

7.3.3.2 Cross-Case Analysis of Knowledge of Student Understanding

Enhancement regarding recognising and acknowledging students' prior knowledge, possible misconceptions, or difficult concepts was seen for all three teachers. Although, it must be noted that the degree of enhancement for each teacher varied, with Tony and David developing this indicator more than Alan. While there was little information about teachers acknowledging misconceptions or difficult concepts, there were interesting differences with regards to acknowledging students' prior knowledge. While all three sought prior knowledge in their pre-CoRe design lessons, the information obtained was often used in a limited way. However, after being involved with CoRe design, these participants appeared much more aware of this information and attempted to use it in a way that informed their actions and strategies during their lessons.

Being pedagogically responsive to students' learning needs and varying approaches during lessons followed a similar trend to the previous indicator. Again, all three teachers showed improvements in this area. Before CoRe design, it was apparent that they all had content they wanted to get through during the lesson, and had a set lesson agenda from which they were reluctant to deviate. However, after the workshop, they became more aware of students' learning needs, and areas where students were having difficulty. This heightened awareness meant they were able to change their teaching approach to address possible issues. All three participants made improvements to this indicator compared to their pre-CoRe design classes.

There was little difference in the manner that David asked questions to probe or extend student understanding between his two classes, using an adequate range of questions to tease out information in both. Tony and Alan did develop in this area, and in a similar way. Compared to their pre-CoRe design classes, both of these teachers used more and varied questions with their students. For example, their use of questions during lessons evolved from simple recall questions that required one-word answer to more sophisticated questions where students had to predict and explain phenomena, and justify their thinking. However, in his practical lessons,

both pre- and post-CoRe design, Alan used less questions. In his last observed post-CoRe design lesson, Alan began to rush through content by transmitting information and asking questions was overlooked.

7.3.3.3 Cross-Case Analysis of Knowledge of Instructional Strategies

All participants enhanced their sequencing of concepts as a result of collaborative CoRe design. In their pre-CoRe design lessons, it appeared that the *intended* sequence of concepts was quite suitable and appropriate for that level of students most of the time. However, the *enactment* of their intended sequence of concepts resulted in students being unsure, which was evident from students' plethora of questions during lessons. Often, explanations which linked concepts together when concept transitions occurred during the lessons were overlooked. However, in the post-CoRe design lessons, the sequence of concepts was much clearer for students in all classes. For example, in their post-CoRe design lessons: Tony explained to students why they were changing concepts and how concepts were related; when working with circuits, David adopted William's idea from the workshop to work with series and voltage first, which was completely different to his first approach; and, Alan broke his practical lessons into more manageable pieces to aid with student understanding.

Similarly, all Group One participants enhanced their use of representations and examples to effectively portray concepts to students. While both Tony and Alan used these strategies in their pre-CoRe design lessons, they were often ineffective at portraying the desired concept. In his pre-CoRe design class, David rarely used these strategies, and when he did, they were often ineffective. In contrast, in all of their post-CoRe design lessons, all teachers were much more effective at using representations and examples. Interestingly, all three teachers used an instructional strategy that they learnt during the workshop: Tony used Nick's diagrams, David used William's analogies, and Alan used PhET simulations.

Tony and Alan improved their use of instructional strategies that provoked metacognition. In their pre-CoRe design classes, instances showing students being encouraged to engage in metacognition were rare from these two teachers; none were apparent in Tony's lessons, and two in Alan's lessons. However, after taking

part, there were many more instances from these teachers where they prompted students to think about their own thinking, and to express their ideas. In comparison, David underwent little change in regards to this indicator. He tried to get students to think about their own thinking a similar number of times during his pre- and post-CoRe design lessons.

7.3.4 Research Question Summary

When CoRe design is used as a collaborative process, it has been shown to be an effective PLD intervention for enhancing PCK, particularly for pre-service or early career teachers (e.g., Hume & Berry, 2011, 2013; Hume et al., 2013; Nilsson & Loughran, 2012). The discussion presented within this section reinforces the effectiveness of collaborative CoRe design for enhancing PCK, and confirms that it also enhances practising science teachers' PCK.

During the Year 10 *Electricity and Magnetism* CoRe design workshop, there were many occurrences where knowledge exchanges were taking place; particularly about what concepts to teach and how to teach them. These occurrences, where the teaching and learning of this topic were discussed in depth, epitomise content focus, which is key characteristic of effective PLD interventions, as shown in Figure 2.8 (see Page 92) by Desimone (2009). (Note the four other key features of effective professional development are discussed when addressing the third research question.)

The result of these knowledge exchange episodes during the workshop affected the case study teachers in ways that Desimone (2009) and Daehler et al. (2015) predicted. That is, their subject matter knowledge and knowledge of topic-specific instructional strategies improved, thus developing their pPCK, which in turn enhanced their classroom practice, or ePCK.

After taking part in collaborative CoRe design, interviews were conducted to explore changes to their pPCK. All participants reported developments in the areas of subject matter knowledge, knowledge of topic-specific instructional strategies, and knowledge of students' understanding and learning. David and Alan acknowledged changes to their pPCK, although they expressed concern that the

school context and assessments would influence how enhancements to their pPCK would transition to ePCK.

The comparison of observational findings shown in Table 7.1 (see Page 348) highlights the ePCK development for each teacher as a result of CoRe design. While each teacher developed their ePCK in their own unique way, there were similarities. For example, by enhancing their own understanding about concepts in science, and hearing how the physics specialists taught those concepts, all three case study teachers further developed their knowledge of instructional strategies. Enhancements of their sequencing of concepts was evident with their introduction of detailed explanations about how concepts might be related to aid student understanding. Similarly, their use of representations improved, with all three participants using strategies they learnt at the workshop. Interestingly, while the nature of the discussions during the workshop focused more on what and how to teach, there were observable pedagogical changes with regards to students' understanding and learning. It appears as the case study teachers developed their own conceptual understanding and how to communicate ideas to students, they naturally became more aware of student understanding. They sought students' prior knowledge and ideas more frequently, and used that information to inform their practice.

In summary, when the Group One teachers took part in collaborative CoRe design workshop with the other participants, it created an environment where professional and pedagogical knowledge could be shared between participants. In particular, the experienced physics teachers offered insights into their conceptual and pedagogical knowledge during the discussions. This knowledge exchange initiated knowledge transformations in the pPCK of all case study teachers that was evidenced by developments to their ePCK.

7.4 Evaluating Collaborative CoRe Design

This section addresses the third research question:

What are teachers' experiences and perceptions of collaborative CoRe design as a professional learning and development (PLD) intervention for enhancing pPCK and ePCK?

To address this research question, a cross-case analysis of the findings from participants' evaluations of collaborative CoRe design (Chapter Six) was done. Note that this analysis also included the Group Two and Three teachers' evaluations.

7.4.1 Cross-Case Analysis Collaborative CoRe Design as a Process

All participants in this study reported positive experiences with collaborative CoRe design. The findings indicate that the collaborative nature of CoRe design used as a PLD intervention was influential in the positive outcomes for the participants. The focused workshop created a stimulating environment where the teachers had opportunities to share, discuss, and critique ideas. For example, during these sessions, participants determined which key ideas they wanted students to learn and discussed why those ideas were important.

There is strong alignment between this feedback and active learning and collective participation, which are components of effective PLD interventions (e.g., Desimone, 2009). For example, Borko (2004), Desimone (2009), and Griffith et al. (2014) indicate that active learning can be achieved by encouraging teachers to participate in a collaborative and dynamic way, as opposed to passive absorbers of information. Similarly, Garet et al. (2001) notes that collective participation can be achieved when teachers are from the same department within a school, and focused on a common curriculum with a familiar year group. Overall, the teacher evaluations in this study indicated they valued the collaborative CoRe design process. They appreciated the opportunity to explore different types of specific pedagogy, investigate different activities, and challenge their own and others'

beliefs. However, several limitations of the process were also highlighted, which could influence the effectiveness of the intervention.

The most noted limitation was the time required to complete the CoRe design process, which is a similar finding to other researchers who have investigated the use of CoRe design for professional learning (e.g., Bertram & Loughran, 2012; Hume et al., 2013). This finding is not surprising though, because as Bailey and Colley (2014) argue, teachers often have time pressures by not being allocated appropriate time to complete their tasks. While the participants and the school supported this study, it was in addition to their normal workload.

As a limitation, time requirements were explicitly mentioned by all Group One and Three teachers, both groups also offered suggestions to overcome the restraints. When reviewing their responses, two recommendations became apparent: find time, or make the process ongoing (as opposed to a one-off event). To find time, it was proposed there be opportunities during the year that could be used for collaborative CoRe design (e.g., teacher only days, or times when students were on examination leave). Nick also commented that if school management thought it was worthwhile, they would create time for it. The other recommendation was to make collaborative CoRe design an ongoing process where the CoRes themselves are living documents that can be updated periodically. For this solution, teachers could also work in collaborative groups (like this study) where particular groups focused on different units of work. That way, teachers could use the time they did have available to address parts of the process, continuing at another time later on (e.g., identifying big ideas, addressing all pedagogical prompts for one big idea, or addressing one pedagogical prompt for all big ideas). Having different groups of teachers and working on different topics would give teachers the opportunity to act in different roles (i.e., experienced versus limited subject matter knowledge). Furthermore, Alan argued an ongoing process of producing CoRes would eventually replace the current schemes of work, and they could be continually updated and refined.

While the Group Two teachers did not explicitly identify time as a limitation, Kate talked about the issue of teaching people about the process (which can be seen as a time issue). She suggested that this problem could be mitigated by having a pilot CoRe design workshop where the focus is on learning the process (which was done in this study).

The problems related to time and making the process ongoing aligns with the duration component of effective PLD interventions (e.g., Desimone, 2009). While effective PLD interventions do not have a definitive time-span, it is important to consider what the goals of the intervention are (Desimone & Stuckey, 2014; van Driel et al., 2012). Since the purpose of these workshops was to allow teachers to openly discuss their knowledge and views to anatomise a unit of work, it is expected that a time commitment is required. Also, when designing this study, the time allocated to completing the process was purposefully shorter than other collaborative CoRe design studies (c.f., Bertram & Loughran, 2012; Hume, 2010; Hume & Berry, 2011; Hume et al., 2013). While time was identified as a limitation, participants expressed that the process was beneficial. Utilising participants' comments about making the process ongoing in the future would also ensure it is not seen as a one-off event, which Griffith et al. (2014) and van Driel et al. (2012) suggest makes the intervention even more effective.

Along with the time required, four additional limitations were signalled:

1. Kate believed there could be an issue with entrenched thinking and getting teachers to think outside of their current practice and discuss the pedagogical prompts openly may be challenging. She thought there was a danger if teachers were too closed-minded; they may inadvertently revert to former practices.
2. Group Three recognised there are different approaches to teaching, and teachers will not necessarily agree on the best approach. In those situations, Chris suggested that teachers need to appreciate different approaches may be more appropriate and useful for different teachers.
3. David worried that one person's opinion may be overlooked by the others. To overcome this tendency, he suggested that teachers need to be assertive to ensure their view is heard.
4. Alan thought some teachers may be so passionate about a particular curriculum area that they may end up discussing things unrelated to the CoRe (thus compounding the time issue). He suggested that the participants, particularly those acting as experienced or expert teachers during a workshop, where possible, remain focused on the task and only have discussions that are informed by the CoRe prompts.

Additionally, while the study teachers did not identify it explicitly as a limitation, David and Alan also raised the relationship between collaborative CoRe design and school assessments as problematic, which was discussed earlier. They argued assessments must also change to reflect decision making in the produced CoRe if the PLD intervention was to have effect on classroom teaching.

Another outcome of this research was all teachers' spoken intent to use collaborative CoRe design in the future as a PLD intervention within their science department. William and Chris were initially apprehensive about the process, commenting that the first workshop was too philosophical and they were not provided enough direction. However, after the second workshop, they were both enthusiastic about taking part again. The Group Three teachers also commented how comfortable they felt being the experienced ones during the second workshop, and were interested in taking part in a new workshop where they had limited subject matter knowledge.

Interestingly, in comparison to the study by Bertram and Loughran (2012), where their practising teacher participants ($n=6$) completed CoRes individually, they found that their practising teacher participants had mixed views about using CoRe design in the future. While their participants saw it as beneficial, two participants thought it could be worked into their regular practice, but would need to be enforced by their school management. Three participants in that study explicitly expressed it was unsustainable (there was no mention of the sixth participant's view on this matter).

7.4.2 Cross-Case Analysis of Collaborative CoRe Design for Enhancing PCK

Responses about how collaborative CoRe design could enhance teachers' PCK were diverse, but there were common themes. Principally, the participants thought the collaborative environment created a thinking space where different forms of knowledge could be shared, and the pedagogical prompts (and the facilitator's guidance) informed and directed the discussions. Different forms of knowledge refer to those represented in the RCM of PCK. For example, subject matter knowledge (e.g., what voltage means), knowledge of instructional strategies (e.g., different approaches to teaching voltage), or knowledge of students' understanding

(e.g., what students may be thinking when learning about voltage). This finding was similar to that reported by Hume and Berry (2013) when researching collaborative CoRe design with pre-service teachers and their mentor teachers. These authors noted that the process encouraged “authentic professional discussion” (p. 2123) to inform and support development in pre-service teachers’ PCK.

As these authentic professional discussions in this study centered on key concepts, how to teach those concepts, and what students might be thinking, there were two pathways by which the teachers could develop their pPCK: they could identify particular areas where their own knowledge may be lacking, which can be rectified; and, teachers could examine different ideas, methods, and strategies for teaching various concepts, allowing them to think beyond what they might already be doing and increase their instructional strategy repertoire. This sharing of aspects of their pPCK with each other, and developing a collective PCK (cPCK), which in turn potentially enhances their own pPCK further, embodies the interplay between a group’s cPCK and teacher’s pPCK, as represented in the RCM of PCK (see Figure 2.7 on Page 76). Enhancements to teachers’ pPCK through this process should influence their ePCK too (i.e., there should be correlations between these two forms of knowledge).

In the previous section, Group One teachers’ PCK development as a result of collaborative CoRe design was discussed, and it was noted that indeed, their PCK (i.e., pPCK and ePCK) had developed. However, when asked similar questions about their overall PCK development, Group Two and Three’s responses were quite different.

The Group Two participants could appreciate how collaborative CoRe design enhances PCK, but reported that there had been no development to their pPCK. Lucas did indicate he would use the information in the future if there were records to consult. This finding is not completely unsurprising, given these teachers were not teaching the topic chosen for the study during the year of data collection, nor did they have any inherent interest in students learning physics for later years. These teachers *could* see the applicability of the process, but their experiences of the process did not necessarily greatly affect their knowledge or practice. For these three teachers, coherence, a component of effective PLD interventions (e.g., Desimone, 2009), did not occur. Coherence is about ensuring strong alignment

between what the teachers value and the goals of the intervention (Desimone, 2009; Griffith et al., 2014), and as van Driel et al. (2012) caution, when it is overlooked or mismatched, the intervention can become less effective.

When asked about PCK development, the Group Three teachers were quick to talk about the development of the Group One teachers as opposed their own. They agreed that the Group One teachers benefited the most, as they were able to clarify their own ideas and learn new instructional strategies. In regards to their pPCK development, the Group Three teachers thought there was little benefit to them as they were all effective teachers of this topic. Again, this lack of development could be attributed to the absence of coherence for them in the intervention, as they were already well-developed in this particular content area. These teachers did have strong interest in students learning and understanding physics (in comparison to Group Two teachers), so there was not complete misalignment. These teachers reported it was useful to think about what they were doing, and to argue about what concepts are important to learn and the best ways to teach them. They also thought it was interesting to hear other teacher's conceptual understanding of concepts and to help them correct any misunderstandings. The Group Three teachers acknowledge that the workshop would affect the level at which they pitch concepts to their students in the future, as they recognised in the past they had expanded concepts to the point where they have become too difficult for students to grasp. This insight indicates a potential shift to the appropriateness aspect of their PCK for these participants (Gardner & Gess-Newsome, 2011).

7.4.3 Research Question Summary

This last research question highlights the value of collaborative CoRe design as a PLD intervention. The collaborative nature of the workshops meant that teachers' PCK could be explicitly shared and they could: debate which concepts are appropriate at different year levels, and why; develop their own conceptual understanding; learn new ways to approach, teach, and represent concepts; and, talk about how students perceived concepts and how they might misunderstand information. The unanimous consensus was that this style of PLD was useful, and these teachers were interested in its adoption into their departmental practices and

were keen to take part in the future. However, the value was contingent on some challenges being met, which limited the effectiveness of the intervention.

Time requirements to complete the CoRe was the biggest issue limiting its success. This finding is not surprising given the purpose of the task was to explore a topic in detail. To overcome the issue, it was suggested there be times of the year set aside for its use. Alternatively, the process could be employed as an ongoing long-term process where teachers work in small collaborative groups and address different units and different parts of the CoRe over time. This strategy should make the process a more streamlined ongoing PLD intervention, as opposed to a single workshop. In this event, the CoRes themselves would become living documents that are updated and revised periodically, which would replace existing unit plans.

Other limitations briefly mentioned included: teacher's opinions being overlooked, which could be addressed by the teacher (or facilitator) being more assertive to ensure they were heard; different teachers advocating for different approaches, and needing to recognise that their approach may be the best one for them as individuals, but not someone else; teachers can be passionate about their subject areas and go 'off-task', which can be addressed by ensuring the pedagogical prompts are at the forefront of discussions; and, teachers need to be able to think outside of their current practices and openly discuss a topic without reverting back to former practices.

Addressing this research question overall, all participants had a positive experience and perceived collaborative CoRe design to be an effective PLD intervention. The process promoted PCK enhancement as it allowed teachers to share their knowledge, and critique their own and others' practice.

7.5 Chapter Summary

By interpreting and discussing the findings from the three individual case study teachers (and the other participants, where appropriate), using the three research questions as a guide, this study identified seven overall findings:

1. The teacher's pPCK (and subsequently their ePCK) was linked to their own unique backgrounds and experiences, and therefore inherently individual. However, based on their limited physics knowledge, there was some commonality when exploring PCK in relation to the Year 10 *Electricity and Magnetism* topic.
2. All participants viewed collaborative CoRe design as a worthwhile and effective PLD intervention for developing their pPCK and ePCK. While there were some limitations identified, participants accepted the benefits outweighed the disadvantages, and they were interested in seeing the process adopted into their regular teaching practices at school.
3. The Group One teachers all benefited from the workshop as they took away new knowledge, such as: subject matter knowledge, knowledge of students' understanding and learning, and knowledge of topic-specific instructional strategies. This finding shows they developed their pPCK.
4. While Group One teachers thought their pPCK had been enhanced, they also indicated that the transformation to their classroom practice may be limited (i.e., application of pPCK, which is ePCK). Limiting factors concerned elements of the school context, such as the structure of the timetable and school assessments.
5. When observed, Group One teacher's ePCK had been enhanced, confirming a transformation of knowledge from the CoRe design workshop. Each teacher's ePCK enhancement was unique (see Table 7.1 on Page 348), but there was significant overlap in the areas of knowledge of students' understanding and learning, and knowledge of instructional strategies. Teachers became more pedagogically responsive to student learning and needs, and their methods of teaching to promote understanding and learning improved.

6. Collaborative CoRe design embodied content focus, active learning, and collective participants, which are characteristics of effective PLD interventions. Coherence was seen with the Group One teachers, but much less with the Group Three Teachers, and very little with the Group Two teachers.
7. There were many instances during the Year 10 *Electricity and Magnetism* CoRe design workshop where knowledge was being transmitted and/or exchanged between participants, and transitioned from one form to another. The most frequent exchanges were from the Group Three teachers to the others, and included subject matter knowledge and knowledge of topic-specific instructional strategies. Although, the identification of big ideas highlighted some knowledge sharing about teachers' knowledge of curriculum, there were also times where knowledge of students' understanding and learning were raised.

The findings from this research showed that collaborative CoRe design was an effective PLD intervention for practising teachers in this school. When teachers with a limited physics background collaborated with experienced physics teachers using CoRe design to teach Year 10 *Electricity and Magnetism*, their PCK was enhanced.

Using the discussion presented in this chapter, the following chapter makes some recommendations about: developing scientifically literate students; ensuring professional development interventions within schools are effective; how collaborative CoRe design can be used for professional development; and, how future PCK research can be strengthened. The limitations of this study are also outlined here, along with suggestions for future research and a conclusion.

Chapter Eight

*Implications, Recommendations,
and Conclusions*

8.1 Overview

The intention of this study was twofold: use the Refined Consensus Model of Pedagogical Content Knowledge (RCM of PCK) as an analytical lens to explore and understand the nature of teacher's personal and enacted pedagogical content knowledge (pPCK and ePCK); and, evaluate the effectiveness and worth of collaborative content representation (CoRe) design as a professional learning and development (PLD) intervention to develop those knowledge bases. Within this thesis: the rationale and scope of this study have been identified; pertinent literature was discussed; theoretical underpinnings, the research design, and data collection and analytical method have been explained; and, the findings have been presented and discussed. Synthesising the previous seven chapters, this final chapter outlines the implications and recommendations for education practices, limitations, suggestions for future research, and conclusions of this study. Ensuring close alignment throughout all of these chapters supports meaningful coherence of the overall work, which Tracy (2010) argues is one of the eight criteria for excellent qualitative research.

This chapter is organised into the following sections: Section 8.2 identifies the implications and recommendations for developing scientifically literate students in New Zealand, professional development in schools, CoRe design as a PLD intervention, and future PCK research; Section 8.3 discusses the limitations of this research; Section 8.5 offers suggestions for future research; and, Section 8.6 offers a conclusion and final remarks.

8.2 Implications and Recommendations from this Study

8.2.1 Effective Professional Learning and Development in Schools

PLD interventions should allow teachers to reflect on and develop their own professional knowledge. This learning process then empowers them to become more effective practitioners in the classroom, thus improving student learning. However there are key considerations for ensuring the process is effective, which is reported in literature and confirmed in this study. If PLD interventions do not provide this kind of support, there is a possibility that teachers receive information

that is not going to develop their pedagogy and they take little away from the process (as in the case of the Group Two teachers). While there is an issue with this process not being hugely beneficial for these teachers, the problem could be further compounded as teachers may also resent the process, feel negatively about it, and be reluctant to engage in professional development interventions in the future (note: the Group Two participants did not indicate they felt negatively about this intervention in this study).

As shown in this study, there can also be an issue of contention between the school context (e.g., school ethos) and the goals of the PLD intervention. As some participants pointed out, even though they thought they developed as teachers, the degree of development was hindered by contextual restraints. Thus, the implication is there are important considerations when developing and planning PLD interventions with the overarching goal of enhancing student outcomes.

The study recommends that if the goal of the particular PLD intervention is to develop teachers' pedagogy and skills to enhance their classroom practice, that the five key features of effective PLD outlined by Desimone (2009) and presented as Figure 2.8 (see Page 92) be closely considered. Within this construct, teacher collaboration is advised as they can share their individual philosophies and ideas, take responsibility for their professional learning, work in partnerships with each other, and collectively reflect on their practice. Heeding this recommendation means PLD interventions are targeted to a specific group with a shared goal, and teachers' professional learning will be increased. Furthermore, to ensure maximum gain, the school itself needs to be flexible in a way that encourages and accepts pedagogical shifts and changes, which result from professional development interventions, rather than being too constrictive.

8.2.2 Using Collaborative CoRe Design for Professional Development

As this study has shown, the implications of using collaborative CoRe design workshops as PLD interventions means that three of the key features of effective professional development can be met. These features are content focus, active learning, and collective participation. The requirements of these components are fulfilled as the process allows teachers to actively collaborate with each other while

they discuss what to teach and how to teach it. However, the other two features (coherence and duration) need more careful consideration when utilising CoRe design in this way. In terms of coherence, there must be alignment between the intentions of the workshop and the teachers' own goals and beliefs. As it was seen in this study, where this criterion is met (Group One teachers), teacher's knowledge and skills develop. Failing to meet this criterion (Group Two teachers) results in little professional learning. Duration is a difficult feature to discuss, as the time span of the intervention depends on the specific goals and the nature of the intervention. With the participants in this study, it appeared that three hours was a suitable time. The workshop was long enough to ensure the process was not rushed, and short enough so participants did not feel adversely about it. While they identified time as a limitation, the feedback indicated that the benefits of the process significantly outweighed that limitation.

Thus, the recommendation from this study is that collaborative CoRe design should be used as a PLD intervention in school settings to enhance teacher knowledge. There are some key considerations for its use, such as: the presence of an external facilitator, ensuring participants' goals align with the workshop, and making sure the actual time of the process is suitable. If these points are factored into the planning stages, the benefits of the process can be maximised. Even if schools feel their staff are already collaborative, CoRe design is a useful mechanism for encouraging teachers to share their conceptual and pedagogical knowledge in an efficient and effective way.

8.2.3 Future PCK Research

Following other studies that have researched teachers' PCK, this study concurs that it is a challenging endeavour. The methodology employed in this study was developed from the advice of other PCK researchers; namely, utilising both interviews and lesson observations to gauge a better understanding about the nature of their professional knowledge, and exploring different PCK conceptualisations to identify researchable entities. While these data collection methods provided useful insights about participant's PCK, there was missing data that would have made assessments even more enlightening (which are also identified as limitations to this study below). Firstly, there was a missing link that exists between the knowledge

teachers have (pPCK), and how they apply it (ePCK), which is their pedagogical reasoning. Data that highlights teachers' pedagogical reasoning in the act of teaching requires them to critically reflect on their practice. For example, viewing a video recording of them teaching and explaining why they did a certain activity, or similarly, writing a reflective journal entry about what they did in the lesson and why. Teachers could also develop and write their own Professional and Pedagogical experience Repertoires (PaP-eRs) (e.g., Loughran et al., 2006) about teaching certain concepts.

The second missing piece of data was about the student outcomes. To gain this type of data, students could be interviewed in focus groups to explore their experiences in lessons. For example, asking them about particular activities the teacher used and how that influenced their understanding.

Thus, the recommendation for future PCK research is that the pedagogical reasoning link between pPCK and ePCK needs further exploration, along with data that captures student outcomes. While collecting such types of data would make the research undertaking larger, findings from such data could be corroborated with those from interview and lesson observation data. The combination of all of these data sources would allow greater in-depth critiques of a teacher's PCK, and subsequent PCK development.

8.2.4 Developing Scientifically Literate Students in New Zealand

While researching how students may develop into scientifically literate citizens was not a focus of this study, it was inadvertently researched as teachers were asked about their opinions about students acting as scientists. Similarly, in the lesson observations, teacher's links to the nature of science and scientific inquiry were investigated. When comparing these emergent findings with the literature, there was a clear disconnect.

Figure 2.1 (see Page 25) was developed by combining work from the NRC (2012), Fives et al. (2014), and N. G. Lederman et al. (2014) concerning the qualities scientifically literate citizens possess. This representation shows that for students to develop scientific capabilities and dispositions, they need to understand three different aspects of science: content knowledge, scientific inquiry, and the

epistemological underpinnings of science (the nature of science). However, findings from this study show that only one of those aspects was the general focus for practising science teachers in the study. From holistically reviewing all Group One teachers' interview and observational findings, and taking the CoRe design discussions into account, it was clear that content knowledge was the primary driver of science education for these participants. While the Group One teachers indicated they wanted to use specific pedagogical approaches that aligned with the two missing aspects of science education, they felt incorporating such pedagogy was unrealistic and unachievable. Thus, the implication is that these teachers' students will not be developing those qualities identified to be scientifically literate.

If the goal of science education is to develop scientifically literate citizens, then this study recommends a stronger focus in schools on students developing their understanding of the epistemology and processes of science. Focus on these may be achieved by allowing teachers greater flexibility in how they teach content, by replacing assessment-driven models of teaching that restricts teaching styles.

8.3 Limitations of this Study

While an appropriate research design was developed and fitting data collection methods were used, the nature of educational research means there will be limitations. Tracy (2010) notes excellent qualitative research is sincere; limitations and mistakes are openly reported by the researcher to the audience. For this qualitative research, there were two general limitations that should be taken into account: the small sample of participants; and the study was contextually bound to one school. To make the conclusions stronger, further research should be completed in a variety of schools with greater participant samples.

When reviewing the data and claims made in this thesis, there were four further specific limitations that emerged:

1. In Chapter Three, Section 3.6.1, the RCM of PCK is shown along with an explanation about searching for researchable entities. Within that discussion, one key theme identified was subject matter knowledge. However, during Group One participants' initial pPCK interview, they were not asked to divulge their understanding about any particular *Electricity and Magnetism*

concepts (e.g., being asked to explain their understanding of voltage). At the time of developing the interview questions, it was decided that the goal of this study was to focus on how they taught different concepts, rather than their direct understanding of concepts. In retrospect, this omission was an oversight, as subject matter knowledge proved to be an important consideration for PCK. During the CoRe design workshops themselves, and in the evaluation interviews, subject matter knowledge was an area that was frequently identified. So, while subject matter knowledge exchanges were made in the workshops, and teachers explicitly stated their subject matter knowledge had improved, there was no initial data about this particular piece of pPCK. Therefore, changes to teachers' subject matter knowledge are based on their own reports, making judgments about them more subjective than if that baseline data had been collected.

2. At the 2nd PCK Summit, there were many discussions about the conceptualisation of PCK and how researchers have tried to measure it in the past. One dominant discussion point was the lack of focus on students. Previous PCK research has focused on teachers' knowledge and classroom actions, without paying attention to student outcomes and experiences. During the inception stages of designing this research, student experiences were going to be explored. However, as the research design developed, it was decided from a pragmatic and management view this aspect would be compromised to allow the focus to be solely on teachers' development and experiences. While this study still contributes to the science education, professional development, and PCK research communities, the contribution may have been more significant if that data had been available. It would have helped provide insights about relationships between students learning' and teachers' actions in the RCM of PCK and how collaborative CoRe design may affect student development.
3. Similarly, at the 2nd PCK Summit, the link between teacher's PCK and their application of that knowledge in lessons was discussed at length (i.e., the transformation of pPCK to ePCK). This discussion focused on a teacher's pedagogical reasoning – why they did something during a lesson. It was

acknowledged by the Summit members that this link is difficult to explore because it cannot be researched through interviews or observations alone. Rather, researchers were encouraged to employ a stimulated recall interview technique and have teachers explain their own teaching actions soon after the lesson. While the use of stimulated recall interviews as a data collection technique has been encouraged by experienced PCK researchers (e.g., Gess-Newsome, 2015; Henze & van Driel, 2015) it was not used in this research. Asking teachers to complete PaP-eRs about particular aspects of their lessons may have also shown this type of data. However, the decision to not use these techniques was pragmatic. The researcher was teaching full-time during data collection along with other commitments, which meant watching observational videos and analysing them, creating questions, and then interviewing the teachers within a quick timeframe was unrealistic. Similarly, as participating teachers were already donating valuable time by taking part in the workshops and interviews, asking them to write reflective journals or complete PaP-eRs as well was seen as an unreasonable request. Again in retrospect, this data would be useful for a deeper analysis with respect to the RCM of PCK. For example, it would expose the link and interplay of transformations from pPCK to ePCK, and in this study, it would have provided further information about the effects of collaborative CoRe design.

4. As it was signalled in Chapter Three, Section 3.4.3, the original intention was to conduct this study over two years. However, when two participants became unavailable in 2015, the decision was made to gather all data during 2016. However, this decision did not take into consideration how the school's contextual restraints and assessments would affect the study. While all Group One participants reported positive experiences, and felt they had become more effective teachers, the influence of assessment on their practice was clear. If the study had been carried out over two years, then there may have been an opportunity for the assessment issue to be somewhat mitigated (for example, aligning a new assessment with the CoRe). By removing the contextual restraints on these teachers, in that regard, a clearer indication of how collaborative CoRe design enhances PCK may have been obtained.

8.4 Suggestions for Future Research

The findings and discussions presented in this study show that when teachers with different backgrounds engage in collaborative CoRe design, their PCK can be enhanced. However, using collaborative CoRe design in this way is not without limitations. Based on the limitations identified (both of the research itself and the use of collaborative CoRe design), participants' comments and ideas, and the researcher's own goals and interests, some suggestions for future research were identified.

Six suggestions for future research were borne out of this research:

1. Using collaborative CoRe design online.

While some researchers have used CoRe design online utilising a wiki platform (e.g., Donnelly & Boniface, 2013; Donnelly & Hume, 2015), they noted that the collaborative aspect was lost. A suggestion for future research would be to utilise an online service where participants can collaborate with each other in real time (e.g., group video calling through Skype). Platforms such as wikis are useful for recording information (i.e., the CoRe itself), but using a service that enables live discussion would allow for collaboration. As collaborative CoRe design has shown to be worthwhile for developing teacher's PCK, this type of online arrangement would be beneficial to those teachers who do not have immediate access to others. For example, in a news article, O'Callaghan (2015) reported that there are schools in New Zealand where teachers are unable to access appropriate PLD because of their geographical location. Thus, teachers could develop their own online communities to achieve similar goals to face-to-face workshops as they work collaboratively with others from all over New Zealand to develop their knowledge and skills.

2. Utilising the same (or a similar) study design as this research, but collecting different data.

To gauge PCK development in more detail, it would be useful to gather two additional data sets: student's experiences and teacher's pedagogical

reasoning. While these two data sets would make the study more complex, they would be useful to make further judgements about how collaborative CoRe design affects the teacher's knowledge, skills, and practices. For example, if a teacher watched a video observation of an aspect of their lesson (soon after the lesson, as opposed to after finishing the unit) and explained their actions, which directly linked to what they had learnt during the CoRe design process, that data would provide further evidence about the worth of the workshop as an effective PLD intervention. Gaining pedagogical reasoning data will also assist the PCK research community in understanding and conceptualising the link between teachers' knowledge and classroom actions.

3. Utilising the same (or similar) study design as this research, but focusing on different topics.

While this study focused on a junior physics topic, it would be useful to focus a different unit of work. Data from this type of study would allow for further generalisations to be made about how collaborative CoRe design may enhance teachers' PCK. It would be interesting to change the focus from junior to senior science. In New Zealand, senior courses are often influenced by assessments so students can gain their National Certificate of Educational Achievement (NCEA). The highest level of qualifications is scholarship, where students complete a three-hour examination that asks difficult and complex cross-concept questions based on the entire year's work. Data focusing on senior science subjects would provide further evidence about the worth of collaborative CoRe design. It would also be interesting to do a similar study in a different curriculum area, for example, social science, or health and physical education.

4. Utilising the same (or similar) study design as this research, but making the process ongoing with different participants.

Taking up participants' suggestions, it would be useful to explore collaborative CoRe design as an ongoing PLD intervention. A school like

River High would be ideal as it has a large science department. Teachers would be able to work in small groups and explore various units of work, where they take turns in different roles: changing between Group One and Three-type roles. This type of study would produce data that would attest to the link between collaborative CoRe design and PCK development. Also, it would provide useful information about the use and sustainability of this type of PLD intervention for practising teachers.

5. Utilising the same (or similar) study design as this research, researching within different contexts.

Data gathered for this research was from a single-sex boys' school where there was a significant focus on assessment. It would be useful to explore teachers' pPCK and ePCK, and their development in different contexts to see how those contextual factors affected outcomes. For example, researching in schools that have a lesser assessment focus. Data could also be gathered from girls' or co-educational schools to see how teachers' actions and professional learning change. This data would highlight how contextual factors influence teachers' pPCK and ePCK.

6. Only use some CoRe design prompts to make the process more efficient (i.e., modify the CoRe template).

A comment was made during the evaluation phase of the research that the key learning from collaborative CoRe design was what to teach and how to teach it. Other information about some pedagogical prompts, while important, was more background information. Thus, it might be useful to summarise and combine the CoRe prompts to ensure the focus is primarily on what to teach and why, and how to teach it. The other information could be summarised so it is still represented. Data from this type of study would investigate whether the process could be made more efficient for practising teachers while still developing their PCK.

8.5 Conclusion and Final Remarks

The purpose of this final section of the thesis is to highlight the significant contribution of this research to knowledge, which is a key outcome of excellent qualitative research (Tracy, 2010). This study sought to find out about the nature of practising science teachers' pPCK and ePCK who had a limited physics background for the Year 10 topic *Electricity and Magnetism*, and to investigate collaborative CoRe design as an effective PLD intervention for enhancing their pPCK and ePCK. From the discussions and key findings presented in the previous chapters, there are five significant conclusions:

1. While the nature of a teacher's pPCK and ePCK is unique as it depends on their own knowledge and experiences, there are some commonalities when comparing teachers with a limited subject knowledge background. The three case study teachers: relied heavily on specific learning outcomes (SLOs) that were provided to them; often had rigid agendas for learning and were reluctant to vary their instruction and deviate from their agenda to develop student understanding; and, taught in a style where information was transmitted to students, as opposed to encouraging students to develop their own conceptual understanding.
2. All participants enjoyed the collaborative nature of the workshops. They remarked it was a beneficial and worthwhile activity as it allowed them to share and critique ideas about teaching concepts. They were interested in utilising this type of PLD intervention in their school, and it was suggested that collaborative CoRe design could become an ongoing process.
3. For the Group One teachers in particular, collaborative CoRe design embodied the key features of effective professional development, as detailed by Desimone (2009). As these features were met, the Group One participants' knowledge and skills developed, making them more effective teachers. In contrast, the features were not as closely aligned with the other teachers, resulting in little changes. This conclusion supports the effective PLD conceptual framework on developed by Desimone (2009) (see Page 92).
4. During the collaborative CoRe design workshop, the identification of the big ideas and the pedagogical prompts provoked many discussions where knowledge was exchanged. When developing the big ideas, teachers'

knowledge of curriculum was being emphasised. Later, knowledge exchanges were primarily concerned with subject matter knowledge and knowledge of topic-specific instructional strategies, while there were also some discussions that focused on students' understanding and learning.

5. Group One teacher's pPCK and ePCK was enhanced as a result of collaborative CoRe design, although, the development was unique to each teacher. They all identified their knowledge had been enhanced during the evaluation interviews, and there were observable changes to their practice showing development.

Collaborative CoRe design has proven to be an effective and worthwhile PLD intervention for practising science teachers. Teachers, who had a limited physics background, enhanced their pPCK and ePCK for teaching Year 10 *Electricity and Magnetism*. These same teachers were also interested and enthusiastic about their school adopting collaborative CoRe design as a faculty-wide strategy, so other teachers could benefit from the same enlightening experiences, in turn improving student outcomes.

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Appendices

Appendix A – Information Letters

Appendix A1 – Information Letter to Principal

TEMS Education
Research Centre
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Date

Dear [name of Principal]

Information about the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

My name is Jared Carpendale and I am writing to you as a motivated educator, who is aiming to develop the teaching of Science, and to invite your school to participate in the development of this. I am a Chemistry, Physics, Electronics, and Science teacher at Hamilton Boys' High School and a doctoral research student at the Technology, Environmental, Mathematics, and Science (TEMS) Education Research Centre. I am very passionate about Science education, Physics education, and teacher development. This interest has motivated me to carry out a Doctor of Philosophy research study focusing on developing junior Science teachers' pedagogical content knowledge in the area of junior physics education.

While this research study is complex and multifaceted, the aim is to:

1. Identify the physics pedagogical content knowledge of teachers who have a limited physics background, and teachers who are considered expert teachers, for the Year 9/10 topic *Electricity and Magnetism*.
2. Work with these teachers in small focus group workshops to take them through a design process called 'content representation' (CoRe design) for the teaching of the Year 9/10 topic *Electricity and Magnetism*.
3. Identify any changes in teacher PCK after this process.

I would like to invite you and your school to participate in this study, which will take place during 2016. Whilst assessing the impact that CoRe design might have for the

classroom, I am also hopeful that being involved in this scheme would benefit your teachers and learners.

With the permission of the participants, I would aim to collect data utilising the following methods:

- a) Meet, interview, and work with six science teachers with a non-physics background, and three experienced physics teachers. The data will be collected over one year and the interview component will take approximately two hours in total over four interview sessions.
- b) Observe three of the six science teachers with a non-physics background teaching electricity and magnetism. Each of these teachers will be video recorded as they teach electricity and magnetism.
- c) Invite all of the participating teachers to take part in CoRe design workshops. These professional development workshops take approximately three hours each. Ideally these workshops would occur during a teacher only day, or may occur during school holiday time.

The total time involvement for participating teachers is less than ten hours during the year of data collection. This includes interviews, focus group discussions and CoRe design workshops.

Data would be collected using audio recording interviews, video recordings of classroom observations, and field notes. Any information that is collected from either staff or students from your school will be carefully coded and pseudonyms will be used throughout the study to ensure anonymity of all participants.

You have the right to withdraw your school at any time during the data collection phase of the research. The teachers and the students have the right to withdraw at any time during the data collection phase of the research. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. Participants will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. Participants will be given the opportunity to view their transcripts during the three week period.

If a participant withdraws three weeks after receiving final interview transcripts, all data collected of the participant will be omitted. However, any analysis at that point may be kept.

Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.

As well as providing the teacher, the students, the parents and yourself with this information through written documentation, I would additionally be pleased to explain the purpose of this study during an initial visit to your school. I would also be happy to meet after the research has been conducted and analysed to share my findings, and would send your school a short summary of the research findings on completion of my thesis.

If you are interested in taking part in this exciting initiative, I would like to come to your school to discuss informed consent. During this time, I would provide you with informed consent forms for you to take away and read. I would then request that you sign and return these forms if you are willing to let your school participate and are satisfied with all of the research aspects.

If you have any questions regarding this study and how it might benefit your Science department and its students, concerns, or complaints, please contact the researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I await your answer with anticipation.



Jared Carpendale

jared.carpendale@gmail.com

Phone 027 294 2434

Appendix A2 – Information Letter for Group One Participants

**TEMS Education
Research Centre**
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



Date

Dear [name of teacher]

Information about the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

My name is Jared Carpendale and I am writing to you as a motivated educator, who is aiming to develop the teaching of Science, and to invite your school to participate in the development of this. I am a Chemistry, Physics, Electronics, and Science teacher at Hamilton Boys' High School and a doctoral research student at the Technology, Environmental, Mathematics, and Science (TEMS) Education Research Centre. I am very passionate about Science education, Physics education, and teacher development. This interest has motivated me to carry out a Doctor of Philosophy research study focusing on developing junior Science teachers pedagogical content knowledge in the area of junior physics education.

While this research study is complex and multifaceted, the aim is to:

1. Identify the physics pedagogical content knowledge of teachers who have a limited physics background, and teachers who are considered expert teachers, for the Year 9/10 topic *Electricity and Magnetism*.
2. Work with these teachers in small focus group workshops to take them through a design process called 'content representation' (CoRe design) for the teaching of the Year 9/10 topic *Electricity and Magnetism*.
3. Identify any changes in teacher PCK after this process.

I would like to invite you to participate in this study, which will take place between the start of the school year for 2015 and would last until the end of 2016. Whilst

assessing the impact that CoRe design might have for the classroom, I am also hopeful that being involved in this scheme would benefit you and your students.

I would aim to collect data from you utilising the following methods:

- a) Interview and observe you to gain an understanding of your PCK around physics education. Interviews will be audio recorded and transcribed at a later date. This individual interview will be approximately 40 minutes. The observation part consists of three full lesson observations during the electricity and magnetism topic and is aimed at exploring your PCK around electricity and magnetism. During observations, photographs or activities may be taken and used along with student work. No person will be identifiable in any photograph used. During the other lessons in this unit video and audio recordings will be made so the researcher can analyse these lessons at a later date. If the researcher is unable to set up the equipment, a delegated person who has signed a confidentiality agreement will. This agreement will forbid that person from viewing or distributing the data.
- b) Work with you collaboratively in a process called CoRe design to develop an overview for teaching the topic. Firstly a CoRe will be made for junior topic of scientific investigations to introduce you to the process, then a second one about junior electricity and magnetism. Each of these workshops will take approximately five hours. These workshops will be audio recorded and the researcher will observe and take notes. The time for this will either be a school teacher only day, or during one day in the school holidays.
- c) Ask some questions in a focus group setting about CoRe design. This will be done over two focus group discussion sessions, both will be approximately 40 minutes.
- d) Observe you teaching junior electricity and magnetism to identify any changes in PCK. Again, the observation part consists of three full lesson observations during the electricity and magnetism topic. During observations, photographs or activities may be taken and used along with student work. No person will be identifiable in any photograph used.
- e) After you have been involved in the CoRe design process I would like to ask some of your students to take part in a focus group discussion.

The time involvement for the data collection includes two 40 minute individual interviews, two five hour professional development workshops, two 40 minute focus group discussions, and six lesson observations. For the interviews and focus group discussions, the questions will be given to you beforehand. Transcripts of the interviews and focus group discussions will also be given to you to ensure accuracy. Any information that is collected from you during interviews or observations will be carefully coded and pseudonyms will be used throughout the study to ensure anonymity of all participants.

You have the right to withdraw at any time during the data collection phase of the research. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. Participants will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. Participants will be given the opportunity to view their transcripts during the three week period.

If a participant withdraws three weeks after receiving final interview transcripts, all data collected of the participant will be omitted. However, any analysis at that point may be kept.

Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.

As well as providing you with the information contained here, I am happy to explain the purpose of this study during an initial visit to your school. I would also be pleased to organise a meeting after the research has been conducted and analysed to share my findings, and would send your school a short summary of the research findings on completion of my thesis.

If you are interested in taking part in this exciting initiative, I would like to come to your school to discuss informed consent. During this time, I would provide you with informed consent forms for you to take away and read. I would then request that you

sign and return these forms if you are willing to participate and are satisfied with all of the research aspects.

If you have any questions, concerns, or complaints, please contact the researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I await your answer with anticipation.

A handwritten signature in dark ink, appearing to read 'J. Carpendale', written in a cursive style.

Jared Carpendale

jared.carpendale@gmail.com

Phone 027 294 2434

Appendix A3 – Information Letter for Group Two and Three Participants

**TEMS Education
Research Centre**
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Date

Dear [name of teacher]

Information about the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

My name is Jared Carpendale and I am writing to you as a motivated educator, who is aiming to develop the teaching of Science, and to invite you to participate in the development of this. I am a Chemistry, Physics, Electronics, and Science teacher at Hamilton Boys' High School and a doctoral research student at the Technology, Environmental, Mathematics, and Science (TEMS) Education Research Centre. I am very passionate about Science education, Physics education, and teacher development. This interest has motivated me to carry out a Doctor of Philosophy research study, focusing on developing junior Science teachers' pedagogical content knowledge in the area of junior Physics education.

While this research study is complex and multifaceted, the aim is to:

1. Identify the physics pedagogical content knowledge of teachers who have a limited physics background, and teachers who are considered expert teachers, for the Year 9/10 topic *Electricity and Magnetism*.
2. Work with these teachers in small focus group workshops to take them through a design process called 'content representation' (CoRe design) for the teaching of the Year 9/10 topic *Electricity and Magnetism*.
3. Identify any changes in teacher PCK after this process.

I would like to invite you to participate in this study, which will take place between the start of the school year for 2015 and would last until the end of 2016. Whilst

assessing the impact that CoRe design might have for the classroom, I am also hopeful that being involved in this scheme would benefit you and your students.

I would aim to collect data from you utilising the following methods:

- a) Ask you some questions about what you consider rich pedagogical content knowledge for teaching the Year 9/10 topic *Electricity and Magnetism* to be, in a focus group setting. This interview will be audio recorded and will be approximately 40 minutes.
- b) Work with you collaboratively in a process called CoRe design to develop an overview for teaching the topic. Firstly a CoRe will be made for junior topic of scientific investigations to introduce you to the process, then a second one about junior electricity and magnetism. Each of these workshops will take approximately five hours. These workshops will be audio recorded and the researcher will observe and take notes. These workshops will occur either at the University of Waikato or at your school. The time for this will either be a school teacher only day, or during one day in the school holidays.
- c) Ask some questions in a focus group setting about CoRe design, again audio recording will be done. This is done using two focus group discussions that will take approximately 40 minutes each.

The time involvement for the data collection includes three 40 minute focus group discussions (one about exploring PCK, and two about CoRe design experiences) and two five hour professional development workshops. For the focus group discussion, the questions will be given to you beforehand. Transcripts of the focus group discussions will also be given to you to ensure accuracy.

Any information that is collected from you will be carefully coded and pseudonyms will be used throughout the study to ensure anonymity of all participants.

You have the right to withdraw from the study at any time during the data collection phase of the research. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. You will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. You will be given the opportunity to view your transcripts during the three week period.

If you withdraw three weeks after receiving final interview transcripts, all data collected from you will be omitted. However, any analysis at that point may be kept.

Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.

As well as providing you with the information contained here, I am happy to explain the purpose of this study during an initial visit to your school. I would also be pleased to organise a meeting after the research has been conducted and analysed to share my findings, and would send your school a short summary of the research findings on completion of my thesis.

When we meet I will discuss informed consent, and give you informed consent forms for you to take away and read, and then sign and return if you are willing to participate and are satisfied with all of the research aspects.

If you have any questions, concerns, or complaints, please contact the researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I await your answer with anticipation.



Jared Carpendale

jared.carpendale@gmail.com

Phone 027 294 2434

Appendix A4 – Information Letter for Students and Parents/Caregivers**TEMS Education
Research Centre**

The University of
Waikato
Private Bag 3105
Hamilton, New
Zealand



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Date

Dear Student, Parents and Caregivers

Information about the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

My name is Jared Carpendale and I am writing to you as a motivated educator, who is aiming to develop the teaching of Science, and to invite your school to participate in the development of this. I am a Chemistry, Physics, Electronics, and Science teacher at Hamilton Boys' High School and a doctoral research student at the Technology, Environmental, Mathematics, and Science (TEMS) Education Research Centre. I am very passionate about Science education, Physics education, and teacher development. This interest has motivated me to carry out a Doctor of Philosophy study.

While you are completing your Year 10 topic of Electricity and Magnetism I would like to carry out some lesson observations to see what activities you do throughout the unit. For this process I would like to video and audio record some of your lessons, and be present at others. During these lessons, the focus is on how the teacher is teaching you, not what you are doing. No data about specific students will be used or reported. No photographs or images from the video will be used. Overall, this study seeks to report about the types of lessons and activities that were used during this topic.

You have the right to decline taking part in this research. In this situation, you will still partake in lessons as per usual, and no data will be reordered or reported about you.

I be grateful for your acknowledgement of receipt of this information using the attached form. It needs to be signed by a parent or caregiver.

If you have any questions, concerns, or complaints, please contact the researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

Kind regards,

A handwritten signature in dark ink, appearing to read 'J. Carpendale', written in a cursive style.

Jared Carpendale

Appendix B – Informed Consent and Acknowledgement

Appendix B1 – Informed Consent Document for Principal

TEMS Education
Research Centre
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Informed Consent for the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

I have read the attached information letter about this research project.

I understand that:

1. My school's participation in the project is purely voluntary.
2. That I am granting consent for the research to include teachers and students from my school.
3. I have the right to withdraw my school at any time during the data collection phase of the research. The teachers and the students have the right to withdraw at any time during the data collection phase of the research. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. Participants will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. Participants will be given the opportunity to view their transcripts during the three week period.
4. If a participant withdraws three weeks after receiving final interview transcripts, all data collected of the participant will be omitted. However, any analysis at that point may be kept.
5. All data collected from my school will be kept confidential and securely stored.

6. The time involvement for teachers is approximately 13 hours over two years, and for students it is one 20 minute interview.
7. Teachers will be video recorded as they teach electricity and magnetism by the researcher for analysis at a later date.
8. These recordings will be done by setting up a tripod with a camera. The researcher will set up the equipment where possible. If the researcher is unable to set the equipment up, a delegated person will set up the equipment. This person will sign a confidentiality agreement declaring they will not view or distribute the data. This data will be safeguarded using a password protected computer.
9. Information will be provided to students and parents about the lesson observations.
10. Lesson observation recordings will not be used for any other purpose, other than this study, and no person will be identified in these recordings. Data about student actions in the lesson will not be used.
11. Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.
12. I can direct any questions or concerns to researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or to the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I give consent for my school to be involved in the research project under the conditions set out above.

Name of School: _____

Principal Signature: _____

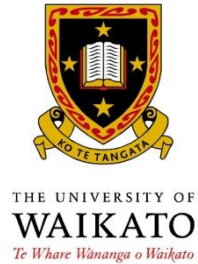
Name of Principal: _____

Date: _____

Appendix B2 – Informed Consent Document for Group One Participants

**TEMS Education
Research Centre**

The University of
Waikato
Private Bag 3105
Hamilton, New
Zealand



Informed Consent for the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

I have read the attached information letter about this research project.

I understand that:

1. My participation in the project is purely voluntary.
2. I am granting consent to be involved with interviews, focus group discussions, observations, and working collaboratively with other staff to develop a CoRe.
3. I have the right to withdraw at any time during the data collection phase of the research. No participant that has withdrawn will be identified, and any data collected from a participant that has been withdrawn will not be used for the analysis, and no further data will be collected. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. Participants will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. Participants will be given the opportunity to view their transcripts during the three week period.
4. If I withdraw three weeks after receiving final interview transcripts, all data collected from me will be omitted. However, any analysis at that point may be kept.

5. Data will be collected from interviews by audio recording discussions and taking notes. Discussions during CoRe workshops will also be recorded for analysis. All data collected will be kept confidential and securely stored.
6. I will be observed three times as I teach electricity and magnetism by the researcher. During these lessons the researcher will be present. For the other lessons in this unit, video and audio recordings will be made for analysis at a later date by the researcher.
7. These recordings will be done by setting up a tripod with a camera. The researcher will set up the equipment where possible. If the researcher is unable to set the equipment up, a delegated person will set up the equipment. This person will sign a confidentiality agreement declaring they will not view or distribute the data. This data will be safeguarded using a password protected computer.
8. Information will be provided to students and parents about the lesson observations.
9. Lesson observation recordings will not be used for any other purpose, other than this study, and no person will be identified in these recordings. Data about student actions in the lesson will not be used.
10. I will not be identified in transcribed excerpts of the discussions.
11. The time involvement for this project is approximately 10 hours plus six lesson observations over two years.
12. Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.
13. I can direct any questions or concerns to researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or to the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I give consent to be involved in the research project under the conditions set out above.

Name of School: _____

Teacher Signature: _____

Name of Teacher: _____

Date: _____

Appendix B3 – Informed Consent Document for Group Two and Three Participants

**TEMS Education
Research Centre**
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



Informed Consent for the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

I have read the attached information letter about this research project.

I understand that:

1. My participation in the project is purely voluntary.
2. I am granting consent to be involved with focus group discussions, and working collaboratively with other staff to develop a CoRe.
3. I have the right to withdraw at any time during the data collection phase of the research. No participant that has withdrawn will be identified, and any data collected from a participant that has been withdrawn will not be used for the analysis, and no further data will be collected. Any data that has already been collected will not be used in the analysis if withdrawal occurs up to three weeks after the final focus group discussion. Participants will be given the right to decline during the data collection phase of the research, and then up to and including three weeks after the final focus group discussion. Participants will be given the opportunity to view their transcripts during the three week period.
4. If I withdraw three weeks after receiving final interview transcripts, all data collected from me will be omitted. However, any analysis at that point may be kept.
5. Data will be collected from interviews by audio recording discussions and taking notes. Discussions during CoRe workshops will also be recorded for analysis. All data collected will be kept confidential and securely stored.

6. I will not be identified in transcribed excerpts of the discussions.
7. The time involvement for this project is approximately 13 hours over two years.
8. Data obtained during this research project will be analysed and used in writing a thesis for a Doctor of Philosophy degree at the University of Waikato. Some of the work may also be presented at conferences, or used in educational journals. All data will be reported anonymously or using pseudonyms so that confidentiality of the participants is maintained. No participant or school will be identified at any stage.
9. I can direct any questions or concerns to researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or to the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I give consent to be involved in the research project under the conditions set out above.

Name of School: _____

Teacher Signature: _____

Name of Teacher: _____

Date: _____

Appendix B4 – Acknowledgement Document for Students and Parents/Caregivers

**TEMS Education
Research Centre**
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



Acknowledgement form for the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

I have read the attached information letter about this research project.

I understand that:

- My science lessons during the electricity and magnetism topic are going to be video and audio recorded.
- The focus is on the lesson and the teacher, not what students are doing.
- No photos from the recordings will be used.
- The purpose of these observations is for research and is not related to school.
- Participation in this research will not affect and future classes or assessments while at school.
- I can direct any questions or concerns to researcher Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or to the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

I have read the information letter and the conditions above.

Name of School: _____

Student Name: _____

Student Signature: _____

Parent/Caregiver Signature: _____

Date: _____

Appendix B5 – Confidentiality Agreement for Assistance with Recordings

TEMS Education
Research Centre
The University of Waikato
Private Bag 3105
Hamilton, New Zealand



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Confidentiality agreement form for the research project:

Enhancing junior secondary science teachers' PCK for teaching *Electricity and Magnetism* using collaborative CoRe Design and implementation: A school-based case study

This form is for people who may be assisting the researcher with setting up audio and video recording equipment for gathering observational data. Please read the following information and sign to acknowledge that you have understood the terms and will adhere to the confidentiality guidelines.

During this process of helping the researcher with carrying out these observations, your task will be to set up the recording equipment. Throughout this process you will ensure that you:

1. Will not view recordings that were made during the lesson observations.
2. Will not distribute the recordings from these lesson observations to anyone.
3. Follow instructions from the researcher.
4. Keep recordings safe and secure until they can be delivered to the researcher.

Any questions or concerns can be directed to the researcher, Jared Carpendale (jared.carpendale@gmail.com, Tel. 027 294 2434), or to the principal supervisor Dr Anne Hume (annehume@waikato.ac.nz, Tel. 07 838 4466 ext 7880).

Date: _____

Name: _____

Signature: _____

Appendix C – Guiding Interview Questions with Prompts

Appendix C1 – pPCK Interviews

These guiding questions were used to explore Group One teacher's pPCK before taking part in the CoRe design workshops.

1 – Context of Teacher: Learning about you as a teacher

- Can you please tell me about your teaching experiences, for example:
 - When did you start teaching?
 - How long you have been teaching for?
 - What qualifications?
 - What is your subject specialisation?
 - What types of schools have you taught in?

2 – Orientation to Teaching Science: Exploring your philosophy of science teaching

- Do you perceive science education as something of value?
 - Why?
 - Why not?
 - What do you think its purpose is?
 - In New Zealand, science is included as one of the eight learning areas of our national curriculum and is compulsory to teach students until Year 10, why do you think that is?
 - What do you see as being the foremost goal(s) for science education?
- What is your goal, as a science teacher, when teaching students about electricity and magnetism?
 - At the end of teaching the unit, what do you want your students to have achieved?
- What qualities or skills do you think students need in order to achieve the goal(s) you outlined earlier?
 - Do you think these qualities or skills are similar to scientists?
 - Why do you think this?

- How would they act like scientists? What would that look like?
 - What types of skills would you want your students to develop?
- Tell me about your understanding of the nature of science.
- What do you think the nature of science is about?
 - How do you incorporate some of these aspects into your lessons?
 - How do you encourage your students to learn about the nature of science?
- Tell me about your understanding of scientific inquiry.
- What do you think scientific inquiry is about?
 - How do you incorporate aspects of scientific inquiry into your lessons?
 - How do you encourage scientific inquiry?
- 3 – Knowledge of Curricula: Exploring your knowledge of the curriculum
- What key ideas/concepts do you think students should learn about electricity and magnetism during this unit?
- Why do you think those ideas are important to learn?
- 4 – Knowledge of Students Understanding of Science: Exploring how you use prior knowledge
- What prior knowledge for electricity and magnetism are you expecting to see from your students?
- What knowledge do you think students need to have from previous years before starting this unit?
- What misconceptions do you think students might have in electricity and magnetism?
- 5 – Knowledge of Instructional Strategies: Exploring how you teach electricity and magnetism

- How do you go about introducing this topic?
 - What is your approach?

- Tell me about your sequence of lessons for teaching electricity and magnetism.

- What do you see as your role as the teacher when teaching this unit?

- What types of learning opportunities do you provide when teaching electricity and magnetism?
 - Can you describe some of your specific methods that you used?
 - What activities were successful for your students?

- Do your students have similar approaches to learning?
 - Do they learn in the same way?
 - (how do you accommodate these different ways?)

6 – Knowledge of Assessment: Exploring how you determine if/what they've learnt

- How are you going to determine if your students have learnt those ideas/concepts that you have described as being important?
 - Do you use formative assessments in your units? How do you use them?
 - How do you determine if your students have developed those qualities/skills you identified earlier?
 - What do you do with this information?

7 – Teacher Efficacy: Exploring your confidence in your abilities

- How effective do you think you are at teaching electricity and magnetism?
 - Why do you think that is?
- Can you describe how confident you are when using some of the learning approaches you described earlier?

-
- How do the activities go if you are not feeling confident about using it?
 - Do you still use it if you are not confident?
 - Yes – how do you feel about using it?
 - No – why not?

 - If there is a new activity that you would like to use, but you are not confident about using it, what do you do?
 - For example, you hear of a new demonstration from another teacher, but you are unsure how it works/how to do it.

Appendix C2 – Evaluating CoRe Design Process

Three guiding questions were used to ask participants about how they saw CoRe design as a process.

1. What aspects of CoRe design do you think are useful?
2. What difficulties do you see with developing a CoRe?
3. Describe your overall experience when creating a CoRe.
 - a. Would you be willing to take part in CoRe design in the future?

Appendix C3 – Evaluating CoRe Design for Enhancing PCK

Four guiding questions were used to ask participants about how they think CoRe design could enhance PCK.

1. How worthwhile was developing the CoRe for electricity and magnetism?
2. How do you think developing this CoRe has affected your PCK?
3. Has it changed how you might approach the unit or a concept?
4. How did you find working collaboratively?

Appendix C4 – Group One Teacher’s Final Comments

At the end of the study, Group One teachers were interviewed one final time using the following six guiding questions.

1. What aspects from the CoRe did you use when you planned your teaching of electricity and magnetism for your second class? (Why?)
2. Did you teach your second class in a different way due to CoRe design? A different approach? (Can you explain why/why not?)
3. Can you give instances where you taught the same concept, but in a different way due to CoRe design?
 - a. If so, how successful was this different way?
 - b. Did students learn more effectively? How do you know?
 - c. Will you continue to teach the concept this way? (Why/why not?)
4. How do you think CoRe design has affected your PCK in Y10 electricity and magnetism? That is:
 - a. Has it affected the way you teach certain concepts?
 - b. Are you more aware of student misconceptions/prior knowledge?
 - c. Are there some concepts and/or skills that you would add/drop?
 - d. Has it affected the way you monitor or assess student learning?
5. What changes do you think could be made to make CoRe design more useful for practising teachers?
6. Do you have any final comments about being involved in this CoRe design study?

Appendix D – Observational Protocol

Appendix D1 – Blank Observational Protocol

Observational Protocol for Exploring ePCK in Lesson Observations

Date of observation:
Teacher Name:
Concept being covered:
Number of students:

Contextual Information about Lesson:

Briefly describe:

- Classroom environment
- Equipment used
- Material that has been prepared for students
- Student response and engagement

Rubric for Scoring Components of Enacted PCK from Video Observations

Subject Matter Knowledge				
CoRe Prompts One, Two, and Three				
ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriateness of concept(s) in relation to NZC – Physical World (Level 5)	No alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Little alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Adequate alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Close alignment of concept(s) in lesson with NZC – Physical World (Level 5)
Accuracy of the explanation of the concept(s)	Explanation(s) were mostly inaccurate, which did not address the concept(s)	Explanation(s) were somewhat inaccurate, which loosely addresses the concept(s)	Explanation(s) were mostly accurate with only small inaccuracies seen, or they were too brief	Explanation(s) were accurate, which addresses the concept with no inaccuracies
Links and/or connections made to other concepts	No possible links and/or connections are made	Few of the possible links are made, but not connected with explanations	Some of the possible links and connections are made	Many of the possible links and connections are made
Links made (implicit or explicit) to the nature of science (NoS) and/or scientific inquiry (SI)	No links made to NoS and/or SI	Few of the possible links to NoS and/or SI are made	Some of the possible links to NoS and/or SI are made	Many of the possible links to NoS and/or SI are made

Knowledge of Student Understanding

CoRe Prompts Four, Five, and Eight

ePCK Indicator	Limited	Basic	Proficient	Advanced
Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions	No recognition or acknowledgement of possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges most/all possible student prior knowledge, difficult concepts, and/or misconceptions
Teacher uses identified variations in student understanding and learning to guide instruction	No acknowledgement and/or use of variations in student understanding and learning to guide instruction	Acknowledgement of variations in student understanding or learning, but not used to guide instruction	Some acknowledgment of variations in student understanding or learning are used to guide instruction	Many instances where teacher acknowledged variations in student understanding or learning and used these to guide instruction
Teacher uses questioning to probe or extend student understanding	No questions are used to probe or extend student understanding	A few questions are used to probe or extend student understanding	An adequate range of questions are used to probe or extend student understanding	Many and varied questions are used to probe or extend student understanding

Knowledge of Instructional Strategies

CoRe Prompt Seven

ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriate sequence for teaching concepts	No overall flow between concepts and the sequence confuses students	Some flow between concepts and the sequence allows some concept building to occur	Suitable flow between concepts and the sequence allows satisfactory concept building to occur	Clear flow between concepts and sequence allows effective concept building
Relevant examples and/or representations are used in the lessons, which appear to be pedagogically effective at portraying the concept	No examples and/or representations used	Examples and/or representations used that are not relevant	Examples and/or representations used have some relevance, but appear pedagogically limited	Relevant examples and/or representations used that appear pedagogically effective
Use of strategies that allow for metacognition	No use of strategies that allow for metacognition	Limited use of strategies that allow for metacognition	Adequate use of strategies that allow for metacognition	Much use of strategies that allow for deep levels of metacognition

Post Analysis Summary

Subject Matter Knowledge

Appropriateness of concept(s) in relation to NZC – Physical World Level 5

Accuracy of the explanation of the concept(s)

Links and/or connections made to other concepts

Links made (explicit or implicit) to the nature of science (NoS) and/or scientific inquiry (SI)

Student Understanding

Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions

Teacher uses identified variations in student understanding and learning to guide instruction

Teacher uses questioning to probe and extend student understanding

Instructional Strategies

Appropriate sequence for teaching concepts

Relevant examples and/or representations are used in the lesson, which appear to pedagogically effective

Use of strategies that allow for metacognition

Appendix D2 – Example of Completed Observational Protocol**Observational Protocol for Exploring ePCK in Lesson Observations**

Date of observation: 8/6/2016
Teacher Name: Tony
Concept being covered: Series + Parallel Circuits

Contextual Information about Lesson:

Briefly describe:

- Classroom environment
- Equipment used
- Material that has been prepared for students
- Student response and engagement

Students seemed to enter classroom in a routine way and take out their equipment.

Teacher reminded students about re-sitting the previous test.

In the previous lesson, students had looked at circuit symbols and diagrams, and had made some simple circuits with guidance from Tony.

Same PowerPoint presentation used.

A YouTube video was used at the end of the lesson.

No practical equipment used in lesson.

Students were reluctant when taking notes, but interested in video at the end.

Reference	Description of events	Indicator
Omin	<p>Introductions and talking to students about re-siting previous test.</p> <p>Reminds students about upcoming exam and shows them Google drive and Google classroom.</p> <p>T: All topics will be there.</p> <p>Tony shows students where to find information.</p>	
2.30	<p>Starts talking about electricity.</p> <p>T: Because we're in the classroom we are going to do lots of notes so when we are in the lab we can do the practicals.</p> <p>T: there are two types of circuits, don't write just yet, and let me explain. Actually, write that down.</p> <p>Tony draws single lamp series circuit and two lamp parallel circuit on the whiteboard – side by side.</p> <p>Tony tells students to finish writing the sentence.</p> <p>Reminds students again about re-sitting test.</p> <p>T: There are two types of circuits – how much time do you need to write that down?</p> <p>Tony asks students what types there are.</p> <p>S: Parallel and series.</p> <p>T: Good.</p>	<p>SMK – App</p> <p>SU – Qu</p>
5.00	<p>Changed to new PPT slide with a series circuit diagram. Two lamps in series – both the actual picture and a schematic diagram.</p> <p>T: Don't write this. Let's talk about it first and get some understanding. In series circuit, all of the</p>	<p>SU – PrK</p>

	<p>components – do you understand what components mean? Components are like the lamps, or anything you put into the circuit. So in this case, the components are two lamps. There is only one pathway for the current to flow, so if one bulb stops working so will the other one.</p> <p>Tony adds another lamp to his whiteboard diagram and reminds students about drawing a schematic diagram.</p> <p>T: To draw a bulb, it's a circle with a cross in it.</p> <p>Referring to his whiteboard diagram: T: Current travels from here to here. Now if I break this wire, what happens to the lamp? They stop working because there is no electrical energy going through that wire. It can't move anymore, so they won't go. That is a series circuit. So all the current must go through this wire.</p> <p>Instructs students to write notes and draw two lamp schematic diagram.</p> <p>T gives student detention for having phone out during the lesson.</p>	<p>SMK – App SMK - Acc</p> <p>SMK – iNoS</p> <p>SU - Qu</p>
9:30	<p>Tony freezes PPT so he can use the computer. Students still taking notes.</p> <p>T: You remember that in a series circuit...</p> <p>S: All the chords are all over the place.</p> <p>T: Yeah, but when you added the lamps to it, do you remember what happened?</p> <p>S: They went dimmer.</p> <p>T: That's right.</p> <p>S: Sir, are we writing this?</p>	<p>SU – PrK SU – Qu</p>

	<p>T: Yeah. I told you to do that before.</p> <p>Tony reads the notes on the board.</p> <p>T completes roll.</p> <p>T: Are you writing this down? You better be.</p> <p>T finishes writing student detention.</p>	
12:20	<p>T: Okay, so series circuit. All done? Tough, because you should have written it down before. The diagram is still on the whiteboard. Now parallel circuits, here is a parallel circuit here (points to board). The thing about a parallel circuit, can you see here, what this means is that there is two pathways. Don't write it down, look at me.</p> <p>Tony goes back to series circuit – T: See current has to go through here <i>and</i> here (lamps). Now with a parallel circuit, it's actually got two options. It comes down here, then some goes through this one and some through the other. Then they join back up here, and it goes like that. So if I cut that wire, this one will not work, but this one will because there is still a pathway for electricity to travel.</p> <p>S: When you cut that, does the current that went to the bottom one now go to the top one?</p> <p>T: That is a really good question. Uh... it won't change the current, but some will still come through there (top one). I am not sure if you noticed it, when we had those two bulbs set up last week, they were dim. But in parallel circuits, they are as bright as each other.</p> <p>(back to series diagram) If I took that circuit out (bulb), and just made one, it would be brighter. If I had</p>	<p>IS – Seq</p> <p>SMK - Acc</p> <p>SMK - Link</p> <p>SMK - Acc</p> <p>SMK - Link</p>

	<p>T: Okay, here is a series circuit, lets imagine for a second that it is.... There some tyres and the front of a car, what would those be? The lights. (Does same to parallel circuit).</p> <p>T: Now, which one would you rather be driving?</p> <p>Collective parallel.</p> <p>T: Why?</p> <p>S: Because if one goes out, the other still goes.</p> <p>T: Exactly, imagine driving at night. If you were in this one (series), if one of your lights when, sometimes a light just blows, it doesn't have to be a broken circuit. But when a bulb blows it makes a break in the circuit. So if something happens, the whole thing doesn't go. It would be dark and you couldn't see. Whereas with this one (parallel), if one of them goes, the other one still goes. You would still be able to get home on one light. So cars are wired in parallel for that reason.</p> <p>T: Back in the day, old Christmas tree lights, were all wired in series. So if one went, it stopped working and someone would have to go through and check every single one to check them. Whereas these days, they are in parallel, so that it is not such a problem.</p> <p>Changes PPT to a series and parallel circuit side by side.</p> <p>T: Series has one pathway, parallel there is more than one. If something happens to a bulb or one of the wires, one will still work.</p>	<p>SU – Qu</p> <p>IS – Ex</p> <p>IS – Ex</p> <p>IS – Seq</p>
22:30	<p>Changes PPT Slide.</p> <p>Current and voltage in series and parallel circuits.</p>	

	<p>T: What do you measure current in?</p> <p>S: Amps.</p> <p>T: We measure current in amps, what about voltage?</p> <p>S: Volts.</p> <p>T: Before you start writing, I am going to add something to that. The voltage symbol is V, the symbol for current is I.</p> <p>T: Now, start writing.</p> <p>Tony starts to talk as students are writing, then retracts and tells them to copy first.</p> <p>Erases diagrams.</p> <p>T: There is some maths in this topic as well, and formulas. It like physics, well it is part of physics.</p> <p>Tony makes a quiet comment that he is not brainy enough for physics and maths, that's why he is a biologist.</p> <p>Tony redraws diagrams – adds two ammeters and two voltmeters to parallel circuit, and two voltmeters and three ammeters to series. Gives the power supply a voltage of 10V.</p> <p>T: Don't draw the diagrams. I want to explain it.</p> <p>Tony writes in values beside each meters that he has drawn.</p> <p>Asks students to finish writing the notes – T: Hurry up, you're writing too slow.</p> <p>Tony talks to students again about re-sitting test. T: If you don't like it, tough. You should have studied for the first one.</p>	<p>SMK –</p> <p>Link</p> <p>SMK –</p> <p>iNoS</p> <p>SMK –</p> <p>Link</p>
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30:25	<p>Directs students to whiteboard.</p> <p>T: Let's look at the series circuit first, I've put in some extra detail. When you're drawing a circuit diagram... We will put in different things, like 10V – that is how many volts are coming out of the battery. And this A, what does it mean?</p> <p>S: Ammeter.</p> <p>T: Ammeter, that is right. What does it measure?</p> <p>S: Amps.</p> <p>T: Current. Ammeter measures current, which is I. In this series circuit it has 2A of current (before lamps), then here (between lamps), 2A, then at the end, 2A of current. What does this tell us about the circuit? It is exactly the same, it doesn't change anywhere. Current has to go through these, so they are all 2A. It is always the same. But look here, I've got 10V here, and five here and five here. $5 + 5 = 10$. It says here (refers to PPT), voltage in a series circuit will be shared between components. Remember we put an extra lamp in and it got less bright – because the voltage is less, because it is shared.</p> <p>S: How do you know it is 5V?</p> <p>T: This with a V in it is a voltmeter that is how I know.</p> <p>T: This other one (parallel), it looks complicated, but it's not. I've voltmeters here measuring the voltage of each lamp. What can you see with each one of those? 10 there, 10 there, 10 there, they are all the same. What about the current, 2 there and 1 there. What is happening here, is they are shared. There are two branches, half of the current goes that way and half</p>	<p>SU – PrK SU – Qu</p> <p>SU – Qu</p> <p>SMK - Acc</p> <p>SMK - Acc</p>
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	<p>goes that way. 1 there, 1 there, and then they join up to make 2A.</p> <p>(refers to PPT) T: and it says there, current is shared and voltage will be the same, okay. That is what these diagrams show. Carefully copy these diagrams down. I want this done by the end of the period, nice and tidy. Get everything that is there on it.</p> <p>Students copy diagrams.</p> <p>T: Make sure they are nice and tidy.</p>	
34:50	<p>Tony talks as students are copying.</p> <p>T: Like the last topic, you need to remember, what do you measure current in, Amps, the symbol for current is I, the symbol for amps is A. Voltage, the symbol for voltage is V, measured in volts. So voltage is a bit easier to understand. There is one other we will have to learn about called resistance.</p> <p>Refers back to PPT.</p> <p>T: This is important, this is key. You need to remember this. In series, voltage is shared and current is the same. In parallel, voltage is the same and current is shared. That is really important, you need to remember that.</p> <p>Tony does some prep work on the computer while students copy diagrams.</p> <p>Tony goes around class to make sure students are completing diagrams correctly.</p>	SMK – iNoS
39:30	Tony goes to board.	IS – Rep

	<p>T: See how the voltmeters are arranged? That is showing how you actually hook them up in real life, and the ammeter. When you want to measure the voltage, you need to hook it up around something. Like a lamp, either side of it. Whereas an ammeter, everything needs to go through it. When you're finished I have an animation to show you.</p> <p>Changes PPT slide.</p> <p>Simulation/Diagram of a series circuit. With 3 ammeters and 2 lamps. [Analogy]. The current is the same all the way around, whereas the voltage is shared. Adds a truck onto the diagram – imagine the load is the voltage. It drops half there and half there. This is now a parallel circuit, it's a bit dumb really. Imagine the truck is 2A... It goes... I thought it was better than this. You guys understand though.</p> <p>T: Let's watch a video instead.</p>	IS – Ex
41:30	<p>Tony goes on YouTube and puts on a video related to electricity for students – video of a person making a Taser using high voltage.</p> <p>Information in video is about AC voltage, transformers, inductors, capacitors, relays, and spark gaps.</p> <p>T: Interesting thing there about voltage – you could get zapped by 10000V... has anyone been zapped by that? If there is not much current... it is the voltage and current that kills you. Current is the amount of electricity passing through out and voltage is the amount of energy they have. So if you're getting heaps of voltage and no current you would be okay.</p> <p>Tony talks about touching an electric fence.</p>	SMK – App

50:00	End of lesson, students pack up.	
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Rubric for Scoring Components of Enacted PCK from Video Observations

Subject Matter Knowledge				
CoRe Prompts One, Two, and Three				
ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriateness of concept(s) in relation to NZC – Physical World (Level 5)	No alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Little alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Adequate alignment of concept(s) in lesson with NZC – Physical World (Level 5)	Close alignment of concept(s) in lesson with NZC – Physical World (Level 5)
Accuracy of the explanation of the concept(s)	Explanation(s) were mostly inaccurate, which did not address the concept(s)	Explanation(s) were somewhat inaccurate, which loosely addresses the concept(s)	Explanation(s) were mostly accurate with only small inaccuracies seen, or they were too brief	Explanation(s) were accurate, which addresses the concept with no inaccuracies
Links and/or connections made to other concepts	No possible links and/or connections are made	Few of the possible links are made, but not connected with explanations	Some of the possible links and connections are made	Many of the possible links and connections are made
Links made (implicit or explicit) to the nature of science (NoS) and/or scientific inquiry (SI)	No links made to NoS and/or SI	Few of the possible links to NoS and/or SI are made	Some of the possible links to NoS and/or SI are made	Many of the possible links to NoS and/or SI are made

Knowledge of Student Understanding
CoRe Prompts Four, Five, and Eight

ePCK Indicator	Limited	Basic	Proficient	Advanced
Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions	No recognition or acknowledgement of possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges some possible student prior knowledge, difficult concepts, and/or misconceptions	Recognises and acknowledges most/all possible student prior knowledge, difficult concepts, and/or misconceptions
Teacher uses identified variations in student understanding and learning to guide instruction	No acknowledgement and/or use of variations in student understanding and learning to guide instruction	Acknowledgement of variations in student understanding or learning, but not used to guide instruction	Some acknowledgment of variations in student understanding or learning are used to guide instruction	Many instances where teacher acknowledged variations in student understanding or learning and used these to guide instruction
Teacher uses questioning to probe or extend student understanding	No questions are used to probe or extend student understanding	A few questions are used to probe or extend student understanding	An adequate range of questions are used to probe or extend student understanding	Many and varied questions are used to probe or extend student understanding

Knowledge of Instructional Strategies

CoRe Prompt Seven

ePCK Indicator	Limited	Basic	Proficient	Advanced
Appropriate sequence for teaching concepts	No overall flow between concepts and the sequence confuses students	Some flow between concepts and the sequence allows some concept building to occur	Suitable flow between concepts and the sequence allows satisfactory concept building to occur	Clear flow between concepts and sequence allows effective concept building
Relevant examples and/or representations are used in the lessons, which appear to be pedagogically effective at portraying the concept	No examples and/or representations used	Examples and/or representations used that are not relevant	Examples and/or representations used have some relevance, but appear pedagogically limited	Relevant examples and/or representations used that appear pedagogically effective
Use of strategies that allow for metacognition	No use of strategies that allow for metacognition	Limited use of strategies that allow for metacognition	Adequate use of strategies that allow for metacognition	Much use of strategies that allow for deep levels of metacognition

Post Analysis Summary

Subject Matter Knowledge

Appropriateness of concept(s) in relation to NZC – Physical World Level 5

The main idea that Tony was teaching during the lesson was about the differences in parallel and series circuits, which is appropriate for this level. However, at the end of the lesson, the video he showed concepts that would be more appropriate for students working at Level 8. Although, he may have intended this video to be more of an ‘engaging experience’ for the students rather than them learning electrical concepts.

Proficient.

Accuracy of the explanation of the concept(s)

Tony’s explanations were mostly accurate. At time though, his explanations were quite brief – reflecting more about learning rules rather than understanding.

Proficient.

Links and/or connections made to other concepts

Tony made some subtle links between different concepts (such as type of circuit and brightness) while he was teaching, but he did not really explain them.

Basic.

Links made (explicit or implicit) to the nature of science (NoS) and/or scientific inquiry (SI)

During the lesson, Tony made some subtle implicit links to the NoS by talking about convention. However, this was on the only example seen in the lesson. There were no instances of SI.

Basic.

Knowledge of Student Understanding

Teacher recognises and acknowledges possible student prior knowledge, difficult concepts, and misconceptions

At times Tony appeared to probe student prior knowledge, but this information was not really used. There was no indication of Tony recognising difficult concepts or misconceptions, which are plentiful when teaching series and parallel circuits.

Basic.

Teacher uses identified variations in student understanding and learning to guide instruction

There were no instances where variations in student understanding and learning were used to guide the lesson. Tony had a set agenda which he stuck to.

Limited.

Teacher uses questioning to probe and extend student understanding

Tony used a few questions to gauge student thinking, but these were mostly closed with little variation. They seemed to be used more for confirmation rather than probing or extending their understanding. Often he answered his own question.

Basic.

Knowledge of Instructional Strategies

Appropriate sequence for teaching concepts

There seemed to be suitable flow between concepts. For example, starting with series and parallel circuits and their basic characteristics, then moving into voltage and current. However, there were times where he could have explained the linkage in a clearer way to help students develop their own understanding.

Proficient.

Relevant examples and/or representations are used in the lesson, which appear to be pedagogically effective

Tony used some relevant examples during the lesson, such as the Christmas tree lights and car head lights. However, his analogy about the truck carrying a load was quite limited, especially since he did not explain it well. It appeared as though that was the first time he had used that analogy.

Proficient.

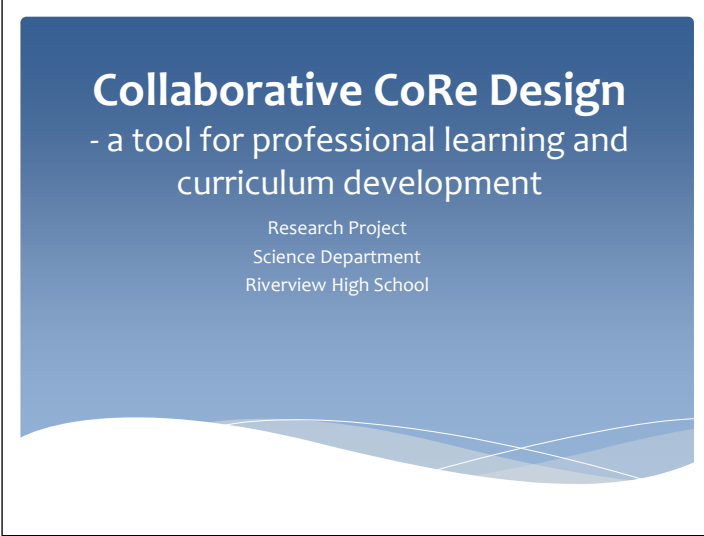
Use of strategies that allow for metacognition

There were no instances during the lesson that indicated metacognition was taking place.

Limited.

Appendix E – Nature of Science CoRe Design Handouts

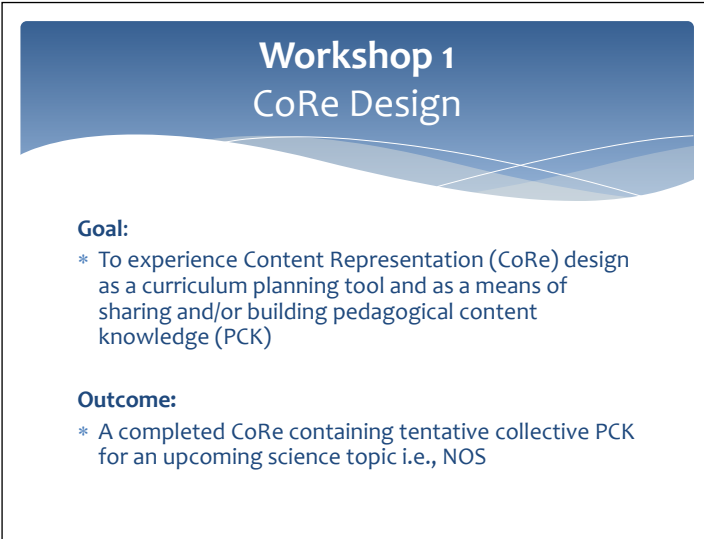
Appendix E1 – CoRe Design Workshop Presentation



Collaborative CoRe Design
- a tool for professional learning and curriculum development

Research Project
Science Department
Riverview High School

Slide 1



Workshop 1
CoRe Design

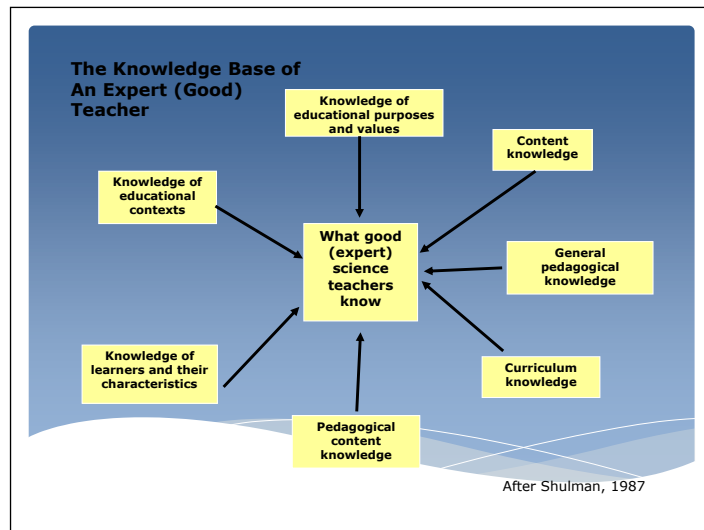
Goal:

- * To experience Content Representation (CoRe) design as a curriculum planning tool and as a means of sharing and/or building pedagogical content knowledge (PCK)

Outcome:

- * A completed CoRe containing tentative collective PCK for an upcoming science topic i.e., NOS

Slide 2



Slide 3

Pedagogical Content Knowledge (PCK)

- * PCK is that very special, often unspoken and unshared form of professional knowledge that individual teachers possess that enables them to successfully teach certain topics to particular groups of students (Shulman, 1987).
- * A crucial source of PCK is classroom experience

Slide 4

Pedagogical Content Knowledge (PCK)

- * Highly personal, idiosyncratic and frequently tacit form of professional knowledge
- * Influenced by teachers' *orientations towards science and science teaching* (beliefs and attitudes) and knowledge of their *learners' characteristics*, which in turn impacts on what *content* they select to teach for a particular topic, the specific *instructional strategies* they choose to use and how they *monitor students' learning* (Magnusson et al., 1999).

Slide 5

Content Representations (CoRes)

- * CoRes were originally developed by Loughran et al., (2008) as a means of making expert science teachers' PCK explicit (to inform teacher education, especially pre-service)
- * They are diagrammatic representations which portray holistic overviews of expert science teachers' collective PCK related to the teaching of a particular topic
- * Complemented by PaP-eRs which are narratives that bring aspects of the CoRe 'alive'

Slide 6

IMPORTANT SCIENCE IDEAS/CONCEPTS			
	Big Idea 1	Big Idea 2	Etc.
PaP-eR 1	1. What you intend the students to learn about this idea.		
	2. Why it's important for students to know this.		
	3. What else you know about this idea (that you do not intend students to know yet).		
	4. Difficulties/limitations connected with teaching this idea.		PaP-eR 3
	5. Knowledge about students' thinking which influences your teaching of this idea.		
	6. Other factors that influence your teaching of this idea.		
PaP-eR 2	7. Teaching procedures (and particular reasons for using these to engage with this idea).		PaP-eR 4
	8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).		

Figure 1. CoRe (Content Representation) and associated PaP-eRs (Pedagogical and Professional experience Repertoires); lines from the PaP-eRs represent the links to particular aspects of the CoRe.

Slide 7

CoRe components

- * **Big Ideas** – these are the key ideas you see as crucial for understanding the topic (5-8)
- * **What you intend the students to learn about this idea** – involves 'unpacking' the big idea to determine what specific concepts and skills students need to learn to understand the big idea
- * **Why is it important for students to know this?** – involves thinking about their future learning, other curricular links and relevance to their everyday life

Slide 8

CoRe components cont'd

- * **What else you might know about this idea (that you don't intend students to know yet)** – what needs to be kept simple for understanding (but careful not to oversimplify), some concepts are best left for later years
- * **Difficulties/limitations connected with teaching this idea** – what alternative conceptions or misconceptions students may have about this idea and the problems this may cause them as they try to construct new knowledge. Also the limitations of some models and analogies in promoting understanding or explaining phenomenon.

Slide 9

CoRe components cont'd

- * **Knowledge about students' thinking which influences your teaching of this idea** – how students have thought about, responded to and learned this idea/similar ideas from your past experience of teaching this idea/similar idea/seeing it being taught.
- * **Other factors that influence your teaching of this topic** – contextual knowledge e.g., available resources (people, books, SLH video clips/animations etc), school timetable, community events, weather etc.

Slide 10

CoRe components cont'd

- * **Teaching procedures (and particular reasons for using these to engage with this idea)** – particular strategies/approach for teaching this idea. Fit for purpose!
- * **Specific ways of ascertaining students' understanding or confusion around this idea** – formative assessment methods including monitoring learning against achievement criteria

Slide 11

CoRes

These CoRes proved to be valuable pedagogical tools for teacher educators because they unpack PCK in ways that reveal the big ideas to be learned by students, their prior knowledge, learning difficulties and likely misconceptions, suitable instructional approaches and strategies, and appropriate assessment.

Like any innovation in education, others took this original idea and gave it new uses.

Slide 12

CoRe Design

Research here and overseas is showing CoRe design to be a very useful thinking tool

- * As a pre-planning tool before unit preparation for pre-service, early-career teachers and teachers developing new topics
- * As a tool for sharing professional knowledge
- * As a curriculum planning tool e.g., whole school science scheme

(Hume & Berry, 2011; 2013, Hume et al. 2015)

Slide 13

CoRe design

- * When you design your own, it helps you to identify what is important for your students to know and how to go about it.
- * Remember some sections of a CoRe may contain more detail than others – some boxes could be left empty. CoRes can be added to/modified over time, especially after/during teaching the topic.
- * There is no one CoRe for a topic – reflects your thinking about how to teach the topic and contextual circumstances.

Slide 14

The Nature of Science (NOS)

The Nature of Science (NOS) embodies what makes science different from other disciplines such as history or religion.

The nature of scientific knowledge refers to the characteristics of scientific knowledge, which are inherently derived from the ways in which that knowledge is developed i.e., through scientific inquiry (SI)

Slide 15

The nature of scientific knowledge

- * **Tentative** (subject to change)
- * **Empirically-based** (based on and/or derived from observations of the natural world)
- * **Subjective** (reflects a mind-set)
- * Involves **human inference, imagination and creativity** (the invention of explanations and generation of ideas)
- * **Socially and culturally embedded**
- * **Observations versus inferences**
- * Functions of and relationships between **scientific theories and laws**

Slide 16

The nature of scientific inquiry (SI)

Scientific inquiry (SI) refers to the systematic approaches used by scientists do their work (answer their questions) and how the resulting scientific knowledge is generated and accepted – referred to as scientific practices

Slide 17

Knowledge about scientific practices

- (1) Scientific investigations all begin with a question, but do not necessarily test a hypothesis.
- (2) There is no single set and sequence of steps followed in all investigations (i.e. there is no single scientific method).
- (3) Inquiry procedures are guided by the question asked.
- (4) All scientists performing the same procedures may not get the same results.
- (5) Inquiry procedures can influence the results.
- (6) Research conclusions must be consistent with the data collected.
- (7) Scientific data are not the same as scientific evidence.
- (8) Explanations are developed from a combination of collected data and what is already known.

Slide 18

Group Task

- * With your topic in mind (and the relevant AOs from the NZC) **brainstorm** all the concepts and skills that are relevant learning for your students – place each concept/skill on a separate piece of paper
- * Now organise the concepts and skills into approximately 5-7 groups where each group of concepts/skills have something in common – a common theme

Slide 19

Forming the Big Ideas

- * Now attempt to turn the common theme for a particular group of concepts and skills into a propositional statement – a big idea

e.g., Water can exist in three states (solid, liquid or gas)

- * share big ideas and come to a consensus

Slide 20

Constructing the CoRe

- * Place your big ideas into your CoRe template and begin compiling and recording appropriate information in the columns under each big idea
- * Use the *Particle Nature of Matter* exemplar, the handout 'Exposing PCK- unpacking the CoRe prompts' and other resources like the SLH to help you pull together your collective PCK around this topic
- * Share CoRes – commonalities and differences

Slide 21

Consensus Model definition of PCK

- * **Knowledge** of the **reasoning** behind and the **planning** for teaching a particular **topic** in a particular **way** for a particular **purpose** to particular **students** for **enhanced student outcomes** (Reflection on Action, Explicit) - espoused PCK
- * The **act of teaching** a particular **topic** in a particular **way** for a particular **purpose** to particular **students** for **enhanced student outcomes** (Reflection in Action, tacit or explicit) – enacted PCK

Slide 22

Pedagogy for scientific literacy

Most progressive science educators are recommending that science programmes should coordinate the learning of science concepts and practices simultaneously through *inquiry learning* where students are:

- * Engaging in scientifically oriented questions
- * Gathering, organising and analysing data
- * Formulating explanations from evidence to address scientifically oriented questions
- * Evaluating explanations in light of alternative explanations
- * Communicating and justifying explanations.

(NRC, 2007)

Slide 23

Appendix E2 – Blank CoRe Template

<i>Year level and Science Topic</i>	Important Science Ideas/Concepts		
	Big Idea “A”	Big Idea “B”	Big Idea “C”
What do you intend students to learn about this idea			
Why is it important for students to know this			
What else you know about this idea (that you do not intend students to know yet)			
Difficulties and/or limitations connected with teaching this idea			
Knowledge about students’ thinking which influences your teaching of this idea			
Other factors that influence your teaching of this idea			
Teaching procedures (and particular reasons for using these to engage with this idea)			
Specific ways of ascertaining students’ understanding or confusion around this idea (include like range of responses)			

Appendix E3 – Completed CoRe from Loughran, Berry, Mulhall (2004, p. 92)

These pages were printed and the stuck together to make one large A1-sized poster.

CHAPTER 5

<p><i>This Core is designed for students in Middle Secondary School, i.e., Year 10.</i></p>	<p style="text-align: center;">IMPORTANT SCIENCE</p> <p style="text-align: center;">A:</p> <p>Chemical reactions involve a rearrangement of atoms.</p>
<p>What you intend the students to learn about this idea.</p>	<ol style="list-style-type: none"> 1. A chemical reaction is a process involving an input (reactants) and an output (products—which have different chemical properties). 2. The same atoms are present at the end of a reaction as at the start but they are rearranged differently. Hence atoms are conserved in chemical reactions. 3. Chemical reactions are all around us. 4. Chemical reactions and physical reactions are not dichotomous: some reactions are not clearly one or the other.
<p>Why it is important for students to know this.</p>	<ol style="list-style-type: none"> 1. Understanding that it is a process is important because when chemical equations are introduced, students can confuse these with mathematical equations in which both sides are equal. 2. This idea is at the heart of explanations of chemical reactions and equations. 3. Students can use their knowledge of chemical reactions in their everyday lives, e.g., when deciding how to remove grass/dirt stains from clothes, understanding the list of ingredients on the packaging of processed food, deciding what may be substituted for a missing ingredient when cooking. 4. Physical reactions may also involve rearrangement of atoms.
<p>What else you know about this idea (that you do not intend students to know yet).</p>	<p>Not all reactions are complete (e.g., some biological reactions & some industrial processes)—this is not addressed unless it is raised by a student.</p> <p>Chemical equilibrium.</p> <p>Why some reactions don't occur.</p>
<p>Difficulties/limitations connected with teaching this idea.</p>	<p>The treatment is difficult to 'contain' - where do we stop?</p> <p>The explanations of what is occurring are quite abstract. This is compounded by the fact that the scale is so small. It is also difficult to teach if students don't have a particulate model of matter.</p>

(NOTE: within each column, statements preceded by the same number or symbol (e.g., *) are linked.)

IDEAS/CONCEPTS	
<p style="text-align: center;">B:</p> <p>To determine if a chemical reaction has occurred it is necessary to look for evidence.</p>	<p style="text-align: center;">C:</p> <p>A special language which has its own symbols is used to represent chemicals and chemical reactions</p>
<p>There are certain indicators that a chemical reaction might be occurring (e.g., bubbling, temperature change).</p> <p>There are practical tests that can be used to identify products, e.g., gases (CO₂, H₂, etc.), colour indicators.</p> <p>It is not always possible to decide whether or not a chemical reaction is taking place or will actually occur, especially in the school laboratory. Instead looking at trends in the behaviour of similar kinds of reactants (based on previous experience) can be helpful in deciding the likelihood of a reaction and its products.</p>	<p>Chemicals are represented by symbols, with different chemicals having different symbols. A particular chemical is always represented by the same symbols regardless from where it comes. Chemists everywhere use the same symbols to represent a particular chemical.</p> <p>Equations are also a form of chemical communication - for a particular reaction, the same equation applies in all parts of the world. The equation represents the proportion of reactants needed and of the products produced.</p> <p>When writing equations:</p> <p>a) It is necessary to use correct symbols for reactants and products.</p> <p>b) Equations need to be balanced because mass is conserved (i.e., the number of atoms is conserved).</p>
<p>Because often it is not possible to provide direct evidence for chemical reactions occurring.</p>	<p>Being able to use the language is important for further studies.</p>
<p>It can be difficult to explore a diverse yet credible (i.e., ones that the students are familiar with) range of reactions.</p>	<p>*Students may ask where valency tables come from. It is difficult for the teacher to provide a satisfactory explanation at this stage but it is important to tell students that there is one.</p>

(NOTE: within each column, statements preceded by the same number or symbol (e.g., *) are linked.)

CHAPTER 5

	A: Chemical reactions involve a rearrangement of atoms.
Knowledge about students' thinking which influences your teaching of this idea.	<p>Students already are familiar with a lot of chemical reactions from their everyday life. Students like learning how to explain these experiences.</p> <p>Most Year 10s have a particulate model of matter (but this needs to be checked).</p>
Other factors that influence your teaching of this idea.	<p>A belief that students should be learning something that is useful to them in their everyday lives.</p> <p>An overall emphasis in the teaching of this topic is that atoms, models, etc., are human-made ideas that have been created to explain chemistry.</p>
Teaching procedures (and particular reasons for using these to engage with this idea).	<p>Text books tend to oversimplify the differences between physical and chemical reactions. In fact there is not a clear cut dichotomy between them. This idea can be brought to the fore by confronting students with a range of situations and asking them to explain whether there are chemical or physical changes occurring in each case.</p> <p>Examples:</p> <ul style="list-style-type: none"> • Methylated spirits and water. • A metal ball which just fits inside a metal ring. The ball is removed from the ring and heated and attempts are made to reinsert it into the ring. • 'AlkaSeltza' and water. • Sand and water. <p>The discussion also enables the teacher to judge whether the students have a particulate model of matter.</p>

(NOTE: within each column, statements preceded by the same number or symbol (e.g., *) are linked.)

B: To determine if a chemical reaction has occurred it is necessary to look for evidence.	C: A special language which has its own symbols is used to represent chemicals and chemical reactions
<p>The idea that chemical reactions are predictable (based on one's previous practical experience/knowledge of trends) is not obvious to students, at least initially.</p>	<p>Visual learners pick up these ideas much faster than non-visual as they recognise patterns more quickly. Such students are often good at algebra as well and good at finding embedded patterns in a list of symbols (e.g., word finds).</p> <p>Non-visual learners take more time to grasp the ideas of a chemical language, it is important that the teaching allows for this. Teachers can help by breaking the ideas up into steps using activities like 'bingo', role plays, flash cards etc which encourage use of/recognition of symbols.</p> <p>*In relation to valency tables, students already have some notion of charge from everyday experiences (e.g., combing hair). They need only be told there are two types (+ and -) and that equal numbers of each give zero charge.</p>
<p>An expectation that students won't accept things on blind faith.</p> <p>Explanations about 'why' are only explored if prompted by the students.</p> <p>An overall emphasis in the teaching of this topic is that atoms, models, etc., are human-made ideas that have been created to explain chemistry.</p>	<p>Even if students are not intending to continue with chemistry it is worth spending time on this as it enables an understanding of the labelling of ingredients on processed food and household chemicals.</p> <p>An overall emphasis in the teaching of this topic is that atoms, models, etc., are human-made ideas that have been created to explain chemistry.</p>
<p>Lots of practical work and discussion leading to an appreciation of the trends in certain reaction types (e.g., acid/base, acid/metal, etc.).</p> <p>Students should be encouraged to use a range of tests to identify some of the products.</p> <p>The remaining products in these reactions can be proposed once students have been acquainted with chemical formulas and equation.</p>	<p>A useful introduction is to for the teacher to write a number of chemical formulae on the computer and then change the font to 'Wingdings'. Students can then be given the task of finding similarities and differences in the Wingdings version of these formulas. The teacher can then point out the usefulness of using letters that are more easily drawn and recognised.</p> <p>Chemical equations can also be treated similarly. This forces students to look for how the substances in the equation are being changed.</p>

(NOTE: within each column, statements preceded by the same number or symbol (e.g., *) are linked.)

CHAPTER 5

	A: Chemical reactions involve a rearrangement of atoms.
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Most Year 10s have a particulate model of matter but the discussion above will check that this is the case for this class.

CHEMICAL REACTIONS: CoRe 2

B: To determine if a chemical reaction has occurred it is necessary to look for evidence.	C: A special language which has its own symbols is used to represent chemicals and chemical reactions
<p>Look for indications that students are processing the lesson content by listening to what they are asking or saying in class discussion and to each other during prac:</p> <p>'What about if we do this ...' 'When I did this at home ... so what if ...'</p> <p>If they are not, the teacher needs to use prompting strategies: e.g., 'What's similar about this?' etc.</p>	

Appendix E4 – VASI Questionnaire**Views about Scientific Inquiry**

The following questions are asking for your views related to science and scientific investigations. There are no right or wrong answers.

Please answer each of the following questions. You can use all the space provided to answer a question and continue on the back of the pages if necessary.

1. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds that eat hard-shelled nuts have short, strong beaks, and birds that eat insects have long, slim beaks. He wondered if the shape of a bird's beak was related to the type of food the bird eats and he began to collect data to answer that question. He concluded that there is a relationship between beak shape and the type of food birds eat.
 - a. Do you consider this person's investigation to be scientific? Please explain why or why not.
 - b. Do you consider this person's investigation to be an experiment? Please explain why or why not.
 - c. Do you think that scientific investigations can follow more than one method?

If no, please explain why there is only one way to conduct a scientific investigation.

If yes, please describe two investigations that follow different methods, and explain how the methods differ and how they can still be considered scientific.

2. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why?

3. (a) If several scientists ask the *same question* and follow the *same procedures* to collect data, will they necessarily come to the *same conclusions*? Explain why or why not.
- (b) If several scientists ask the *same question* and follow *different procedures* to collect data, will they necessarily come to the same conclusions? Explain why or why not.
4. Please explain if “data” and “evidence” are different from one another.
5. Two teams of scientists were walking to their lab one day and they saw a car pulled over with a flat tire. They all wondered, “Are certain brands of tires more likely to get a flat?”

Team A went back to the lab and tested various tires’ performance on one type of road surface.

Team B went back to the lab and tested one tire brand on three types of road surfaces.

Explain why one team’s procedure is better than the other one.

Minutes of light each day	Plant growth-height (cm per week)
0	25
5	20
10	15
15	5
20	10
25	0

6. The data table below shows the relationship between plant growth in a week and the number of minutes of light received each day.

Given this data, explain which one of the following conclusions you agree with and why.

Please circle one:

- a) Plants grow taller with **more** sunlight.
- b) Plants grow taller with **less** sunlight.
- c) The growth of plants is **unrelated** to sunlight.

Please explain your choice of a, b, or c below:

7. The fossilized bones of a dinosaur have been found by a group of scientists. Two different arrangements for the skeleton are developed as shown below.

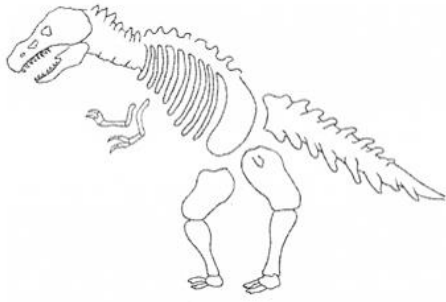


Figure 1

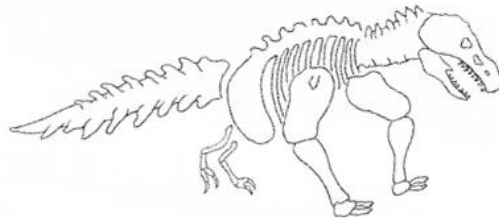


Figure 2

- a. Describe at least two reasons why you think most of the scientists agree that the animal in *figure 1* had the best sorting and positioning of the bones?

Thinking about your answer to the question above, what types of information do scientists use to explain their conclusions?

Appendix E5 – Relevant Parts of the NZC



*Mā te whakaaro nui e hanga te whare;
mā te mātauranga e whakaū.*

What is science about?

Science is a way of investigating, understanding, and explaining our natural, physical world and the wider universe. It involves generating and testing ideas, gathering evidence – including by making observations, carrying out investigations and modelling, and communicating and debating with others – in order to develop scientific knowledge, understanding, and explanations. Scientific progress comes from logical, systematic work and from creative insight, built on a foundation of respect for evidence. Different cultures and periods of history have contributed to the development of science.

Why study science?

Science is able to inform problem solving and decision making in many areas of life. Many of the major challenges and opportunities that confront our world need to be approached from a scientific perspective, taking into account social and ethical considerations.

By studying science, students:

- develop an understanding of the world, built on current scientific theories;
- learn that science involves particular processes and ways of developing and organising knowledge and that these continue to evolve;
- use their current scientific knowledge and skills for problem solving and developing further knowledge;
- use scientific knowledge and skills to make informed decisions about the communication, application, and implications of science as these relate to their own lives and cultures and to the sustainability of the environment.

How is the learning area structured?

The fundamental aims of science education are expressed as a series of achievement aims, grouped by strand. (For these, see the chart of achievement objectives for science, available separately.) The achievement objectives at each level are derived from the aims and are similarly grouped by strand.

The **Nature of Science** strand is the overarching, unifying strand. Through it, students learn what science is and how scientists work. They develop the skills, attitudes, and values to build a foundation for understanding the world. They come to appreciate that while scientific knowledge is durable, it is also constantly re-evaluated in the light of new evidence. They learn how scientists carry out investigations, and they come to see science as a socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions. These outcomes are pursued through the following major contexts in which scientific knowledge has developed and continues to develop.

The **Living World** strand is about living things and how they interact with each other and the environment. Students develop an understanding of the diversity of life and life processes, of where and how life has evolved, of evolution as the link between life processes and ecology, and of the impact of humans on all forms of life. As a result, they are able to make more informed decisions about significant biological issues. The emphasis is on the biology of New Zealand, including the sustainability of New Zealand's unique fauna and flora and distinctive ecosystems.

The **Planet Earth and Beyond** strand is about the interconnecting systems and processes of the Earth, the other parts of the solar system, and the universe beyond. Students learn that Earth's subsystems of geosphere (land), hydrosphere (water), atmosphere (air), and biosphere (life) are interdependent and that all are important. They come to appreciate that humans can affect this interdependence in both positive and negative ways.

Students also learn that Earth provides all the resources required to sustain life except energy from the Sun, and that, as humans, we act as guardians of these finite resources. This means knowing and understanding the numerous interactions of Earth's four systems with the solar system. Students can then confront the issues facing our planet and make informed decisions about the protection and wise use of Earth's resources.

The **Physical World** strand provides explanations for a wide range of physical phenomena, including light, sound, heat, electricity, magnetism, waves, forces, and motion, united by the concept of energy, which is transformed from one form to another without loss. By studying physics, students gain an understanding of interactions between parts of the physical world and of

the ways in which they can be represented. Knowing about physics enables people to understand a wide range of contemporary issues and challenges and potential technological solutions.

The **Material World** strand involves the study of matter and the changes it undergoes. In their study of chemistry, students develop understandings of the composition and properties of matter, the changes it undergoes, and the energy involved. They use their understanding of the fundamental properties of chemistry to make sense of the world around them. They learn to interpret their observations by considering the properties and behaviour of atoms, molecules, and ions. They learn to communicate their understandings, using the symbols and conventions of chemistry. Using their knowledge of chemistry, they are better able to understand science-related challenges, such as

environmental sustainability and the development of new materials, pharmaceuticals, and sources of energy.

The core strand, Nature of Science, is required learning for all students up to year 10. The other strands provide contexts for learning. Over the course of years 1–10, science programmes should include learning in all four context strands.

Students in years 11–13 are able to specialise in one or more science disciplines, depending on the choices offered in their schools. The achievement objectives in the context strands provide for strand-based specialisations, but a wider range of programmes is possible; for example, schools may offer programmes in biochemistry, education for sustainability, agriculture, horticulture, human biology, or electronics.



Level Five Science

Nature of Science

Students will:

Understanding about science

- Understand that scientists' investigations are informed by current scientific theories and aim to collect evidence that will be interpreted through processes of logical argument.

Investigating in science

- Develop and carry out more complex investigations, including using models.
- Show an increasing awareness of the complexity of working scientifically, including recognition of multiple variables.
- Begin to evaluate the suitability of the investigative methods chosen.

Communicating in science

- Use a wider range of science vocabulary, symbols, and conventions.
- Apply their understandings of science to evaluate both popular and scientific texts (including visual and numerical literacy).

Participating and contributing

- Develop an understanding of socio-scientific issues by gathering relevant scientific information in order to draw evidence-based conclusions and to take action where appropriate.

Living World

Students will:

Life processes

- Identify the key structural features and functions involved in the life processes of plants and animals.
- Describe the organisation of life at the cellular level.

Ecology

- Investigate the interdependence of living things (including humans) in an ecosystem.

Evolution

- Describe the basic processes by which genetic information is passed from one generation to the next.

Planet Earth and Beyond

Students will:

Earth systems

- Investigate the composition, structure, and features of the geosphere, hydrosphere, and atmosphere.

Interacting systems

- Investigate how heat from the Sun, the Earth, and human activities is distributed around Earth by the geosphere, hydrosphere, and atmosphere.

Astronomical systems

- Investigate the conditions on the planets and their moons, and the factors affecting them.

Physical World

Students will:

Physical inquiry and physics concepts

- Identify and describe the patterns associated with physical phenomena found in simple everyday situations involving movement, forces, electricity and magnetism, light, sound, waves, and heat. For example, identify and describe energy changes and conservation of energy, simple electrical circuits, and the effect of contact and non-contact on the motion of objects.

Using physics

- Explore a technological or biological application of physics.

Material World

Students will:

Properties and changes of matter

- Investigate the chemical and physical properties of different groups of substances, for example, acids and bases, fuels, and metals.
- Distinguish between pure substances and mixtures and between elements and compounds.

The structure of matter

- Describe the structure of the atoms of different elements.
- Distinguish between an element and a compound, a pure substance and a mixture at particle level.

Chemistry and society

- Link the properties of different groups of substances to the way they are used in society or occur in nature.



Appendix E6 – Relevant Parts from the Schools Junior Science Manual**BEST PRACTICE ACTION PLAN FOR BETTER TEACHING AND LEARNING**

Best practice	Evidence
High expectations	<p>Teachers will establish and communicate high expectations for learning to students by:</p> <ul style="list-style-type: none"> Using specific learning outcomes in their teaching. Administering the unit tests that measure student achievement against the specific learning outcomes. Using strategies to determine the level of understanding of their students before moving on to the next sub-topic. Setting, marking and tracking homework pertaining to the concepts being taught.
	<p>Teachers will have an expectation of excellence for all students regardless of their ethnicity, social background, ability or needs by:</p> <ul style="list-style-type: none"> Being consistent in their use of the specific learning outcomes. Ensuring assessments are marked as per their schedules. Setting realistic expectations of excellence e.g. 3-band classes.
	<p>Teachers encourage students to set high personal learning goals and take some responsibility for achieving these, by:</p> <ul style="list-style-type: none"> Reviewing assessment results with students. Setting agreed goals for improvement. Highlighting learning strategies that can be used to help improve achievement. Ensuring their discussions are documented and follow-ups to these are done. Emailing or phoning home to discuss concerns as they arise.
	<p>Teachers identify strengths and weaknesses of students and work with these by:</p> <ul style="list-style-type: none"> Setting specific learning targets with students. Providing extension activities where appropriate.
Teacher knowledge of curriculum, pedagogy	<p>Teachers are familiar with the NZ curriculum at Levels 4 and 5; teachers:</p> <ul style="list-style-type: none"> Adhere to the specific learning outcomes of each unit of work which are linked to the appropriate levels within the curriculum. Regularly review the updates provided for their copy of the Junior Science Department manual.
	<p>Teachers re-enforce the values and competencies of Riverview High (and therefore, of the NZ curriculum) by:</p> <ul style="list-style-type: none"> Establishing and maintaining classroom routines.

	<p>Ensuring the students adhere to the Riverview High Code of Conduct for general behaviour and presentation. Issuing green referrals and faculty certificates to positively enforce improvements in academic achievements and general attitude.</p>
	<p>Teachers differentiate their teaching styles to suit the learner by: Incorporating different teaching strategies into daily lessons. Using differentiated worksheets to scaffold student learning. Breaking hourly lessons into phases which may incorporate various teaching and learning strategies. Regularly participating in Professional Development and trying new things in their teaching. Continually reflecting on their teaching practice and the impact it has on student achievement.</p>
Learning environment	<p>Teachers maintain a safe, positive and constructive learning environment by: Establishing and maintaining classroom routines. Ensuring the students adhere to the Riverview High Code of Conduct for general behaviour and presentation. Following the Pastoral care disciplinary procedures. Displaying student work in their classroom. Allowing collaborative group work e.g. practical work, developing explanations as appropriate. Using peer mentoring and/or one-on-one mentoring as appropriate. Using mastery quizzes for material that is suitable for rote learning e.g. definitions. Teaching students to draw concept maps to help summarise key concepts in a unit of work. Fostering learner self-responsibility. Using green referrals and faculty certificates to reward achievement, diligence, good deeds, high motivation etc.</p>
Effective classroom management	<p>Teachers ensure the classroom culture is focussed on learning rather than behaviour by: Establishing and maintaining classroom routines. Ensuring the students adhere to the Riverview High Code of Conduct for general behaviour and presentation. Following the Pastoral care disciplinary procedures. Making contact with parents/caregivers to discuss behavioural issues related to a particular student.</p>
Assessment	<p>Teachers ensure the assessment information is valid and reliable by: Ensuring unit tests are completed at the end of each topic. Entering results into Kamar at the completion of marking and class review.</p>

	Maintaining Markbook summaries to track results of individual students and highlight trends requiring follow-up.
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NZ CURRICULUM AND SCIENCE

Achievement objectives	Achievement Aims	NZC Key Competencies
<p>Nature of science</p> <p><i>Students will:</i></p> <p>Understanding about science Appreciate that science is a way of explaining the world and that science knowledge changes over time. Identify ways in which scientists work together and provide evidence to support their ideas.</p> <p>Investigating in science Build on prior experiences, working together to share and examine their own and others' knowledge. Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations.</p>	<p>Nature of science</p> <p><i>Students will:</i></p> <p>Understanding about science Learn about science as a knowledge system: the features of scientific knowledge and the processes by which it is developed. Learn about the ways in which the work of scientists interacts with society.</p> <p>Investigating in science Carry out science investigations using a variety of approaches: classifying and identifying, pattern seeking, exploring, investigating models, fair testing, making things, or developing systems.</p>	<p>Thinking Using creative, critical and metacognitive process to make sense of information, experiences and ideas. Competent thinkers and problem-solvers that actively seek, use and create knowledge. They reflect, ask questions, challenge.</p> <p>Using language, symbols and text Working with making meaning of the codes in which knowledge is expressed. Students can interpret, use words, number, images, movement metaphor and technologies.</p> <p>Managing self Self-motivation and students seeing themselves as capable learners. Students who manage themselves are enterprising, resourceful, reliable and resilient. Establish personal goals, make plans, manage projects, and set high standards.</p>
<p>Communicating in science Begin to use a range of scientific symbols, conventions, and vocabulary. Engage with a range of science texts and begin to question the purposes for which these texts are constructed.</p> <p>Participating and contributing Use their growing science knowledge when considering issues of concern to them. Explore various aspects of an issue and make decisions about possible actions.</p>	<p>Communicating in science 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.</p> <p>Participating and contributing Bring a scientific perspective to decisions and actions as appropriate.</p>	<p>Relating to others Interacting effectively with a diverse range of people in a variety of contexts. Students are open to learning and able to take different roles in different situations. Know when it is appropriate to compete and when it is appropriate to co-operate. By working closely together they can come up with new approaches, ideas and ways of thinking.</p> <p>Participating and contributing Being actively involved in communities. Communities include family, whanau, school. Students who participate and contribute in communities have a sense of belonging and the confidence to participate in new contexts.</p>

SCIENTIFIC METHOD UNIT PLAN

Unit: Scientific Method	Strand: Nature of Science
<p>NZC Nature of Science Key Concepts:</p> <p>Science is evidence based.</p> <p>Scientific knowledge is provisional.</p> <p>Scientists use theories and models to describe the natural and physical world.</p> <p>Science is influenced by society.</p>	<p>Curriculum Links</p> <p>Level 4 NZC Nature of Science: Understanding in Science Students will appreciate that science is a way of explaining the world and that science knowledge changes over time.</p> <p>They will identify ways in which scientists work together and provide evidence to support their ideas</p> <p>Level 4 NZC Nature of Science: Investigating in Science They will ask questions, find evidence, and carry out appropriate investigations to develop simple explanations.</p> <p>Level 5 NZC Nature of Science: Investigating in Science Students will develop and carry out investigations by considering variables and drawing logical and justifiable conclusions.</p> <p>Level 4 NZC Nature of Science: Communicating in Science Students will begin to use a range of scientific symbols, conventions and vocabulary.</p> <p>They will engage with a range of text types and begin to question the purposes for which these texts are constructed.</p> <p>Level 5 NZC Nature of Science: Communicating in Science Students will apply their understanding of science to evaluate both popular and scientific texts (including visual and numerical literacy).</p>

Specific Learning Outcomes	Unit Vocabulary	Duration: 2 weeks
<p>Students will be able to:</p> <p>Explain the importance of laboratory safety rules.</p> <p>Accurately read various scales of measurement.</p> <p>Use and explain fair testing techniques: control of variables, repeats.</p> <p>Write up an experiment in the format: aim, hypothesis, equipment, method, results, processing and analysis, conclusion</p> <p>Draw tables and collect data. Draw and interpret line graphs.</p> <p>Explain the process for the development of a scientific theory.</p> <p>Describe how the model of the atom has been developed over time on the basis of experimental evidence: Dalton, Thompson, Rutherford, and Bohr.</p> <p>Conduct an experiment and discuss the validity and accuracy of the results.</p> <p>Analyse and evaluate a scientific article for scientific merit.</p>	<p>Students will have definitions for:</p> <p>Aim</p> <p>Hypothesis</p> <p>Method</p> <p>Results</p> <p>Conclusion</p> <p>Independent variable</p> <p>Dependent variable</p> <p>Fair testing</p> <p>Reliable results</p> <p>Valid results</p>	<p>Practical Activities</p> <p>Design an experiment, e.g.,:</p> <p>Paper planes</p> <p>Bow and arrows</p> <p>Reaction rate using sugar</p> <p>Rubber bands and rulers</p> <p>Heating curve of water</p> <p>Assessments</p> <p>Following instructions/accurate completion of tasks</p> <p>Q & A/starter activities</p> <p>Pre-test & Topic Test</p> <p>Workbook review</p> <p>Homework</p> <p>ICT</p>

Appendix F – Electricity and Magnetism CoRe Design Handouts

Appendix F1 – Relevant Parts from the Schools Junior Science Manual

(Best practice and curriculum information is the same as earlier)

ELECTRICITY AND MAGNETISM UNIT PLAN

Unit: Electricity and Magnetism	Strand: Physical World
<p>NZC Physics Key Concepts:</p> <p>The universe is made of matter and energy.</p> <p>The universe evolves by means of interactions.</p> <p>Some quantities are conserved.</p> <p>There four fundamental forces.</p> <p>Waves carry energy.</p>	<p>Curriculum Links</p> <p>Level 4 NZC Nature of Science: Investigating in Science Ask questions, find evidence and carry out appropriate investigations to develop simple explanations.</p> <p>Level 5 NZC Nature of Science: Investigating in Science Students will develop and carry out investigations that use a variety of approaches. Variables will be considered and logical and justifiable conclusions drawn.</p> <p>Level 5 NZC Nature of Science: Communicating in Science Use a wider range of science vocabulary, symbols, and conventions.</p> <p>Level 4 NZC Physical World: Physical Enquiry and Physical Concepts Use some scientific ideas to explain physical phenomena such as movement and heat.</p> <p>Level 5 NZC Physical World: Physical Enquiry and Physical Concepts Identify physical phenomena and concepts associated with everyday situations involving electricity and magnetism.</p> <p>Level 5 NZC Physical World: Using Physics Explore issues related to technological applications of physics.</p>

Specific Learning Outcomes	Unit Vocabulary	Duration: 4 weeks
<p>Students will be able to:</p> <p>Explain how static electricity occurs.</p> <p>Describe occurrences where static electricity can occur and the problems or benefits associated with it.</p> <p>Name and draw the symbols for common electrical equipment: wire, cell, battery, resistor, voltmeter, ammeter, and switch.</p> <p>Draw simple parallel and series circuits using symbols.</p> <p>Draw circuits showing the addition of a voltmeter and ammeter.</p> <p>Define current, voltage and resistance.</p> <p>Use Ohm's law to calculate circuit values. ($V=IR$)</p> <p>Describe how current and voltage change in series and parallel circuits.</p> <p>Calculate current and voltage for simple series and parallel circuits.</p> <p>Discuss the advantages and disadvantages of series and parallel circuits.</p> <p>Draw the magnetic field for a bar magnet and for the Earth.</p> <p>Describe how to make an electromagnet.</p> <p>Discuss the factors that affect the strength of the magnetic field.</p> <p>Discuss the advantages and disadvantages of hydroelectricity and possible alternatives for electricity generation in New Zealand.</p>	<p>Students will have definitions for:</p> <p>Voltmeter</p> <p>Ammeter</p> <p>Series circuit</p> <p>Parallel circuit</p> <p>Resistance</p> <p>Volts</p> <p>Amps</p>	<p>Practical Activities</p> <p>Van der Graff</p> <p>Insulators and conductors</p> <p>Series and parallel circuits:</p> <p>Amps</p> <p>Volts</p> <p>Making electromagnets</p> <p>Magnetic field around bar magnets</p> <p>Making compasses</p> <p>Effect of resistance</p> <p>Assessments</p> <p>Following instructions/accurate completion of tasks</p> <p>Q & A/starter activities</p> <p>Pre-test & Topic Test</p> <p>Workbook review</p> <p>Homework</p> <p>ICT</p> <p>Brainiac video with electric fence</p> <p>Electricity ? from Clickview with student worksheet</p>

Appendix F2 – NCEA Level 1 Achievement Standard

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Achievement Standard

Subject Reference	Physics 1.3		
Title	Demonstrate understanding of aspects of electricity and magnetism		
Level	1	Credits	4
		Assessment	External
Subfield	Science		
Domain	Physics		
Status	Registered	Status date	30 November 2010
Planned review date	31 December 2018	Date version published	20 November 2014

This achievement standard involves demonstrating understanding of aspects of electricity and magnetism and may include using methods when solving related problems.

Mutual exclusion exists between this standard and AS90941.

Achievement Criteria

Achievement	Achievement with Merit	Achievement with Excellence
<ul style="list-style-type: none"> Demonstrate understanding of aspects of electricity and magnetism. 	<ul style="list-style-type: none"> Demonstrate in-depth understanding of aspects of electricity and magnetism. 	<ul style="list-style-type: none"> Demonstrate comprehensive understanding of aspects of electricity and magnetism.

Explanatory Notes

- This achievement standard is derived from *The New Zealand Curriculum*, Learning Media, Ministry of Education, 2007, Level 6. It is aligned with the Physical Inquiry and Physics Concepts achievement objectives in the Physical World strand and the Communicating in Science achievement objectives in the Nature of Science strand, and is related to the material in the *Teaching and Learning Guide for Physics*, Ministry of Education, 2010 at <http://seniorsecondary.tki.org.nz>.

This standard is also derived from Te Marautanga o Aotearoa. For details of Te Marautanga o Aotearoa achievement objectives to which this standard relates, see the [Papa Whakaako](#).

- Demonstrate understanding of aspects of electricity and magnetism* typically involves providing evidence that shows awareness of how simple facets of phenomena, concepts or principles relate to given situations. This may include using methods for solving problems involving aspects of electricity and magnetism.

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- 3 *Demonstrate in-depth understanding of aspects of electricity and magnetism* typically involves providing evidence that shows how or why phenomena, concepts or principles relate to given situations.
- 4 *Demonstrate comprehensive understanding of aspects of electricity and magnetism* typically involves providing evidence that shows how or why phenomena, concepts, or principles are connected in the context of given situations. Statements must demonstrate understanding of connections between concepts.
- 5 Evidence may be written, mathematical, graphical, or diagrammatic.
- 6 *Aspects of electricity and magnetism* will be selected from the following:
- Static Electricity: positive and negative charge, conductors and insulators, uniform and non-uniform charge distributions, earthing, electrical discharge in air, separation of charge by friction, charging by contact.
- DC Electricity: voltage, current, resistance, power, series circuits and simple parallel circuits, circuit diagrams, the relationships
- $$V = IR, P = IV, P = \frac{E}{t}, R_T = R_1 + R_2 + \dots$$
- Magnetism: magnetic field directions, interactions and the result of interactions (including magnetic field of bar magnets, the earth's magnetic field, magnetic fields due to currents in straight wires and solenoids), right-hand grip rule, electromagnet, the relationship $B = \frac{\mu_0 I}{2d}$.
- 7 Assessment Specifications for this achievement standard can be accessed through the Physics Resources page found at www.nzqa.govt.nz/ncea/resources.

Quality Assurance

- 1 Providers and Industry Training Organisations must have been granted consent to assess by NZQA before they can register credits from assessment against achievement standards.
- 2 Organisations with consent to assess and Industry Training Organisations assessing against achievement standards must engage with the moderation system that applies to those achievement standards.

Consent and Moderation Requirements (CMR) reference

0233

Appendix G – Completed CoRes

As the CoRes are large documents (e.g., A1 paper size), they have been presented here in chunks. Only two or three big ideas are represented on each page, and all eight prompts continue across two pages. All headings are included to aid understanding.

Appendix G1 – Nature of Science CoRe

	Big Ideas	
Pedagogical Prompts	Scientific knowledge changes over time	Scientific knowledge is useful for our continued existence
What do you intend students to learn about this idea	In the past scientific theories have developed. New ideas means that theory must be rethought. Scientific knowledge is not static, continually evolving, often as technologies & skills advance, new evidence emerging. Knowledge changes. New evidence & technology modifies ideas and theories	Allows issues to be identified e.g., O ₃ , pollution. Allows solutions to be identified e.g., CFCs. Science makes us <u>aware</u> of the problems the world has and possible solutions. Also science creates these problems in the first place. Science knowledge can be used to avoid these problems in the first place.
Why is it important for students to know this?	So that people can critically analyse information that they are presented with. Remove the fear of science, scientists/science is open-minded, scientists have different perspectives. The world and societies need to adjust to new information	They are the next generation. It is the passing on of information.
What else you know about this idea (that you do not intend students to know yet)	Peer review. Politics. Political, moral, ethic, religious ideas to be discussed at a more senior level.	[Blank]

Difficulties and/or limitations connected with teaching this idea	Varying degrees of prior knowledge. Misconceptions	[Blank]
Knowledge about students' thinking which influences your teaching of this idea	All knowledge is perceived as rigid/final and not thought of as changing.	[Blank]
Other factors that influence your teaching of this idea	Teacher knowledge base, current events, local context. Logistics of general school systems e.g., Timetables, room allocations etc.	[Blank]
Teaching procedures (and particular reasons for using these to engage with this idea)	Case studies e.g., Continental Drift v Plate Tectonics. Models for development of the atom.	[Blank]
Specific ways of ascertaining students' understanding or confusion around this idea	Formative Assessment.	[Blank]

	Big Ideas		
Pedagogical Prompts	Science makes the world more understandable	Scientists use systematic approaches to scientific inquiry using a variety of methods	Scientists use specialised language to describe ideas, objects and processes
What do you intend students to learn about this idea	[Blank]	Hypothesising, Control of variables, Measuring and observing, Interpreting data, Evaluating method and conclusions for validity and reliability, Research skills, Evaluating information (especially from the internet), Practical Skills	[Blank]
Why is it important for students to know this?	[Blank]	They need to be able to do a good experiment and collect valid, reliable data and interpret it. Need to be able to critically evaluate information in the media	[Blank]
What else you know about this idea (that you do not intend students to know yet)	Greenhouse gases-kept simple with regard to climate change.	[Blank]	[Blank]
Difficulties and/or limitations connected with teaching this idea	Chemical equations, Electromagnetic radiation etc.	People believe everything they see on TV.	[Blank]

Knowledge about students' thinking which influences your teaching of this idea	Lack of understanding of how global warming occurs and the Greenhouse effect definition.	[Blank]	[Blank]
Other factors that influence your teaching of this idea	[Blank]	[Blank]	[Blank]
Teaching procedures (and particular reasons for using these to engage with this idea)	[Blank]	[Blank]	[Blank]
Specific ways of ascertaining students' understanding or confusion around this idea	[Blank]	[Blank]	[Blank]

Appendix G2 – Electricity and Magnetism CoRe

Big Ideas (Tony's Working Group)			
Pedagogical Prompts	Charges produce electric fields which exert a force on other charges	Current is the flow of charge	Voltage is the difference in electric potential energy between two points
What do you intend students to learn about this idea	<ul style="list-style-type: none"> • Rubbing different materials together can separate charges. • Like charges repel and opposite charges attract. 	<ul style="list-style-type: none"> • Current flows from positive to negative. • Charge is conserved. • Current is the same in all parts of a series circuit. • Current divides in a parallel circuit. • Current (I) is measured in Amperes (A). • Ammeters are used in series so that all of the current flows through them. 	<ul style="list-style-type: none"> • Energy is conserved. • The supply voltage is divided over the components in a series circuit. • Voltage is the same for each branch of a parallel circuit. • Voltage (V) is measured in Volts (V). • Voltmeters are used in parallel to measure the difference between two points.
Why is it important for students to know this?	<ul style="list-style-type: none"> • It explains everyday phenomena - e.g., shocks on trampolines or lighting. • Basis for current electricity. 	<ul style="list-style-type: none"> • These are foundational concepts for understanding the behaviour of all electrical circuits. 	
What else you know about this idea (that you do not intend students to know yet)	<ul style="list-style-type: none"> • Electromagnetic induction. 	<ul style="list-style-type: none"> • Conventional current vs. electron flow. 	<ul style="list-style-type: none"> • Volts = joules per Coulomb.

Difficulties and/or limitations connected with teaching this idea	<ul style="list-style-type: none"> • Humid conditions can wreck electrostatic experiments. 	<ul style="list-style-type: none"> • You can't see it. • Analogies can lead to misconceptions. • Conventional current vs. electron flow. 	<ul style="list-style-type: none"> • You can't see it. • Everyday use of the word - 'power'.
Knowledge about students' thinking which influences your teaching of this idea	<ul style="list-style-type: none"> • Students usually have some prior experience of static electricity. 	<ul style="list-style-type: none"> • Common misconception of single charge units moving as opposed to a wire full of charges that are all moving. 	<ul style="list-style-type: none"> • Students get hung up on wire colours.
Other factors that influence your teaching of this idea	<ul style="list-style-type: none"> • Weather 	<ul style="list-style-type: none"> • Students need to be able to build circuits. 	<ul style="list-style-type: none"> • Voltage is difficult to model.
Teaching procedures (and particular reasons for using these to engage with this idea)	<ul style="list-style-type: none"> • Rods and clothes to demonstrate static charging - picking up paper and electroscopes. • Van der Graaf generator. • YouTube videos 	<ul style="list-style-type: none"> • Definitions. • Measuring current in series and parallel circuits and establishing rules. • Discussion of why the rules work. • Can use model of students as charges moving single path/multiple paths. 	<ul style="list-style-type: none"> • Definitions. • Measuring voltage in series and parallel circuits and establishing rules. • Discussion of why the rules work.
Specific ways of ascertaining students' understanding or confusion around this idea	<ul style="list-style-type: none"> • Can explain applications - e.g., why a person's hair stands up when touching Van der Graaf. 	<ul style="list-style-type: none"> • Can measure current and voltage in circuits. • Can calculate current and voltage in series and parallel circuits. 	

Big Ideas (Alan's Working Group)		
Pedagogical Prompts	Ohm's law is the relationship between voltage, current, and resistance in a closed circuit.	Circuit diagrams are representations of electrical circuits
What do you intend students to learn about this idea	<ul style="list-style-type: none"> • To learn the correct symbols and units for voltage, current, and resistance. • To measure these variables in a circuit. • To calculate the third variable when the other two are known. • To rearrange the formula: $V=IR$ 	<ul style="list-style-type: none"> • How to correctly draw a circuit diagram using correct symbols. • That diagrams are used to represent wiring in a simplified, visual form. • To be able to build the circuit using appropriate components following the diagram (equipment limited to: power supply, voltmeter, ammeter, variable resistor, switches, rheostat, and lamps).
Why is it important for students to know this?	<ul style="list-style-type: none"> • So they have a better understanding of the natural world. • To identify physical phenomenon and concepts associated with everyday situations involving electricity. • To be able to use a wider range of science vocabulary and symbol conventions. 	<ul style="list-style-type: none"> • In order for electricity to be used, it needs to be connected in a certain way. • To be able to troubleshoot faulty circuits.
What else you know about this idea (that you do not intend students to know yet)	<ul style="list-style-type: none"> • Ohm's law is only true for constant temperature. • The knowledge about what really causes resistance at atomic level collisions. • The mathematical equation related to an Ohm's law graph. 	<ul style="list-style-type: none"> • A limited number of components used. • Understanding the working of some components (e.g., battery). • The concept of electrical power.
Difficulties and/or limitations connected with teaching this idea	<ul style="list-style-type: none"> • To troubleshoot student circuits. • Faulty equipment. • Making sense of something you cannot observe - e.g., flow of charge. 	

Knowledge about students' thinking which influences your teaching of this idea	<ul style="list-style-type: none"> • Misconceptions in terminology (e.g., voltage and current). 	<ul style="list-style-type: none"> • Making connections between diagrams and physical circuits (i.e., interpreting the circuit diagram).
Other factors that influence your teaching of this idea	<ul style="list-style-type: none"> • Time to spend helping eight groups is limited. • Timetabling and room allocation (e.g., not a lab). • Faulty equipment. • Problem solving. 	
Teaching procedures (and particular reasons for using these to engage with this idea)	<ul style="list-style-type: none"> • Use computer simulations. • Use a simple, teacher led, practical to allow students to understand this relationship. 	<ul style="list-style-type: none"> • Start with symbols of components. • Show students real components. • Draw circuit diagram. • Set up circuits using components.
Specific ways of ascertaining students' understanding or confusion around this idea	<ul style="list-style-type: none"> • Recognise direct relationships. • Graph raw data to demonstrate the relationship 	<ul style="list-style-type: none"> • Successfully complete circuits. • To be able to draw and construct circuits taking reading correctly.

Big Ideas (David's Working Group)		
Pedagogical Prompts	Electrical circuits can be constructed to solve problems	Magnetism is another effect of moving charge
What do you intend students to learn about this idea	<p>Set up the following circuits. Use a multimeter to take measurements and check for faults:</p> <ul style="list-style-type: none"> • Short circuits. • Build a simple series circuit with one lamp. Check function. • Build series circuits with more than one lamp. • Build simple parallel circuits with 2 or 3 lamps. 	<ul style="list-style-type: none"> • Permanent and temporary magnets. • Brief overview of alignment of electrons. • Magnetic field around bar magnets and Earth. • Interaction between poles.
Why is it important for students to know this?	<ul style="list-style-type: none"> • Ensure students are conversant with how to build circuits. • Ensure students can work out why their circuits do not work. • To develop their problem solving skills. • So they can work independently. 	<ul style="list-style-type: none"> • Use in electric motors. • Knowledge of Earth's magnetic field and compasses
What else you know about this idea (that you do not intend students to know yet)	<ul style="list-style-type: none"> • Definition of Voltage as energy per coulomb of charge. • Electric fields. 	<ul style="list-style-type: none"> • Nature of electrons and magnetism occurs involving these electrons.
Difficulties and/or limitations connected with teaching this idea	<ul style="list-style-type: none"> • Understanding voltage. • Remembering and having skills to ensure meters are connected correctly. 	<ul style="list-style-type: none"> • Understanding magnetism. • Only some metals can be magnetised.

Knowledge about students' thinking which influences your teaching of this idea	<ul style="list-style-type: none"> • Idea that current flows 'up to' an open switch. 	<ul style="list-style-type: none"> • Compasses point to 'north'. • Only iron can be magnetised.
Other factors that influence your teaching of this idea	<ul style="list-style-type: none"> • Teacher pre-conceived ideas. • Lack of teacher knowledge. • Pre-conceptions/prior knowledge of students. • Time available. 	
Teaching procedures (and particular reasons for using these to engage with this idea)	<p>Make circuits in the following order. Remove lamps each time in a process that enables students to draw conclusions about current and voltage in both circuits.</p> <ul style="list-style-type: none"> • Series • Parallel • Series with voltmeter • Parallel with voltmeter • Series with ammeter • Parallel with ammeter • Series with voltmeter and ammeter • Parallel with voltmeter and ammeter 	<ul style="list-style-type: none"> • Bar magnets and iron filings. • Show permanent magnets. • Interactions between magnets. • Draw magnetic fields. • Make electromagnets.
Specific ways of ascertaining students' understanding or confusion around this idea	<ul style="list-style-type: none"> • Formative assessment. • Review with readings, conclusion table. • Discussions. • Practice problems. • Summative test. 	

Appendix H – River High School ERO Report

Please note that this is an adapted ERO report from the actual participating school. Any reference made in the report that could identify the school has been removed to protect the anonymity the school, as per the informed consent agreement.

1. Context

What are the important features of this school that have an impact on student learning?

River High School is a large, urban secondary school for boys in Years 9 to 13. The roll has continued to increase since the last ERO review in 2009 and is now over 2000. Nineteen percent of students are Māori, 11 percent are Asian and 5 percent are Pacific. There are 48 international fee paying students and 151 students in two hostel facilities. There is an enrolment scheme in place. Students come from a wide area, mostly from outside the school's catchment area.

Leadership of the school is unchanged since the last ERO review. There is a new board of trustees, including a new chairperson. Board members bring a range of appropriate experience and expertise to their roles. Significant property developments include the construction of a large, modern gymnasium, the refurbishment of a number of classrooms and extension of the hostel.

A notable feature of the school is the culture of care and high expectations for learning and success that are promoted and modelled by the principal and other school leaders. The school's vision, that aims to inspire values such as service, respect and commitment is visually represented in the school's crest and is evident in many aspects of the school's operation. Effective, high-quality and ongoing self-review is strongly evident in the school.

The school has a very positive ERO reporting history. The last ERO report contained areas for review and development about the leadership of learning, the use of assessment information to improve achievement, and engagement with Māori parents and community. The school has responded positively to this report and each of these areas has been a focus for school improvement and staff professional

development. Leadership of learning is now more focussed, there is more effective use of student achievement information, and there has been significant progress in promoting success at all levels for Māori students.

2. Learning

How well does this school use achievement information to make positive changes to learners' engagement, progress and achievement?

The school is using achievement information very effectively to support student learning and engagement. This has been a major priority for school-wide development, is a current objective for teacher improvement, and is reflected in teachers' performance appraisals. The introduction of a new student management system is allowing for a more effective and efficient sharing of information among staff.

Achievement information is used very effectively to support the following practices:

- provision of information to teachers about students in their classes together with guidelines as to how this information should be used to inform teaching and learning
- twice yearly meetings of core subject teachers in Years 9 and 10 classes to share information about student achievement and progress
- the identification of students who require extension and those who need further support in their learning
- provision of tracking sheets which allow individual students to monitor their own progress in senior school assessments
- annual, evidence-based review and target setting by curriculum departments.

Academic dean positions have been established to assist in monitoring and supporting students who may be at risk of under achieving. Student achievement information, especially in Years 11 to 13, is regularly reported to the board and is used well to inform strategic planning and resourcing decisions.

Information about the achievement of Māori and Pacific students in Years 11 to 13 is used to determine annual achievement targets for these students that are reported at school-wide and subject department levels. The school is able to show that the achievement of Māori and Pacific students in the National Certificate of Educational Achievement (NCEA) has improved each year since the last ERO report. The progress of students with special learning needs is monitored and well supported by the Learning Support Department and through the work of teacher aides. The school recognises the need to continue to establish and monitor targets for priority learners from low socio-economic backgrounds.

Results of assessments carried out on school entry are used to place students in class in Year 9. Parents of students in Years 9 and 10 receive written reports twice yearly about their students' marks and grades in tests and examinations.

An important next step for the school to consider is the development of ways to more effectively monitor and report the progress of students in Years 9 and 10 in relation to national expectations. This should assist teachers to:

- use assessment information more effectively to identify and respond to the specific learning needs of students
- monitor and evaluate the accelerated progress of priority learners
- share assessment information with students and parents to encourage a partnership in identifying next learning steps.

Data from senior school qualifications indicates that students, including Māori and Pacific, are achieving very well in relation to national expectations and when compared to students in similar schools. Achievement levels have continued to improve over time. The school is proud of the increasing number of New Zealand Scholarships students have gained since 2011. Public Achievement Information (PAI) data shows that over the past four years the school has met the Ministry of Education target of 85% of students leaving school with a Level 2 NCEA qualification or equivalent. This data also shows that levels of retention and attendance are consistently high and rates of suspension and exclusion are very low.

3. Curriculum

How effectively does this school's curriculum promote and support student learning?

The school has a broadly based curriculum that effectively promotes and supports student learning.

The curriculum has a strongly academic focus with an increasing range of practical and applied knowledge courses. Students have access to a very wide range of options and learning pathways that are designed particularly for boys. Accelerated and differentiated programmes offer flexibility to meet individual student learning needs and interests. Students are well supported through a range of strategies to make appropriate decisions about their learning and career pathways.

A feature of the school is the high level of participation by students in an extensive range of co-curricular experiences. High-quality sports programmes have led to notable success in a variety of sporting codes at regional and national level.

In keeping with the vision and values of the school, leadership and service are promoted as integral aspects of the curriculum. A wide range of opportunities is provided for students to serve others, and develop leadership skills through positions such as prefects and house leaders as well as within tutor groups, sports teams, cultural groups and clubs. The school has recently increased the number of opportunities available for Māori and Pacific students to mentor and support other students.

As a result of professional development in the leadership of learning, the roles of heads of faculty and teachers with curriculum responsibility have been enhanced. Clearly documented guidelines for programme delivery have been established in each learning area. Recently developed best teaching-practice action plans provide useful expectations for classroom practice. There is clear alignment between the overall school strategic direction, department goals and priorities, professional learning and development and teacher appraisal.

Classrooms are characterised by respectful and affirming relationships amongst teachers and students and are settled, productive environments for learning. Teachers are positive and enthusiastic about their roles. They know their students well and

actively support them in academic and co-curricular activities. ERO observed examples of effective teaching practice including the establishment of the purpose for learning, acknowledging prior learning, the use of strategies to engage boys, checking understanding and providing feedback.

ERO and the school agree that teachers should continue to deepen their understanding of, and work towards implementing, best practice in their respective curriculum areas. This could include the use of teaching strategies to further empower students to be more actively involved in their own learning.

School leaders recognise that there is a need to continue to develop information and communications technologies (ICT) to ensure they are readily accessible learning tools for all students. This should include the provision of resources as well as the development of staff capability.

The holistic wellbeing of students, promotion of positive relationships and provision of a safe, inclusive environment are important priorities for all staff. High expectations for the care of students are clearly articulated by the principal and are evident in the school's vision and values and in the commitment of staff. These expectations are reflected in the comprehensive, multi-layered pastoral care network that continues to be a strength of the school. This network provides both learning and pastoral support for students. A significant feature is the range of opportunities for older students to support and mentor younger students.

Ongoing self-review to evaluate the effectiveness of pastoral care could be strengthened by considering alternative ways to obtain student voice.

How effectively does the school promote educational success for Māori, as Māori?

Improving the success and achievement of Māori students has been a priority for the school since the last ERO report. School leaders have been involved in the He Kākano professional learning project and demonstrate high levels of goodwill and commitment to fostering the engagement and success of Māori students across the school. Student surveys on a range of pastoral care matters and perspectives of the place of Māori within the school have been used to develop a set of targets to

improve the place and status of Māori students. Department and individual teacher performance management documents now include goals related to Māori student engagement and success.

Key positions, including a dean for Māori students and a whānau liaison teacher, have been established. The two Māori tutor groups are focal points in helping to establish a sense of identity and belonging for Māori students.

Other important developments that promote the identity of Māori students include:

- a Māori and Pacific awards evening
- an evening for the parents of Year 8 Māori students to support their transition into the school
- the introduction of Māori performing arts into the curriculum in the senior school.
- Parents spoken to by ERO indicated that opportunities for their boys to experience success as Māori, have improved.
- ERO and the school agree that useful next steps that will further strengthen success for Māori are to continue:
 - professional development for staff on implementing Māori preferred ways of teaching and learning and increasing their understanding of Māori perspectives
 - to increase the amount of Māori content and context included in curriculum areas and the visibility of Māori cultural identity in the school.

How effectively does the school promote success for Pacific Students?

Since the last ERO review the school has made considerable progress in providing support for the learning, wellbeing and identities of Pacific students. The development of a Pacific Education Plan has led to the establishment of a Pacific tutor group, the appointment of a dean and tutor teacher for Pacific students, a Māori and Pacific awards evening, an induction evening for Year 8 Pacific parents and opportunities for involvement in Pacific performing arts.

4. Sustainable Performance

How well placed is the school to sustain and improve its performance?

The school is very well placed to sustain and improve its performance.

A key factor in the continued progress of the school is the highly effective leadership provided by the principal in articulating and promoting the vision, values and direction for the school. She is ably supported by an experienced and highly competent executive team, heads of faculty and a large number of other staff with curriculum and pastoral responsibilities.

The board of trustees governs the school in the best interests of students and staff. The policies, systems and procedures that guide their work are of high quality and ensure that school accountabilities are met. There are a number of effective systems for ongoing self-review informed by evidence including information about student achievement and engagement.

Teachers consistently demonstrate good practice and effectively promote positive educational outcomes for students. All staff work very well together as a collegial team. They are proud of the school, and there is a strong sense of common purpose.

Students are actively engaged in their learning, and are achieving well. They enthusiastically participate and experience success in the extensive range of opportunities that are available to them. Students respond well to the culture of care, respect and high expectations.

The school benefits from high levels of community contribution and engagement. There are many opportunities for parents and the wider community to be involved in school activities, particularly sport. The school has a range of systems for communicating with parents in relation to their sons' wellbeing and learning.

Provision for international students

The school is a signatory to the *Code of Practice for the Pastoral Care of International Students* (the Code) established under section 238F of the Education Act 1989. The school has attested that it complies with all aspects of the Code.

ERO's investigations confirmed that the school's self-review process for international learners is thorough.

International students receive very good learning opportunities, enjoy participation in co-curricular activities, and are well supported by the school's high-quality pastoral care systems. At the time of this review there were 48 international fee-paying students attending the school. Their well-being, academic progress and achievements are closely monitored.

The Director of International students and ERO agreed that it would be useful for the board to receive information about the students' academic progress in the regular reports they receive. In addition, surveying students anonymously would give assurance that their pastoral and educational needs are being met.

Provision for students in the school hostel

The school hostels accommodate 151 students, which represents 7% of the school roll. It is owned by the River High School Board of Trustees and operates 7 days a week. The hostel owner has attested that all the requirements of the Hostel Regulations are met. While there have been some changes, there has been a good level of continuity in staffing since the last ERO review. The hostels are being efficiently and effectively managed and have the support of the school community and parents. There are many hostel features which promote positive relationships and high levels of student welfare and safety. These include:

- well-documented and transparent policies and procedures for both students, and parents with clear definitions of expected behaviours, an emphasis on consideration and respect, and a non tolerance of negative behaviours
- detailed and effective communication processes between hostel and school staff, board of trustees, boarders and their families
- high levels of pastoral care and academic support for boarders
- quality nutritious meals for students
- excellent facilities for daily supervised preparatory periods

- access to school recreational facilities out of school hours such as the school pool, gym, library and grounds
- very positive relationships among the hostel director, hostel staff, families and school stakeholders
- opportunities for Year 12 and 13 boarders to undertake leadership and mentoring roles with younger hostel students.

Board assurance on legal requirements

Before the review, the board of trustees and principal of the school completed the ERO Board Assurance Statement and Self-Audit Checklists. In these documents they attested that they had taken all reasonable steps to meet their legislative obligations related to:

- board administration
- curriculum
- management of health, safety and welfare
- personnel management
- financial management
- asset management.
- During the review, ERO checked the following items because they have a potentially high impact on student achievement:
- emotional safety of students (including prevention of bullying and sexual harassment)
- physical safety of students
- teacher registration
- processes for appointing staff
- stand-downs, suspensions, expulsions and exclusions
- attendance.