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Secondary school science teachers' Pedagogical Content Knowledge (PCK) in their classroom practice

A thesis

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Imran Tufail

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Abstract

Research on teacher expertise has identified pedagogical content knowledge (PCK) as the most important factor impacting student progress (Neumann, Kind & Harms, 2019; Park & Chen, 2012) and supported its recognition in teacher practice (Kind & Chan, 2019). Since the recognition of PCK as something that teachers possess, there has been theorizing and research into its nature, its components, and the relationship among these components. To address such issues, two international summits were organized in 2012 and 2016. The key outputs of these summits were theoretical consensus models of PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015). This study builds on novel emerging ideas in the first PCK consensus model (Gess-Newsome, 2015). These consensus models stressed the need for examination of PCK in classroom practices. Researchers have argued for research to understand teachers' PCK in their practice, with the ultimate goal of the enhancement of students' learning (Abell, 2007; Barendsen & Henze, 2019; Lee, 2020). This study then had the aim to examine experienced science teachers' PCK during their classroom practices when they taught a chemistry topic to Year 10 students in New Zealand.

A case study approach was adopted for an in-depth examination of these teachers' practices (e.g. Cohen, Manion, & Morrison, 2018; Yin, 2009). The sample of this study was two experienced science teachers who were selected by the convenient sampling technique. The data were collected from teachers only. The data were gathered through a pre-topic questionnaire, document analysis, follow-up lesson interviews, follow-up topic interviews, and classroom observations including video recordings of lessons. Each class lesson within a 12 lesson topic for each teacher was observed and video-recorded. The lesson follow-up interviews were conducted after each lesson and follow-up topic interviews were conducted after completion of the topic. A conceptual and analytical framework was developed to interpret and analyze the data using the knowledge components of the Consensus Model-2015 (Gess-Newsome, 2015). Data were analyzed systematically. First, recorded data from observations and interviews were transcribed, and where appropriate, validated by the participants. Second, all data were imported into NVivo for analysis. Data were coded by using deductive (using aspects of the Consensus Model) and inductive approaches. The codes were grouped into themes and considered.

The analyzed data helped to illustrate each teacher's PCK. Each teaching episode or event was analyzed for knowledge components when they identified as prominent in teaching. This analysis identified knowledge components in the form of combinations in their teaching which reflects that PCK is a product of combinations of knowledge components. Significantly, this study indicated that there were four different types of combinations of knowledge components in their teaching. The data show that the two teachers conducted their teaching in a similar situation using different combinations of knowledge components. These findings contribute to understanding the nature of the relationship of knowledge components of PCK, which was not clear in previous PCK models. The diagrammatic representation of teachers' knowledge combinations within PCK in this study can help to visualize teachers' PCK and be used for teachers' self-evaluation, teacher education, and further research into PCK in teaching practice.

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Presentations from this Thesis

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- **Tufail, I**., (2017, October) *PCK models help to develop PCK concept in science Education* paper presented at TEMS Centre Symposium, The University of Waikato, New Zealand.

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Chapter 1
Introduction

1.1 Overview

This chapter introduces this research project and thesis. Firstly, it offers a summary of my background and interest in science teaching to show why I began this study. Secondly, this chapter deals with the key information of the research context and the participants involved. Thirdly, it discusses the rationale behind the study, followed by the significance of the study. Subsequently, it discusses the statement of the research, which includes the research objectives and research questions. Finally, the structure of this thesis is given in overview.

1.2 Researcher’s Background

A researcher interprets science teaching practice or colors the examined situation in research (Basit, 2010), so the researcher’s background has a value for collecting, presenting, analyzing, and interpreting research data. This section describes my background.

I grew up in a middle-class business family in Pakistan where the central purpose is not education, especially for the male members. I did my education at local institutes. I did my secondary and high secondary schooling with a major in Chemistry, Biology, and Physics. I earned a Bachelor of Science degree in Chemistry, Botany, and Zoology. From childhood, I was interested in teaching and research as a profession, so I entered the Institute of Education and Research at the University of Punjab for gaining a professional teaching degree, a Master of Science Education with a research thesis.

After completing my postgraduate degree, I got a job in the same institute where I achieved that degree. The responsibilities of this job included teaching chemistry to high school students, and observing, evaluating, providing guidance, and assessment of pre-service science teachers in their practicums. Furthermore, I have worked as a teacher trainer in different in-service teacher training programs run by the provincial government body. I have developed and designed science teaching training courses, manuals, and materials for teacher trainers. During my professional career as a secondary school chemistry teacher, I noticed that different science teachers taught a single concept differently in their classrooms. Such observations at my workplace developed my research interest in examining science teachers’ teaching practices in the classroom.

To upgrade my qualification, I got admission to the master of philosophy in education (M.Phil Edu) in the evening program run by the University of Education, Lahore, Pakistan. Both my master and M.Phil research theses focused on science teaching and learning by using quantitative research methods. After completing my M.Phil, I flew to New Zealand for achieving a doctoral degree in education, with my focus on science teaching practices in a New Zealand secondary school. This focus was because doing such a study on pedagogical content knowledge in a Pakistan classroom is very difficult. The shift of research context was a big challenge for me as I initially had little knowledge about New Zealand teaching practice. I worked to reduce those challenges in a number of ways, which are discussed in Section 3.4.1 in Chapter 3. The next section presents the context of this study.

1.3 The Context of the Study

The data were gathered when science teachers taught a chemistry topic to Year 10 students in their New Zealand secondary classrooms. New Zealand secondary schooling goes from level Year 9 to Year 13 (ages 13 to 18). Year 9 and Year 10 students are required to study core subjects in English language, and these subjects are: English, Mathematics, Science, Arts, Social Sciences, Technology, as well as Health and Physical Education as recommended by *The New Zealand Curriculum* (Ministry of Education, 2007). Additionally, secondary schools offer a variety of options for students to choose other subjects at higher levels of secondary schooling.

The New Zealand Curriculum governs what students learn in their first 10 years of schooling (i.e. Year 1 to Year 10) (Ministry of Education, 2007), which serves as a guide for institutes and teachers (Hipkins, 2013). *The New Zealand Curriculum* describes eight Curriculum Levels and New Zealand students need to achieve all these eight levels during their Year 1 to Year 13 of schooling.

The *New Zealand Curriculum* provides general guidelines for schools and teachers to achieve national goals and objectives. Then schools develop a school-based curriculum to implement these guidelines into a particular context. Bolstad (2004) reviewed some studies to discuss a process of school-based curriculum development. According to these studies, all or selected members of a school community plan, implement, and/or evaluate single or all aspects of the curriculum that the school offers, and this process should consider the national curriculum, and schools' own values, priorities, contexts, students' voice, and goals and objectives (Brady, 1992; Bezzina, 1991; Brooker & MacDonald, 1999). In the observed context, the school science department provided their school-based curriculum to the science teachers. This document provided a general framework of topic content and student learning objectives (SLOs) which were based on the national curriculum for the school.

The Science learning area of *The New Zealand Curriculum* is further divided into strands: Nature of Science, the Living World, the Planet Earth and Beyond, the Physical World and, the Material World. The Nature of Science is an overarching strand with a set of aims, but it does not have achievement objectives. The other strands have achievement objectives that are across all eight Curriculum Levels. The strand Material World includes chemistry as a subject. Here, the purposes of chemistry are to develop students' understanding of composition and properties of matter, changes in matter and energy involved in it, use their understanding of chemistry to make sense of their surroundings, interpret their observation in the light of properties and behavior of particles (atoms, molecules, and ions), using symbols and conventions of chemistry in their communication; and understand the science-related challenges such as sources of energy (Ministry of Education, 2007).

The Nature of Science is an overarching strand and compulsory for all school years up to Year 10 (Hipkins, 2013). When students are in Year 8 it's a good idea to select any areas of interest or particular strengths as this may affect which school and which subject options they choose when moving on to Year 9 (Ministry of Education, 2020). Year 10 is a transitional academic year between lower secondary and higher secondary when students prepare themselves to enter higher secondary education (Years 11-13) to undertake NCEA (National Certificate of Educational Achievement), which is New Zealand school's main secondary school credential and is regulated by the New Zealand Qualifications Authority (NZQA), or to take an alternative school exit qualification. Midway through Year 10, students in most schools can begin looking at subject area choices for these qualifications. This involves deciding what qualifications they will need when they leave school and move on to their choice of employment or tertiary studies (Ministry of Education, 2020).

During students' Year 10, New Zealand science teachers are expected to be focused on making a science conceptual foundation to prepare their students for further higher study because the national qualification influences key decisions about what to teach (Hume & Coll, 2010) and New Zealand secondary school teachers make their classroom practice to meet the NCEA requirements (Hipkins & Neill, 2006).

Another factor that influences the New Zealand classroom practice is students' cultural backgrounds because teachers need to set a learning environment according to their students (Parr & Limbrick, 2010). The students of observed classes in this project have appeared as Pākehā, Māori, and Asian (see Sections 4.2.1 and 5.2.1). Māori people are the native people of New Zealand, while Pākehā is a Māori language term used to describe European origin New Zealanders. Some researchers have simply separated New Zealand students into Māori and Non-Māori students in their research (e.g. Averill & McRae, 2020).

The participants in this study are two experienced science teachers, and they each have over 20 years of New Zealand science teaching experience. Both are science graduates who also have professional teaching qualifications. They had taught chemistry continuously to Year 10 students from the start of their teaching careers. It is the common assumption that experienced teachers develop knowledge well about how to teach a topic (Chan & Yung, 2018). The participants completed their schooling and higher studies in New Zealand institutes and started their teaching profession in the same country. A detailed description of each participant appears in Sections 4.2.2 and 5.2.2 respectively.

The science teaching and learning in *The New Zealand Curriculum* is underpinned by ideas of constructivism (Garbett, 2011) and this document promotes the learner-centered approach in the classroom (Hume & Coll, 2010). Besides, McDowall and Hipkins (2019) found New Zealand teachers integrated their work with biotic [students, colleagues] and abiotic [physical part] contexts of the classroom. *The New Zealand Curriculum* suggests that teachers create a positive relationship with students and create a learning environment. The positive teacher-student relationship is a key aspect of classroom practice for raising student learning in New Zealand classrooms (Averill, 2009; Bishop et al., 2007), moreover, these relationships influence students in a multitude of ways to foster better attendance, high achievement score, and feelings of connectedness to school (Ransom, 2019). *The New Zealand Curriculum* describes some teaching actions (e.g. create a supportive environment, facilitate shared learning, encourage reflective thought and action) that have been shown to consistently have a positive effect on student learning (ERO, 2018). Science teachers need to use their knowledge to enact these teaching actions in their classroom practice to positively affect students' learning. Science teachers may use different knowledge components in their classroom practice to complete a teaching action or task, and a key reason behind this study is to examine the combinations of knowledge components used by New Zealand science teachers in their classroom practice.

1.4 Statement of the Study

The main objectives of science education in New Zealand are to prepare students for science-based careers and to be citizens who are scientifically literate (Gluckman, 2011). Therefore, it is the responsibility of science teachers to engage students in a way to develop their ability to apply scientific concepts, principles, laws, processes for decision-making, understand the world, and consider their future careers in science. This is possible when teachers have a range of knowledges along with excellent teaching skills, which helps the students to construct a meaningful understanding of science concepts and skills and apply those concepts in their lives. Abell (2008) noted that the development of teacher subject matter knowledge and its understanding is critical for success in science teacher education. In order to understand teachers' teaching knowledge, it is important to examine teachers' pedagogical content knowledge (PCK) and how they use knowledge(s) in their teaching. This study aimed to examine experienced science teachers' PCK in their New Zealand secondary science classrooms.

The new emerging ideas in the Consensus Model of PCK-2015 (Gess-Newsome, 2015) dealt with a new dimension of teaching in classroom practice. This model attempts to explain what teachers know and how they use this knowledge during classroom practice to make an impact on students' understanding of a concept or skill (Schultze & Nilsson, 2018). Gess-Newsome (2015) perceived PCK as a knowledge base used in planning for delivery of topic-specific teaching in a very specific classroom context, which connects to skills when involved in teaching practice. Teaching skills are needed to organize knowledge before and during classroom practice, to teach effectively, and develop teaching practice. The development of teaching by evaluating teaching practice is also discussed by *The New Zealand Curriculum* as 'Teaching as Inquiry' (Ministry of Education, 2007, p. 35). For teaching practice in a classroom, teachers need to learn how to use their knowledge in a meaningful way. Learning to teach in the classroom is to learn systematically how to organize knowledge components that can be drawn upon and applied to new situations (Berliner, 2001). As yet, there has been not much written in the literature about how teachers apply their PCK in the classroom, as the focus on classroom practice is a new addition to previous models. This study will contribute to an understanding of teachers' PCK in their classroom practice.

Teaching is a complex, problematic and uncertain creative activity; teachers are required to continually adjust their instructional strategies and representations to effectively make on-the-spot decisions, respond to students to meet their needs, and support student learning (Park &

Oliver, 2008; Williams et al., 2012). It is clear there is no facile set of instructions to inform and prepare teachers for the challenges of teacher planning and practice (Barnett & Hodson, 2001) because an effective classroom practice is not an absolute thing; it varies from context to context (Parr & Limbrick, 2010). Teachers in classrooms adjust their knowledge according to contextual needs, and teachers make connections between knowledge components of PCK by using their knowledge and skills to try to address students' learning needs. The classroom practice is a dynamic process so teachers adjust their teaching accordingly.

The next subsection discusses the rationale for this study.

1.5 Rationale for the Study

According to Shulman (1987), a teacher knows something unique that is not understood by others; using this knowledge, the teacher can transform understanding, skills, or attitudes and values into the teaching process. This unique way of understanding is teachers' PCK that is developed by them, and mostly this knowledge is tacit in nature, so it is difficult to capture PCK in teaching (Park & Oliver, 2008). PCK appears as the main teaching knowledge that distinguishes expert teachers from content specialists (Chan & Hume, 2019; Park et al., 2018). Moreover, Loughran et al. (2012) argue that, "a real and serious issue in teaching is the ability to capture, portray, and share knowledge of practice in ways that are articulable and meaningful to others" (p. 15). The recent PCK consensus models (Carlson & Daehler, 2019; Gess-Newsome, 2015) emphasized the importance of classroom practice to understand science teachers' PCK. Recent developments in the PCK concept have shown that there is a need for research to contribute its understanding of PCK in classroom practice. Therefore this study examined science teachers' PCK in their classrooms.

Shulman (2015) points out a limitation in the classical concept of PCK that this concept was conceptualized without involving non-cognitive aspects of teaching, such as emotion and motivation. This issue was addressed by the Consensus Models with the inclusion of teachers' and students' Amplifiers and Filters (e.g. Belief, Prior Knowledge, Context). Gess-Newsome (2015) claims that teachers can accept, reject or modify knowledge, skills, and practice as they are free agents in the classroom. Teachers' amplifiers and filters can be understood as teachers' non-cognitive aspects which can impact classroom practice. These Amplifiers and Filters include teachers' beliefs about teaching and learning, experience of different contexts, and prior knowledge that may be relevant to their teaching. One or more of these aspects may influence teachers' knowledge component(s) that could amplify or filter their classroom practice. Grossman (1990) suggested that teachers' beliefs, and goals for teaching science influence knowledge components in establishing PCK. During filtering, these aspects influence teachers' PCK in a way that teachers may filter the given content, provide brief explanation, or provide simple responses such as 'Yes' or 'No' without explaining it further. On the other hand, these aspects influence teachers' PCK in a way whereby teachers could add extra content in the school curriculum. These non-cognitive aspects of individuals are also implicit in classroom practice and, as such, have an impact on students' learning, attitudes, affiliations with school, etc. These impacts have been both observed internationally by researchers (e.g. Cowie & Summers, 2020) and in the New Zealand teaching context (Bishop et al., 2007). How these aspects contribute toward teachers' PCK in their classrooms are not completely discussed in the CM. The engagement of teachers' PCK with their Amplifiers and Filters in classroom practice needs to be explored in more depth to understand their role in PCK. To this effect, this study considers examining the science teachers' Amplifiers and Filters in their chemistry topic teaching in New Zealand classrooms.

It had been considered that teaching was a simple activity of transferring knowledge (Warren, 1985). However, research has shown that teaching is a complex activity where teachers continuously need to adjust their instructional strategies to improve students' ongoing learning (Barnett & Hodson, 2001) and the development of PCK is recognition of this complexity (Williams, Eames, Hume and Lockley, 2012). Teacher knowledge has come to be perceived as more personal from the 1980s on, with a change towards a cognitivist and constructivist perspective on learning and teaching (Barendsen & Henze, 2019). For example, sometimes PCK is referred to as having an integrative nature, or a transformative nature, or being knowledge–on-action and knowledge-in-action. Knowledge-on-action is explicit while knowledge-in-action is explicit as well as tacit (developed and enacted) but it is often tacit and more difficult to capture (Park & Oliver, 2008) because it is less visible during classroom practice. On the other hand, PCK is visible in the form of teachers' expression of knowledge, selection of instructional strategies and representations, and the integration of multiple factors in the teaching (Carlson & Daehler, 2019). In my view, this controversy was generated because most PCK research to date has tended to focus on PCK as knowledge rather than operational PCK in practice. The teachers' actions and knowledge in the classroom are fundamental elements of the education process where teachers' actions have a direct influence on students' learning (ERO, 2018). This research examined the experienced science teachers' PCK when they taught a chemistry unit to their Year 10 students in New Zealand classrooms. This research focused on teachers' combinations of knowledge components for a particular task in the classroom practice. These combinations will help to understand experienced teachers' PCK in the forms of combinations they use to tackle their teaching situations that could help pre-service teachers to approach upcoming teaching situations. Moreover, this contribution could afford teacher educators to support pre-service science teachers' learning to teach because learning to teach not only comprises specific content but also combinations of knowledges specific to a teaching instance. These contributions help to enhance science teaching that impact students' learning and produce citizens with better scientific understanding, which would ultimately contribute to the wellbeing of any country or the world.

In the light of these arguments, I can rationalize: first, PCK experts emphasized to explore teachers' PCK in their classrooms to understand how teachers use their knowledge within their teaching. Second, it is well established in literature about how teachers' amplifiers and filters impacted on teachers' teaching, but there is little knowledge about how it amplify and filter teachers' PCK. Teachers' PCK and amplifiers and filters are implicit during teaching practice and need to be explored. By knowing, capturing, and framing of PCK, it can help to enhance teachers' understanding of what teaching means. When teachers account for their knowledge components in their PCK, along with amplifiers and filters, then they can bring changes in their teaching practices for students' learning. This study will explore the implicit nature of PCK through framing it as a set knowledges that are detectable in their classroom practice. The next section described the importance of this study in the field of PCK to contribute to its understanding.

1.6 Significance of the Study

The Teacher Professional Knowledge and Skills including PCK (TPK&S) model [PCK Consensus Model-2015] has a theoretical basis that experienced researchers of PCK agreed upon at the PCK Summit 2012, but they also emphasized the need to test it (NARST, 2013). As mentioned in the summary of the Summit report, "Overall, the understanding that PCK as a theoretical construct is a useful concept to facilitate access to science education, partly because of its sensitive nature to learners in context, was re-affirmed." (NARST, 2013, p. n). The addition of new ideas in the agreed theoretical model (i.e. PCK Consensus Model-2015) indicated a gap in PCK research in recent years to understand PCK in the classroom context. The theoretical importance of the CM is strong, notwithstanding it being without an explicit research base, this gap provides a motivation to researchers to conduct new research. This study focused on a central aspect of this model (classroom practice) to examine PCK of science teachers in secondary school chemistry classrooms in New Zealand. Furthermore, the findings of the study would help science teachers to improve their teaching practice in their classrooms.

Researchers have argued for research to understand teachers' PCK during their practice, including a need for in-depth research on teacher knowledge and classroom practice, with the ultimate goal of the enhancement of students' learning (Abell, 2007; Barendsen & Henze, 2019; Lee, 2020). These researchers claimed, by knowing the interactions of knowledge components within PCK give better understanding of teachers' PCK. Better understanding of teachers' PCK in the classroom helps to understand teachers' teaching practice to achieve the ultimate goal of enhancement of students' learning, because it has been identified that teachers' PCK is the most important factor that impacts students' progress (Neumann, Kind & Harms, 2019; Park & Chen, 2012). The recent consensus PCK models also stressed the investigation of PCK in the classroom practice (Carlson & Daehler, 2019; Gess-Newsome, 2015). The first PCK consensus model (Gess-Newsome, 2015) is set as a conceptual framework of this study to understand teachers' PCK. The findings of this study will help to see the operationalization of this model which expands the scholarship of PCK by adding evidence from actual classroom practice. By using the conceptual framework, this study frames teachers' PCK in the form of knowledge combinations, and pictorial representation of combinations can offer visualizations of PCK to understand its tacit nature. The visualizations of PCK may help science teachers to reflect on their knowledge combinations to enhance their teaching. During teaching practicums, this PCK framing of combinations could help preservice science teachers to observe experienced science teachers' PCK in teaching situations.

To understand teachers' PCK, most studies have involved pre-service teachers (e.g. Boz & Belge-Can, 2020; Hume & Berry, 2011; Mavhunga & Rollnick, 2013; Nilsson & Karlsson, 2018; Van Driel et al., 2002), with some research including experienced teachers (e.g. Carpendale, 2018; Chan & Yung, 2018; Van Driel et al., 1998). In addition, some PCK studies have observed experienced science teachers' PCK in the classroom (e.g. Barendsen & Henze, 2019; Chan, 2014; Ekiz-Kiran & Boz, 2020; Lankford, 2010; Nilsson & Vikström, 2015; Park & Chen, 2012). These studies have contributed to enhance our understanding about PCK but research is needed to explore some areas of PCK needs to minimize the ambiguity in the notion of PCK, for instance, how knowledge components combine for PCK. I aimed to examine experienced science teachers' teaching in the classroom to understand their PCK through observing teachers' PCK in a particular situation, content, and context. My study will add a new angle of investigating PCK with a deep insight into it. Previous PCK studies aimed to investigate science teachers' PCK in their classroom focused on one or more aspects of science teachers' PCK, components of PCK and their interactions. For instance, the study of Barendsen & Henze, (2019) organized to examine the interrelationship of knowledge components of PCK that were discussed in Magnusson, Krajcik, and Borko model (1999) and found some components have a strong connection, while others have a weak relationship. The authors did not explain how these components interact with each other in the classroom setting. My study describes how PCK components combine for particular teaching.

There is little literature providing empirical evidence for PCK in the classroom. There is also limited literature on research on the knowledge and beliefs held by experienced teachers and how their beliefs about teaching act as amplifiers or filters in the classroom. Missing in the PCK literature is research into knowledge and beliefs held by experienced teachers (Lankford, 2010). The findings of this study contribute to PCK literature on how teachers' beliefs, educational context, and their prior knowledge act as amplifiers or filters for their knowledge use in their classroom practice. The framework of this study would offer a way for science teachers to note their Amplifiers and Filters in their teaching, by identifying and revisiting the impact of Amplifiers and Filters that could enhance their practice. After establishing the importance of the issue and significance of the study, this study has some objectives and research questions that are presented in the following section.

1.7 Research Objectives and Research Questions

Generally, a researcher identifies a problem from their surroundings and finds a gap in the existing literature. Through organized research, a researcher tries to fill the gap and solve the identified problem. This research prescribed some objectives at the start, and in relation to those objectives, I developed research question that guided the study. The objectives and research questions of this study are presented here.

1.7.1 *Research objectives*

The objectives of this study are:

1. To examine science teachers' PCK in their chemistry classroom practice.
2. To examine science teachers' way of combining knowledge components in their PCK to facilitate their teaching.

A research question was developed to achieve these objectives.

1.7.2 ***Research question***

The question that guided this study is:

> RQ: How do science teachers combine the knowledge components within their Pedagogical Content Knowledge (PCK) in their classroom practice?

1.8 Thesis Structure

This section presents an overview of chapters and their organization in this document. Chapter 2 provides a comprehensive and in-depth discussion of the literature review. This detailed literature review highlights and discusses both historical and current research in the field, which in turn strengthens this research. This chapter is delineated by two focus areas: PCK, and secondary science education in New Zealand. The first section explains the origin of PCK and discusses PCK models that are relevant to this study. This section also illuminates the influences of PCK summits on this concept, recent developments in PCK, and new emerging ideas in it. Also, the consensus models are explained in detail, and provide the rationale behind the selection of the first PCK Consensus Model-2015 for this study. The second area of this chapter encompasses New Zealand schooling, *The New Zealand Curriculum*, and New Zealand science education classroom practices. This section provides detail about the context of the study, structure of science teaching in NZC, pedagogies recommended by *The New Zealand Curriculum*, and classroom practices established in New Zealand, moreover, it also enlighten science learning trends among New Zealand high school students.

Chapter 3 outlines and discusses the methodology that guided the study followed by the conceptual framework of this study. This chapter by establishing the philosophical stances that underpin the nature of this study. The research approach deals with the type of case study, researchers' background, and procedures adopted to select research participants, and discusses data collection phases. The data collection process explains how, when, and what type of data was collected for this project. The research tool section deliberates the structure and development of research tools (questionnaire, interviews, document analysis, observations, and video recordings) which were itemized for this particular research to examine the science teachers' PCK in the classroom. The research quality section establishes the credibility, transferability, dependability, and confirmability of this study. The data analysis section portrays the treatment of data and use of this treated data for presenting findings of the study. Subsequently, ethical issues are discussed that are important to this study in the New Zealand context. Finally, this chapter presents how the conceptual framework is established for this study by using the Consensus Model of PCK-2015.

Chapters 4 and 5 present and interpret the data to describe the emergent themes and trends in PCK in the science teachers' classroom practice. Particularly, each chapter discusses the PCK of each science teacher. Both chapters have the same arrangement: these chapters report the context of the study that provides the details of the classroom setting and participant's background. The second portion is the major body of these chapters that deal with components of his PCK in his teaching practice; it includes evidence of the participant's Assessment Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge. The presented data for each section were selected when that knowledge appeared prominent in their teaching. The name of each section represents the prominent knowledge of Teacher Professional Knowledge Base (TPKB) in the consensus model-2015 (e.g. Assessment Knowledge). Finally, these chapters present a summary of the chapter.

Chapter 6 presents the findings of this research and compares them to the literature. This chapter first discusses each of the research questions which guided this study. After discussing these questions, this chapter concludes this study and mentions its limitations. Finally, it presents the implications of this research followed by some suggestions for future research extending beyond the scope of this study.

Chapter 2
Review of the Literature

This chapter presents a review of the literature related to the subject of this study. Firstly, it discusses the development of the idea of pedagogical content knowledge (PCK) and the taxonomy of PCK. The second section of this chapter provides a detailed discussion of some selected PCK models including the PCK consensus models that are relevant to my study. It also presents elements of the first PCK consensus model and the reason why I select this model for this study. Thirdly, the chapter offers a brief description of science classrooms and teaching practice, which is followed by an explanation of science education and science classroom practice in New Zealand. Finally, the chapter presents conceptual framework of this study and chapter summary.

2.1 Development in PCK

Recent studies of PCK attempt to bring teachers' knowledge components and their teaching actions together under one umbrella. Since the notion of PCK was first suggested, its development by educators has included knowledge and influences and more recently has included skills (PCK&S). To account for how PCK development for this study from a literature review has progressed this concept in science education all around the globe in last three decades, the upcoming paragraphs of this subsection discuss the voyage of PCK from its classical germination to its recent development.

Interestingly, this PCK concept did not emerge in a single corner of the world; its emergence during the last three decades has been nourished by researchers from across the globe. Lee Shulman first introduced the concept of PCK in 1986, after which it became a prominent aspect in education, particularly in science education (Cooper & van Driel, 2019). Initially, most PCK studies were conducted in the USA, although its proliferation as a concept and model became more apparent once it began to be picked up by researchers on other continents. A recent review of science teachers' PCK literature generated between 2008 and 2018 by Chan and Hume (2019) illustrates that PCK research was very popular in Europe (35.4% of publications in the field) and North America (28.3%) compared to the rest of the world. Asia contributed 26.3% and Africa 8.1% in this area of research. In the result of the research journey from PCK birth to today, this idea has achieved some level of maturity but it is not yet fully developed. In the upcoming paragraphs, I discuss how PCK, as a concept, is classically understood while going on to discuss the complexity of its recent development.

Shulman's (1986) publication *Those Who Understand: Knowledge Growth in Teaching* emphasizes that previous educational researchers have largely ignored various basic questions to do with PCK in teaching domains. These questions include: "Where do teacher explanations come from? How do teachers decide what to teach? How to represent subject matter knowledge? How to question students about it, and how to deal with problems of misunderstanding?" (p. 8). Shulman claimed that these questions are important when it comes to understanding how to identify the sources of teachers' knowledge and how teachers develop their knowledge components.

Teachers gather knowledge from different sources and these include the teachers' own schooling, teacher training programme, continued professional training, and teaching practice (van Driel et al., 2014), daily life experiences, professional gatherings with colleagues, staying in touch with current knowledge of content, and context. Grossman (1990) broadly categorized these sources as formal and informal sources of teachers' knowledge. These formal and informal sources can be specifically identified as involving the (a) observation[s] of experienced teachers, (b) education within the context of a specific discipline (e.g. Physics, Chemistry.), (c) courses during teacher education, and (d) teaching experience. Therefore, a teacher constructs knowledge as an individual (influenced by his or her beliefs, idiosyncratic thinking, etc.) and develops professionally (influenced by teacher training, teachers' schooling). The ideas that teachers have, the idiosyncratic thinking that teachers engage in, among other things, increase the complexity of a teacher's professional learning (Campbell et al., 2017).

Examining these ideas about teacher knowledge, Shulman (1987) proposed that, if teacher knowledge were organized into a handbook, this handbook would need to include at least the following elements:

- Content knowledge,
- General pedagogical knowledge, with reference to those broad principles and strategies of classroom management and organization that appear to teach subject matter,
- Curriculum knowledge, with [a] particular grasp of the materials and programs that serve as "tools of the trade" for teachers,
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the area of teachers, their own special form of professional understanding,

- Knowledge of students and their characteristics,
- Knowledge of educational contexts, feeding from the colleagues or classroom, the governance and financing of school districts, to the character of societies and cultures, and
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. (p. 8)

Within this list, pedagogical content knowledge (PCK) appeared as a new term that attracted the attention of educational researchers. Many studies were conducted at its introduction to understanding this teachers' amalgamation of content and pedagogy for their teaching. In the late 1980s, the concept of PCK provided a breakthrough in debates on the process of professionalization in teaching, for the reasons that this concept expressed a specific body of knowledge belonging to teaching (de Sá Ibraim & Justi, 2019), and that sought to identify the knowledge necessary for teaching (van Driel et al., 2014).

Shulman (2015) explained the background of PCK development at the first PCK summit in 2012 in the following way: in the 1980s, he and his colleagues conducted two different studies, and the results of those two studies generated this concept. One study focused on identifying the relationship between the quality of teachers' content knowledge and their teaching practice in the classroom. The other study aimed to investigate the relationship between teachers' pedagogical knowledge and their teaching. The findings of the first study illustrated that there is a weak relation between the quality of teachers' content knowledge and their teaching practice. On the other hand, the second study noted that the quality of teachers' general pedagogical knowledge has a significant influence on their teaching practice. In the light of these results, Shulman and collaborators became active in trying to pinpoint the presence of teachers' specific knowledge contributing towards a construction between their content knowledge and pedagogical knowledge, and consequently, their efforts identified PCK (de Sá Ibraim & Justi, 2019). Shulman and his co-researchers (1986) understood that PCK works beyond both teachers' pedagogical and content knowledge and that it is in this way that PCK generates teaching in the classroom. Making this point, Shulman wrote:

> The most regularly taught topics in one's subject area, the most useful forms 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…, [PCK also includes] an understanding of what makes the learning of specific topics easy or difficult: the conceptions and

> preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. (Shulman, 1986, p. 9)

In this statement, Shulman (1986) presents a very comprehensive definition of the emergence of this concept in education. Elaborating on Shulman's work, many scholars have put their efforts into furthering their understanding of this definition. For example, they developed tools to measure PCK and constructed PCK models, while some professional organizations arranged summits to find the relationship of PCK elements. However, most researchers are unable to agree on *what* PCK is (Neumann et al., 2019). Some of them consider PCK as a mixture of several types of knowledge of teaching that are required by teachers, while others interpret PCK as a synthesis of all knowledge needed to be an effective teacher (van Driel et al., 2014). Whether or not PCK is a mixture or synthesis of the aforementioned elements, its main purpose is to support teaching practice and therefore learning. Darling-Hammond (1998) puts it succinctly when she says, "what teachers know and do is one of the most important influences on what students learn" (p. 6). In my opinion, PCK is a special set of knowledge combinations that are constructed by teachers for teaching. It is a set of knowledges for teaching, and when it is applied in the classroom it becomes practice. The uniqueness of this knowledge depends on knowledge components in the combinations according to the situation, content and context to enhance students' learning. Teachers' construction of their practice from available knowledges refers to teachers' teaching skill.

Although originally seen as one type of teaching knowledge among others (Shulman, 1986), PCK has gradually emerged as a way of representing and formulating subject matter such that PCK makes the subject matter more comprehensible to learners. Shulman also declared that PCK includes teachers' understanding of what makes the learning of a specific topic easy or difficult. de Sá Ibraim and Justi (2019) claim that Shulman's (1986,1987) initial publications suggest that PCK consists of two elements: *knowledge of instructional strategies* and *knowledge of the students' learning difficulties*. In the late 1980s, knowledge of instructional strategies was referred to as the knowledge of practices of representing content. Contrarily, knowledge of the students' learning difficulties was considered a key constituent for teachers' PCK because it helps to back their judgments on what makes a topic difficult or easier for the learner. When thinking of teachers' knowledge bases, PCK is understood to include opportunities for re-examining subject matter content from the perspective of student learning (Ben-Peretz, 2011). In summary, PCK was perceived as a general kind of teacher knowledge that is essential for teaching and that makes a teacher a professional teacher.

The early ideas about PCK then were fostered as generalised knowledge, and thereafter, this concept was transformed from having a generalised function to one that needed more specific knowledge of its foundations. The concept's trajectory can be represented hierarchically which, in turn, can be depicted as a taxonomy. The nature of this taxonomy is outlined in the next section.

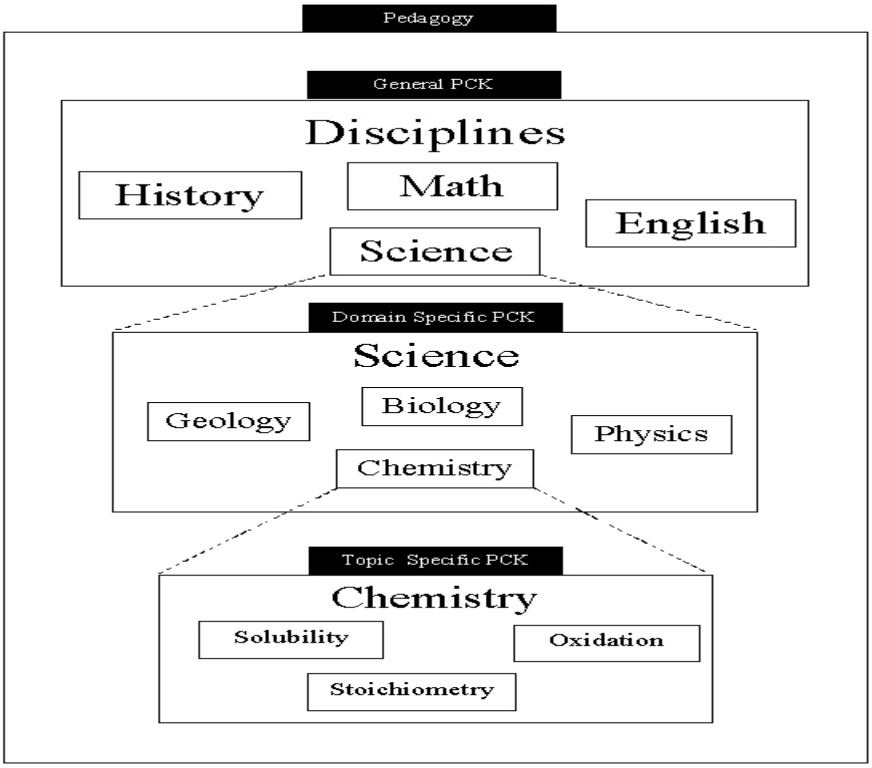
2.2 Taxonomy of PCK

This study aims to examine the combination of PCK components in science teaching practices. With these aims in mind, the following sections document the evolution of PCK from its classical models to its consensus models; the latter of which is related to the focus of study. Despite the 30 years of research involved in the exploration of PCK, the concept continues to develop. Many researchers have contributed to the development of the concept through a wide variety of projects. One result of these studies is that there has been a noticeable proliferation of the use of PCK through the adding of new components, the use of measurement methods, and the application of more sophisticated modeling techniques. However, while different levels of PCK have been discussed by PCK experts, Veal and MaKinster (1999) propose the idea that there is a unique hierarchical relationship between PCK levels. The remainder of this subsection will concern a discussion of this hierarchical relationship between the PCK levels.

Veal and MaKinster (1999) adopted the same steps for the development of PCK taxonomy as Bloom, Engelhart, Furst, Hill, & Krathwohl used in 1956 in their design of a taxonomy for the ordering of behavioural phenomenon. Later, this taxonomy became popularly known as *Bloom's taxonomy*. However, Veal and MaKinster had different intentions in that they intended to illustrate the order of the level of specificity in PCK. Methodologically, Veal and MaKinster generated a list of all previously explained PCK attributes, and then determined the most prevalent features, in addition to which they also generated a complete list of the epistemological components that contribute to the development of PCK. They used these attributes collectively to design a taxonomy that represented the nature and relationship of the knowledge bases that contribute to the development of PCK. Finally, these researchers evaluated their PCK taxonomy according to the criteria outlined in Bloom (1956) and Krathwohl et al. (1964) and compared this taxonomy against examples of existing taxonomies in science education. Their categorized levels of PCK taxonomy are shown in Figure 2.1.

Figure 2.1

Model of General Taxonomy of PCK



Note. This Figure is produced by Veal and MaKinster in 1999 (Veal & MaKinster, 1999, Discussion section, para. 2) to show the interconnectedness of PCK levels. The Figure is reprinted with the permission of the author [William R. Veal].

According to this figure, Pedagogy is presented as the outer core of this taxonomy and it is considered to be the base of all other PCK levels. It includes general teaching skills, selection of teaching methods, teaching planning, evaluation, group work, individual instruction, questioning in the classroom, etc. All PCK levels were constructed based on this general notion of pedagogy.

The first level of this classification is General-PCK: it refers to particular knowledge used by teachers for teaching, rather than the general pedagogical foundation because content and strategies are employed within the subject content areas like History, Math, Science, etc. This label [General-PCK] does not precisely match its explanation because it represents teachers' teaching knowledge for a specific discipline. Magnusson, Krajcik, and Borko (1999) restructured this level and renamed it "subject-specific strategies" (p. 109). A subject-specific strategy is a more suitable term. Veal and MaKinster (1999) acknowledged that this development and the renaming of this category would serve to clarify the use of PCK in future educational research.

Domain-specific PCK is located in the figure just below the general PCK and is distinctive because it focuses on one specific domain within a particular discipline. For example, chemistry teachers might use a laboratory for explaining the process of evaporation, whereas biology teachers might use the laboratory for elaborating the phenomena of transpiration. In this example, both groups of science teachers are using science laboratories within the disciplines of science, but their teaching objectives, purposes, topics, and scientific apparatus are specific to the domain in which they are teaching. In their study, Magnusson et al. (1999) labeled this category topic-specific PCK.

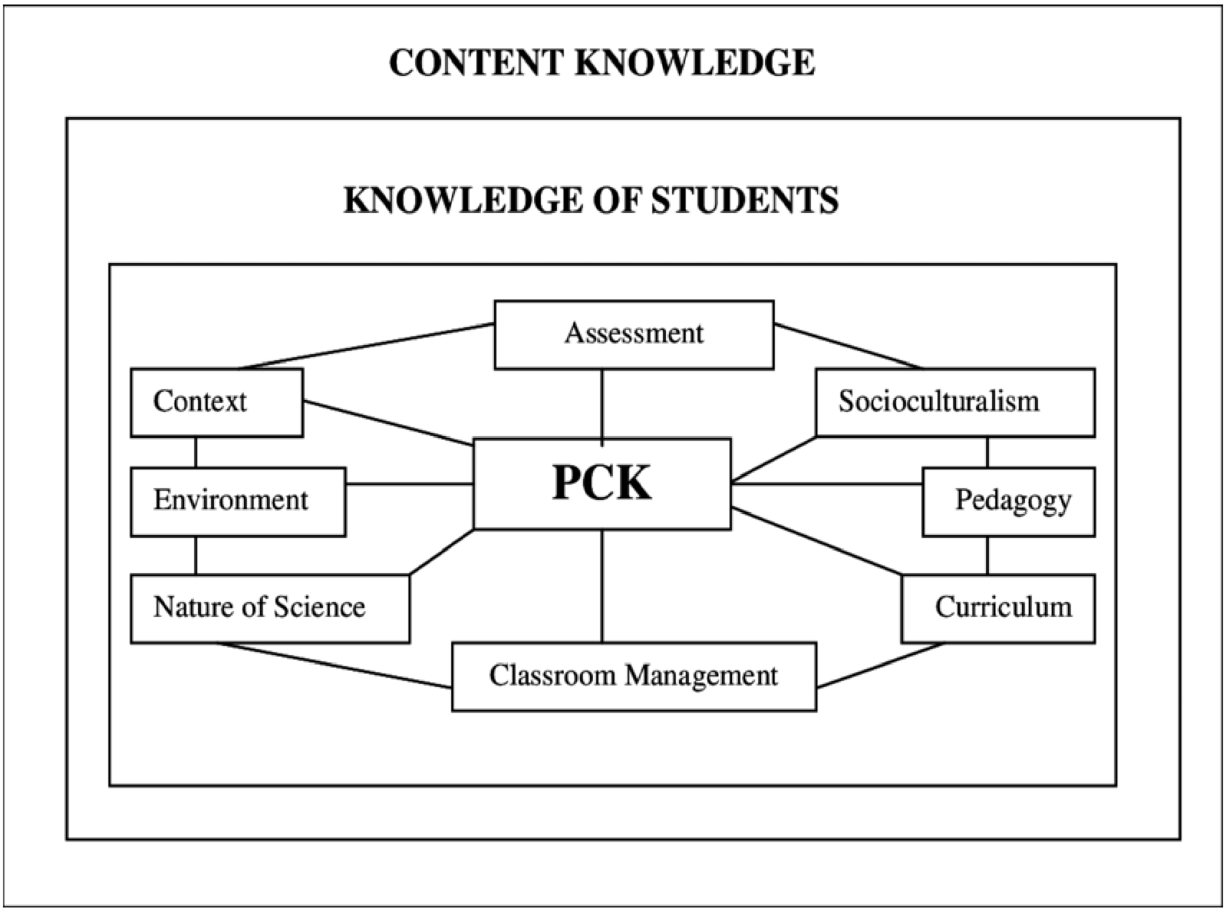
Topic-specific PCK is the most specific of all levels of PCK. It is associated with teaching a specific topic, for example, Acid and Base, Ionic Chemistry, Cell Division, the Laws of Motion, and so on. Supposedly, this level of understanding is perceived as being more valuable PCK to teaching knowledge, as it is considered that a teacher has in-depth knowledge of topic-specific PCK that could represent a repertoire of skills and abilities to teach a concept (Veal & MaKinster, 1999). In detail, each subject is different in relation to its teaching and learning aspects, particular topics, concepts, and terms. Furthermore, some of these phenomena might overlap with the phenomena of other domains; for instance, when the idea of diffusion in chemistry deals with the nature of particles or ions, whereas in biology the same concept deals with the movement of particles or ions, while in physics, it deals with the size and morphology of particles. This is to say, that overlapping topics have a different purpose and function within the domain. Or put more simplistically, different concepts require a different set of teaching objectives, assessment methods, planning strategies, and teaching skills. Therefore, PCK always represents an amalgamation of specific knowledge in which teachers construct topic-specific PCK, particular skills, and planning strategies to serve the best learning for students.

PCK at the center in the above figure indicates its significance and the surrounding attributes are all connected and represent an integrated nature of its epistemological components (Veal & MaKinster, 1999). The explicit hierarchical structure of PCK shows that teachers have strong topic-specific PCK if they have both strong domain-specific PCK and strong general PCK. The attributes of this taxonomy do not imply there is a linear progression of knowledge development and integrations of PCK levels. Consequently, it is possible to explain these attributes of taxonomy by presenting a bird's-eye-view and side-view (Veal & MaKinster, 1999) of the above Figure 2.1. These views are shown below in Figures 2.2 and 2.3.

Veal and MaKinster claim that when a teacher develops a better understanding of their respective students, then they are able to use any of the other eight teaching attributes (assessment, context, classroom management, curriculum, environment, nature of science, pedagogy, or socio-cultural); all of which are interlinked (Figures 2.2 and 2.3). This inter-relationship of attributes supposes that the development of one attribute can trigger the development of other knowledge (Veal & MaKinster, 1999); a point that illustrates the dynamic nature of the hexagonal linkage when assuming a bird's-eye-view of this taxonomy. In summary, teachers with strong content knowledge and knowledge of their students should be able to develop the ability to integrate these eight attributes in a coherent manner when teaching. In this model, one attribute has a direct link with two others, such as assessment is linked with context and sociocultural but has no direct link with the other six. But, a teacher's PCK may provide a web channel to connect all attributes, therefore developing one of the components of PCK could support all other six attributes.

Figure 2.2

Bird's-Eye-View of General PCK Taxonomy

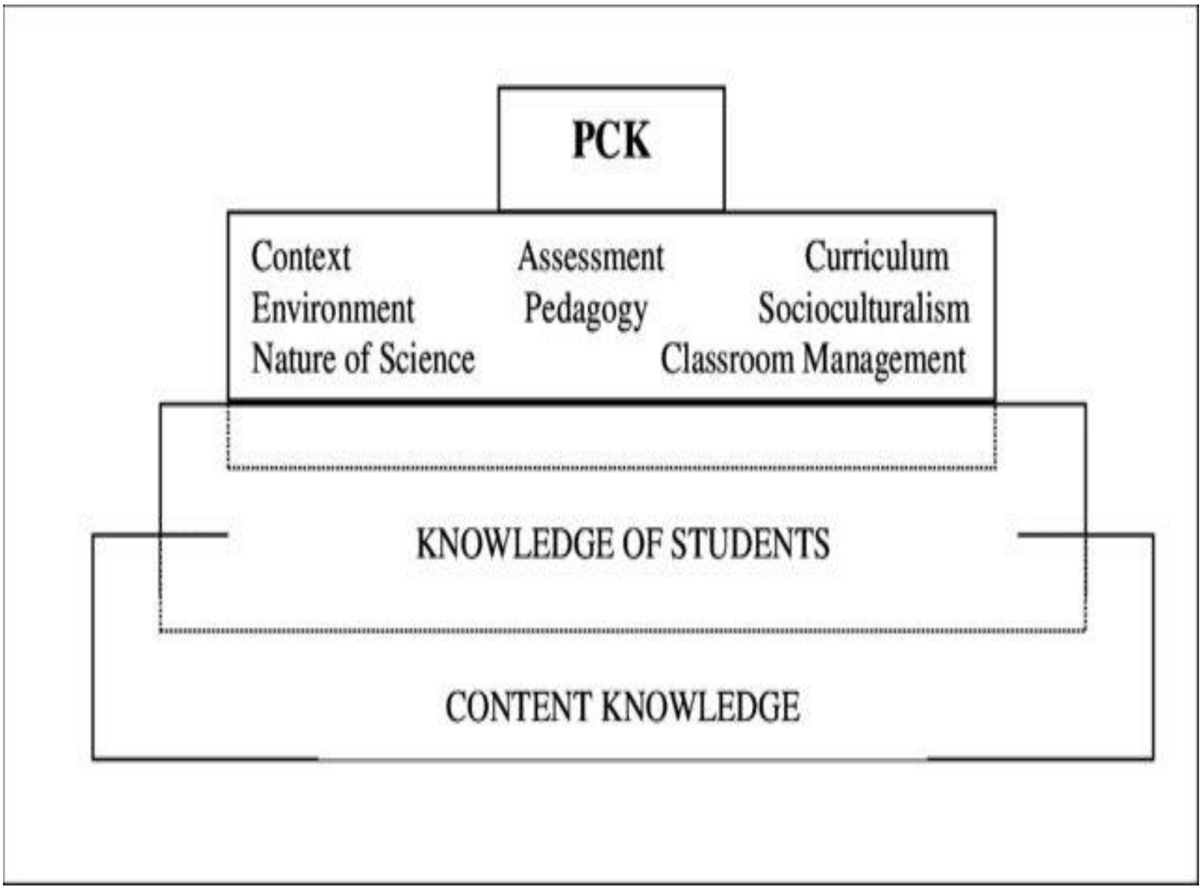


Note. This figure was produced by Veal and MaKinster in 1999 (Veal & MaKinster, 1999, Discussion section, para. 14) to show eight teaching attributes that are interlinked. The figure is reprinted with the permission of the author [William R. Veal].

The above figure shows that Content Knowledge and Knowledge of Students provide a foundation for the development of teachers' PCK. The side view of the figure portrays (Figure 2.3) that the Knowledge of Students is embedded in Content Knowledge. According to Veal and MaKinster (1999), knowledge of students should include teachers' understanding of their students' possible errors and misconceptions. Teachers' understanding of students makes it easier for a teacher to recognize misconceptions and errors in students' thinking.

Figure 2.3

Side-View of General Taxonomy of PCK



Note. This figure was produced by Veal and MaKinster in 1999 (Veal & MaKinster, 1999, Discussion section, para. 14). The figure is reprinted with the permission of the author [William R. Veal].

The interconnections of PCK attributed within the taxonomy promotes the idea of continued development in teachers' knowledge through their career development; a process which in turn strengthens PCK. Veal and MaKinster (1999) claimed that the PCK taxonomy permits the possibility of an operational definition of PCK: "Pedagogical Content Knowledge is the ability to translate subject matter to a diverse group of students using multiple strategies and methods of instruction and assessment while understanding the contextual, cultural, and social limitations within the learning environment" (Veal & MaKinster, 1999, Discussion section, para. 19). Veal and MaKinster used the term 'ability to translate' instead of 'transform' as used by Shulman (1987). The term 'ability to translate' appears to refer to the teachers' content adjustment according to their students.

In a nutshell, this taxonomy provides a view of PCK levels and their relationship. These levels are arranged from general PCK to topic-specific PCK while pedagogy provides a base to all levels. The Bird's-eye-view of this taxonomy indicates the eight attributes of teaching which are interlinked to each other and linked with PCK. The side-view shows the embeddedness of knowledge components.

I discussed the taxonomy before discussing PCK models because it presents a view of PCK levels, teaching attributes, and their relationship which help to understand each model. Researchers have developed diverse models of PCK to explore its tacit and complex nature, its potential impact on classroom practice and student outcomes. Each model has contributed to understanding the concept of PCK and its components. The following sections describe some of the models with which this study is concerned.

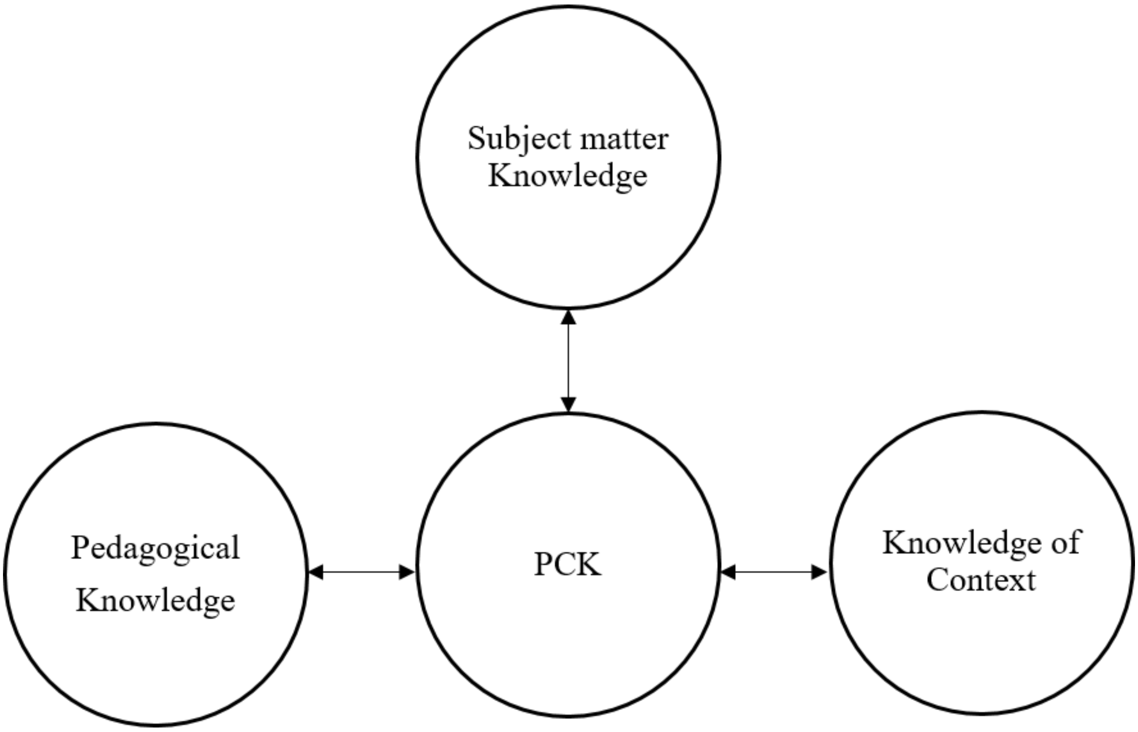
2.3 PCK Models

A conceptual model is a systematic description of a complex phenomenon that presents the core characteristics of a phenomenon and demonstrates a relationship between various aspects. The process of production of models is a reliable practice of science because the construction of models is a way to express thinking, knowledge, and results of research (Gilbert & Justi, 2016) in a very precise arrangement. The first diagrammatic model of PCK was presented by Shulman's doctoral student Grossman (1990), which then spurned the development of various other conceptual models of PCK. All these models have tried to explain PCK by developing the idea of the concept. The most relevant models used in this study are discussed in the following sub-sections, with special attention given to describing what each model has contributed to my understanding of PCK that develop my critical and comparative thinking to review one model to another, particularly, development of the first PCK Consensus Model (CM).

Diagrammatically, PCK was not first presented by its conceptual founder Shulman. However, Shulman identified PCK's three essential components: Subject Matter Knowledge, Pedagogical Knowledge, and Knowledge of Context. Initially, PCK was conceptualized as always representing content, and formulating the subject to make it understandable to students' and teachers' understanding of what makes the learning of specific topics easy or difficult. Van Dijk and Kattmann (2007) later presented Shulman's idea in diagrammatic form by using Shulman's essential components, as shown in Figure 2.4.

Figure 2.4

Shulman's (1986) Notion of PCK Presented as a Unique Knowledge Domain



Note. This figure was produced by Van Dijk and Kattman in 2007 (p. 889) to represent Shulman's idea of PCK through a diagram. The figure is reprinted with the permission of the author [Ulrich Kattmann].

The above Figure depicts how Subject Matter Knowledge, Knowledge of Context, and Pedagogical Knowledge all contribute to PCK, even though there is no direct relationship shown between these components. According to this model, the concept of PCK revolves around what teachers know about, and how they think their students learn best. However, this model does not include some aspects of teaching practices, such as a teacher's self-efficacy or self-confidence or skills, such as using feedback for improving classroom practice. Kind (2015) noted that these aspects are important when learning to teach, as teachers must be resilient, reflective, and able to provide and respond to feedback during the process of establishing a good quality practice. Kind quotes Shulman, saying that "Shulman himself noted that his model lacks recognition of non-cognitive attributes, such as self-efficacy and self-confidence" (Shulman, 2012, as cited in Kind, 2015 p. 180). de Sá Ibraim and Justi (2019) argue that Shulman (2015) highlights four limitations to his primary notion of the concept of PCK: First, the construction of PCK was proposed without considering non-cognitive aspects like teachers' feelings, affection, motivation, etc. Second, PCK did not consider the use of teachers' skills during the action of teaching in the classroom. Third, PCK was also not discussed as an aspect related to the social and cultural context. Lastly, PCK did not include aspects associated with students' outcomes, or put simply, PCK does not discuss the products of teaching. Regarding this, Shulman (2015) acknowledged that teaching must be positioned in the subject, as well as the personal, cultural, and social contexts. This is to say, contexts such as these must be considered when constructing an applicable model of PCK.

While the first diagrammatic exercise of a PCK model attempted to explain its components in detail through reference to the original idea, the upcoming section involves a discussion of this model.

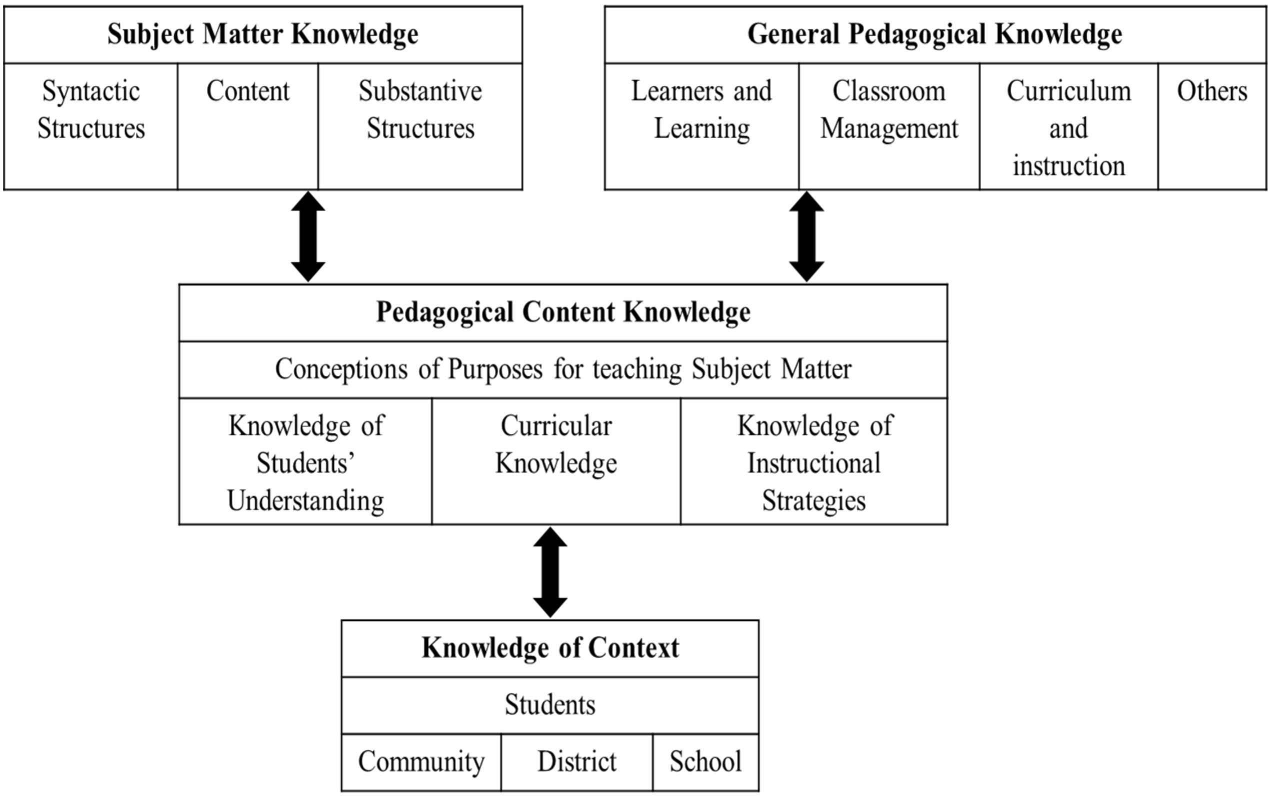
2.3.1 *Grossman's model for PCK*

PCK developed in Shulman's thinking after making a combination of findings during two research projects. These findings supported the notion that there should be a theoretical base and not just a possibility of mixing knowledge components. Lederman and Gess-Newsome (1992) equated this theoretical idea with gas law in chemistry, in that gas law does not perfectly describe the behavior of real gas in a system, just as, Shulman's proposed PCK does not characterize the knowledge demonstrated by a teacher in a real classroom teaching situation. Because gas law has its value in chemistry when explaining the behavior of gas, the importance of which we cannot ignore, the same can be said of the theoretical concept of PCK and the importance this concept acquires in education.

Grossman (1990), a scholar who adopted PCK during the germinating stage of its development, presented a PCK model using the original concept as explained by Shulman. Although her proposition about the knowledge of the organization of PCK was different from Shulman's knowledge, her model (see Figure 2.5) also explains the relationship between knowledges and their development (de Sá Ibraim & Justi, 2019). Grossman emphasized the following four general areas of teacher knowledge: subject matter knowledge (SMK), general pedagogical knowledge, knowledge of context, and pedagogical content knowledge (PCK). This model elaborates more deeply on the nature of teacher knowledge, its impact on PCK, and its relationship with other knowledge; meaning that PCK can be considered to be the centerpiece of this model, as shown in Figure 2.5.

Figure 2.5

Grossman's Model of Teacher Knowledge



Note. This figure was produced by Grossman in 1990 (p. 5) to show further division of PCK components that discussed by Shulman in 1986. The figure is reprinted with the permission of the author [Pam Grossman].

Figure 2.5 illustrates the nature of the relationships that the four knowledges share and do not share. Each knowledge is categorized into further subcategories. The subject matter knowledge, general pedagogical knowledge, and knowledge of context share no direct link to each other and are rather connected through PCK. Consequently, development in one element of knowledge may influence PCK (de Sá Ibraim & Justi, 2019).

Subject matter knowledge is referred to here as teachers' knowledge for science teaching, which is furthermore broken down into teachers' content knowledge, syntactic [the set of ways in which validity or invalidity in a subject are established] and substantive structures [a variety of ways in which basic concepts of the discipline are organized as facts]. This knowledge in the teaching process includes the content representation to students by supporting syntactic and substantive structures.

Another element in this model is teachers' general pedagogical knowledge, which is referred to as the knowledge teachers have of general teaching. Grossman deconstructed science teachers' knowledge such that it is understood to involve classroom management, curriculum and instruction, students and learning, and others as shown in the Figure. 'Others' refers to any potential teacher knowledge for general pedagogical knowledge, for instance, teachers' knowledge concerning the use of materials for teaching, lesson planning, etc. Classroom management is understood to be a key component of this knowledge.

Knowledge of context is another constituent element of PCK in that it deals with the set of knowledges that assists in the building of PCK. This component includes the knowledge of the community, the district, the school, students, expectations, and constraints. Knowledge of students is the key in the construction of the knowledge of context and all these subcategories have a link with teachers' knowledge.

This model embraces PCK as a central component of the purposes of teaching. PCK itself is divided into three further knowledges: Knowledge of student understanding, curricular knowledge, and knowledge of instructional strategies. Knowledge of student understanding refers to teachers' knowledge about students' understanding of specific content that can be learned. Curricular knowledge refers to goals, objectives, etc. discussed in the curriculum. Knowledge of instructional strategies deals with teachers' use of the teaching methods when working with a concept.

This model does not indicate a direct relationship between subject matter knowledge, general pedagogical knowledge, and knowledge of context. The two-headed arrows between the areas of teacher knowledge and PCK in this model may indicate that these links are reciprocal and influence one another. Grossman suggested that knowledge, beliefs, and goals for teaching science influence other knowledge components in establishing PCK (de Sá Ibraim & Justi, 2019).

The early models had not developed the concept of PCK in the entirety of its more contemporary form but their contributions are a valuable treasure to understanding the development of the concept. A model then reshaped the PCK concept due to its unique features. This model is discussed in the next section.

2.3.2 *Magnusson, Krajcik, and Borko's model for PCK*

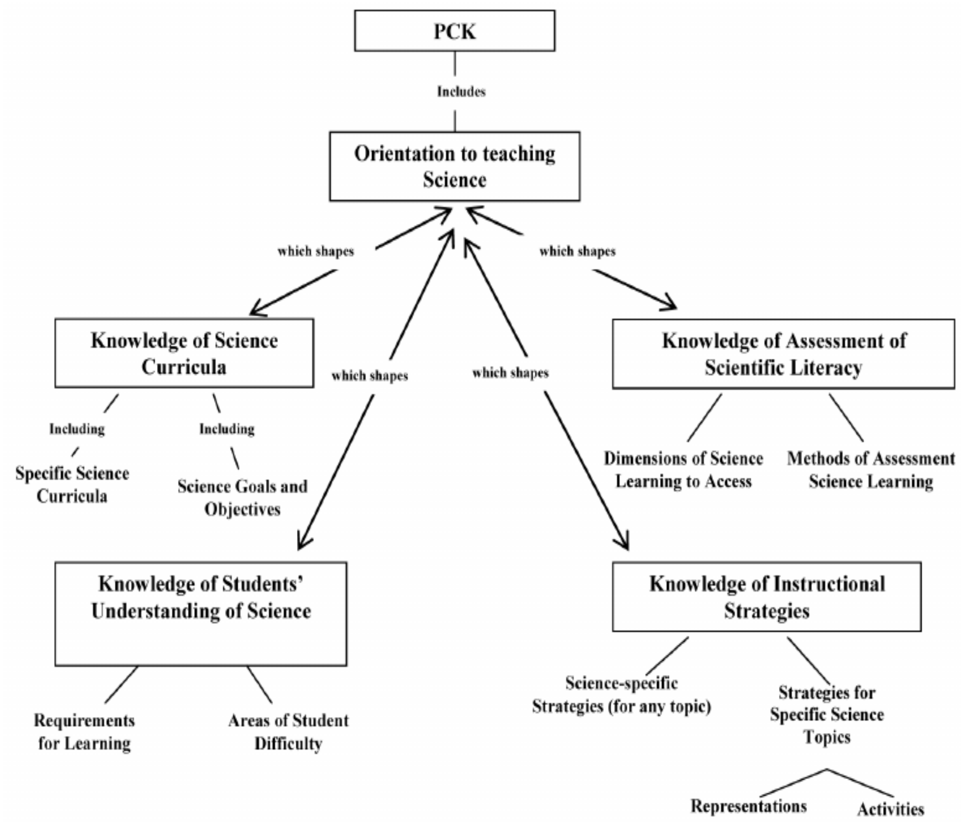
Even though many models of PCK now exist, one model that is cited in PCK research more than others is the model developed by Magnusson, Krajcik and Borko (1999). This model discusses the specificity of teachers' knowledge and its transformation for teaching. The upcoming paragraphs of this subsection explain each aspect of this model and its relation to PCK.

Magnusson et al. (1999) considered PCK to be "the transformation of several types of knowledge for teaching" (p. 95). Furthermore, they discussed that while teachers formulate PCK through engagement with different pieces of knowledge, subject-specific knowledge is the major contributor to this development. PCK refers to the teacher's own understanding of the criteria according to which the specific topic can be made understandable to learners (Magnusson et al., 1999). In this way, the teacher develops their teaching skills relative to their scientific or general skills (e.g. by generating subject-related questions in class, assessment actions, constructing new ideas, analysing the classroom situation, through the use of context, etc.). Magnusson et al. (1999) also underlined that PCK should include how teachers organize issues and problems related to the particular subject matter of a topic, through adapting to the various interests and abilities of students.

This model originated from hybridization of ideas about PCK that were developed by Shulman (1986) and Grossman (1990). Friedrichsen, Driel and Abell (2011) claim this model is heavily based on Grossman's (1990) work, while the terminology is borrowed from work done by Anderson and Smith (1987). Magnusson et al's model, shown in Figure 2.6, includes the five major components: orientations to teaching science, knowledge of science curriculum, knowledge of students' understanding of science, knowledge of assessment of scientific literacy, and knowledge of instructional strategies.

Figure 2.6

PCK Model for Science Teaching



Note. This figure was produced by Magnusson et al., in 1999 (p. 99). The figure is reprinted with the permission of the publisher.

Magnusson et al. (1999) suggest that *orientation to teaching science* should be the main element of PCK and that all other components are connected to PCK before becoming part of it. Actually, this component – orientation to teaching science – is an alternative terminology to Grossman's (1990) "conceptions of purposes for teaching subject matter" (p. 99). According to Magnusson et al. (1999), the orientation to teaching science has to do with "the knowledge and beliefs possessed by teachers about the purposes and goals of teaching science at a particular grade level […such that] the orientations are generally organized according to the emphasis of instruction" (p. 97). Teaching orientations work as 'conceptual maps' guiding the teacher when setting learning objectives, engaging with curricular materials, and evaluating students' learning (Magnusson et al. 1999, p. 97). While this orientation to teaching shapes the other knowledges, Magnusson et al. (1999) do not explain how this component actually shapes the other knowledges.

Magnusson et al. (1999) gathered orientations to teaching from previous studies and presented each orientation in relation to two components of teaching: the first being, ‘the goals of teaching science’ and the second being ‘typical characteristics of the instruction’. These researchers identified nine orientations: (1) activity-driven, (2) didactic, (3) discovery, (4) conceptual change, (5) academic rigor, (6) process, (7) project-based, (8) inquiry, and (9) guided inquiry. In contrast, Talanquer, Novodvorksy and Tomanek (2010), identified only three orientations toward teaching: (1) motivating students, (2) process, and (3) activity-driven. The orientation, ‘motivating students’ is an additional factor to Magnusson et al.’s list. Friedrichsen and Dana (2005) point out that investigating orientations toward teaching is convoluted in teaching practice because teachers often hold multiple goals. In this model, ‘orientation to teaching science’ is depicted as an overarching component. Furthermore, teaching orientation connects with two-way arrows with the other four knowledge components. It shows that it shapes and is shaped by the other elements in the model. These connections are described as “shaping” but there is no explanation for what “shaping” means in their original paper (Friedrichsen et al., 2011, p. 366). Magnusson et al. (1999) discussed nine teaching orientations under one concept that depicts the complexity of orientation. This complexity brings complications in sorting out which particular teaching orientation shapes teachers’ PCK in particular teaching.

In this model (Figure 2.6), *knowledge of science curricula* refers to teachers’ understanding of the sequencing of the scientific concepts, goals, and objectives that support student learning. It is further divided into two categories: knowledge of goals and objectives, and knowledge of specific curricula. Knowledge of goals and objectives embraces the teachers’ understanding of what students know about a particular subject and the concepts this subject uses and what learners are expected to learn in the coming years. The second subcategory covers the knowledge teachers have of the programs and materials that are relevant to teaching a particular subject and specific topics within a subject.

Knowledge of students’ understanding of science refers to the knowledge a teacher has about learners’ understanding of specific concepts. Magnusson et al. (1999) split this component of the concept of PCK into two categories: requirements for learning, and areas of student difficulty. The first category includes teachers’ knowledge and beliefs about student prior knowledge about specific scientific learning, and knowledge of abilities and skills that students might need. Knowledge of student’s learning difficulties relates to teachers’ knowledge of the science concepts that students will find difficult to learn. The teacher asks questions of themselves about how to investigate the reasons for these difficulties. Such questions might be, why do students feel their learning is difficult? What factors make learning difficult, etc.? The answers to these questions help teachers to understand students' difficulties when learning specific concepts. There are different reasons that make a concept difficult for students, for instance, the lack of connection students might have to find with real-life experiences or poor prior learning in a particular concept. The teacher needs to be knowledgeable about the area of students' difficulties (Magnusson et al., 1999) for effective teaching to take place but there is no certainty that teachers, who have a mastery of the content, will have the ability to solve students' difficulties. Knowledge of specific areas of difficulties draws a line between content experts and expert teachers.

Knowledge of assessment seems to be a new addition to the PCK model at this point. Friedrichsen et al., (2011) highlight that the importance of assessment to PCK is derived from Tamir's (1988) work, and including it as part of PCK is the contribution of this model. Magnusson et al. (1999) categorize this element into subparts: 'dimensions of science learning to assess' and 'knowledge of methods of assessment'. The first category links aspects of teachers' knowledge to assessment of students' learning. The 'knowledge of methods of assessment' addresses teachers' knowledge about methods of assessment and the utilization of these methods when teaching.

Knowledge of instructional strategies consists of two significant sorts of knowledge in this model: Firstly, there is knowledge of subject-specific strategies, which has to do with teachers' abilities to use general teaching strategies when teaching any topic. Secondly, there are science-specific strategies that deal with teachers' knowledge and ability to present a specific concept or initiate a specific activity. The science-specific strategy is aligned with teachers' knowledge of topic representation (topic-specific representation) and teachers' knowledge of activities (topic-specific activity), both of which help develop students' learning of particular science concepts. Topic-specific representation comprises teachers' knowledge of ways of representing particular concepts to improve student understanding and awareness. It also includes knowing the strengths and weaknesses of the adopted teaching method for particular content. Various studies report that limited knowledge of topic-specific representation can negatively impact science teaching (Magnusson et al., 1999). For this reason, a teacher should be knowledgeable about when there is the need to choose the appropriate method for teaching a specific concept. The topic-specific activity refers to teachers' knowledge of conceptual understanding of the specific scientific activity, why this activity is important for students at a particular level, the extent to which an activity fits in a topic, and to clarify information about specific concepts or relationships within an activity.

The components of this model are presented as if they were tree roots that have not interlinked with each other. A recent study conducted by Barendsen and Henze (2019) used the four knowledge elements of Magnusson's PCK model to examine the interconnectedness between these elements, as the basis of their analysis of teacher interview responses and classroom observations. Barendsen and Henze were interested in how these interconnections might influence the quality of a teacher's PCK. These researchers found that some elements have strong interconnections while some have weak interconnections, while others exhibit a lack of any interconnectedness at all. A strong interconnectedness was noted between knowledge of science curricula and knowledge of instructional strategies, and a strong interconnectedness was observed to exist between knowledge of students' understanding and knowledge of assessment, while a moderate interconnectedness was found to exist between knowledge of students' understanding and knowledge of instructional strategies. In contrast, there was no or a weak interconnectedness between knowledge of science curricula, knowledge of students' understanding, and knowledge of assessment.

Some researchers have highlighted the topic-specific nature of PCK such as Magnusson et al. (1999) who included 'strategies for specific science topics' under the 'knowledge of instructional strategies. Veal & MaKinster (1999) also indicated toward this level of PCK. The next model that is discussed involves an attempt to bring detailed clarity to this topic-specific nature of PCK.

2.3.3 *Mavhunga and Rollnick's model of Topic-Specific PCK*

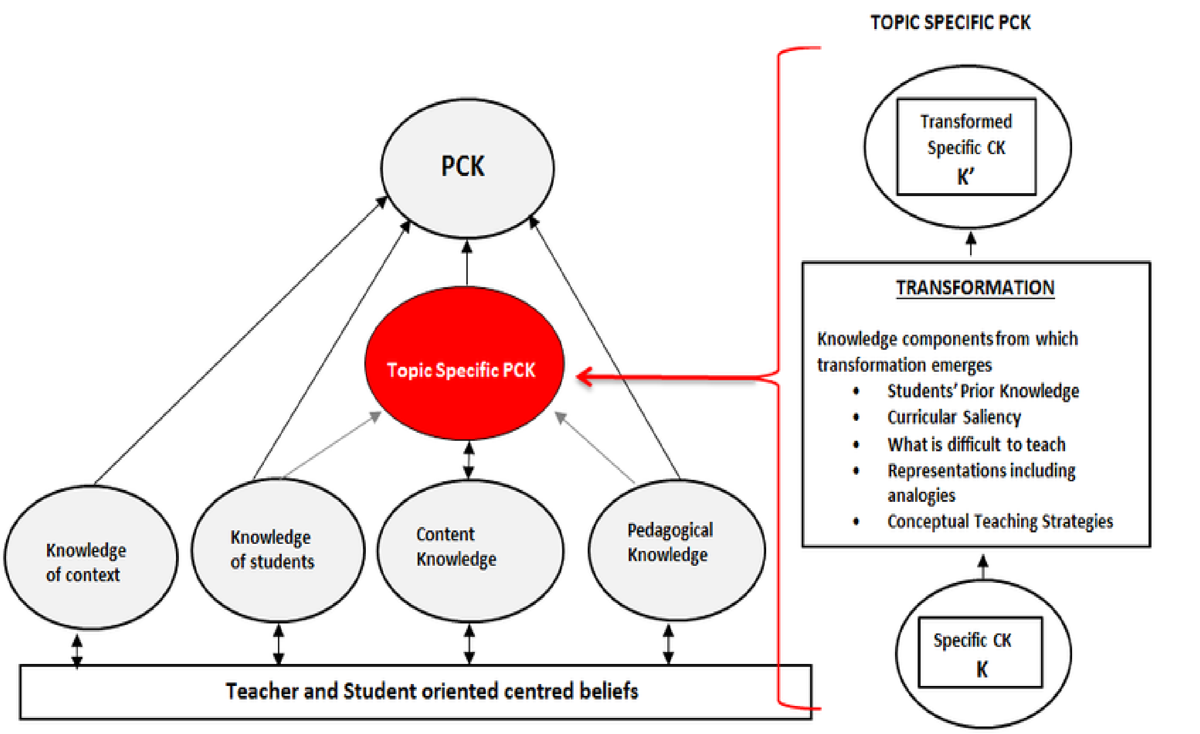
Researchers like Loughran, Mulhall, and Berry (2004), Magnusson, Krajcik, and Borko, (1999), Park and Chen, (2012), van Driel, Verloop and de Vos (1998), and Veal and MaKinster (1999) have all noted the topic-specific nature of PCK in their studies and yet none of them have explained this aspect in any particular depth. Mavhunga and Rollnick (2013) came up with a Topic-Specific PCK (TSPCK) model that elaborates on the detail of what the PCK concept and practice comprises. The remaining portion of this section is taken up by providing a detailed explanation of the TSPCK model.

Mavhunga and Rollnick (2013) elucidated specific PCK in the same way as Shulman did in his original concept: the ability of a teacher to transform the knowledge of a specific topic when teaching and for the benefit of student learning. Mavhunga and Rollnick (2013) claim that their model is different from that of other PCK models because other scholars suggest that PCK elements refer to teachers' knowledge at the level of the discipline, while Mavhunga and Rollnick's model illustrates their understanding of PCK at the topic level. This means that, for instance, teachers' knowledge at a generic level, such as teaching orientation, is not part of it. de Sá Ibraim and Justi (2019) presented their point of view, this model has an advantage over other PCK models in terms of investigating teachers' PCK in teaching situations.

Mavhunga and Rollnick's model (Figure 2.7), combines a 'multitude of particular things' which have been identified by Geddis (1993) and four teacher-knowledge domains which were derived from the work of Davidowitz and Rollnick (2011), (as cited in Mavhunga & Rollnick, 2013, p. 115). The aforementioned 'multitude of particular things' for teaching is displayed on the right side of the model in a rectangular box. These things include Learners' Prior Knowledge, Curricular Saliency, What is difficult to teach, Representations, and Teaching Strategies.

Figure 2.7

Model of Topic Specific PCK



Note. This figure was produced by Mavhunga and Rollnick in 2013 (p. 115) to show the construction of Topic-Specific PCK. The figure is reprinted with the permission of the author [Elizabeth Mavhunga].

Mavhunga and Rollnick (2103) considered ‘particular things’ as content-specific components in their study. The right side of the Figure shows that specific Content Knowledge [represented by K] is developed into Transformed Specific Content Knowledge [represented by K’] through passing through Topic-Specific PCK components: Learners’ Prior Knowledge, Curricular Saliency, What is difficult to teach, Representation, and Teaching Strategies. This transformation from K to K’ needs teachers’ ability of transformation that was indicated by (Shulman, 1987) as “the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful” (p. 15). For instance, if we use the thinking from the right-hand side of this model in a teaching situation, when a teacher is teaching a concept (for example, organic chemistry). A teacher needs to use their content knowledge in general [how to teach chemistry], identify big ideas in the topic, but the teacher is also required to consider the specificities related to this topic, for example, students’ prior knowledge regarding a particular concept. Furthermore, the teacher needs to consider several possible effective styles of representation of the concept.

Additionally, the right-hand side of the model consists of Topic Specific PCK Components while the left-hand side shows the construct of TSPCK and describes how TSPCK results from the transformation of Content Knowledge. The four knowledge domains [Knowledge of Context, Knowledge of Students, Content Knowledge, and Pedagogical Knowledge] have been borrowed from the conceptual work of Davidowitz and Rollnick (2011), which itself was originally suggested by Grossman (1990) in her model. According to Grossman, these knowledge bases are influenced by a teacher and student-oriented beliefs concerning science teaching and learning, which is to say, the conceptual arrangement on the left side of this model is grounded by beliefs. On the left side of the model, Pedagogical Knowledge, Knowledge of Students, and Knowledge of Context play a direct role in the development of PCK but do not show their direct relationship with topic-specific PCK. In other words, that knowledge develops teachers’ PCK but is not involved in the development of topic-specific PCK. On the other hand, a teacher can tailor the Content Knowledge to develop Topic-Specific PCK, which is then developed into PCK. Knowledge of Students and Pedagogical Knowledge are thought to have an influence on TSPCK, hence the use of light grey arrows.

Overall, this model provides an operational view of PCK in the classroom and discusses how teachers’ Specific Content Knowledge converted into Transformed Specific Content Knowledge. This model indicates that knowledge components (Knowledge of Context, Knowledge of Students, and Pedagogical Knowledge) have one-directional relationships to

PCK. Content Knowledge has a two-way relationship with Topic-Specific PCK then this Topic-Specific develops PCK. This model does not provide the detail of these relationships. It also does not discuss the relationship among knowledge components. The PCK [at the top], in this model, is not clarified for readers about its specification, is it subject-specific PCK or general PCK?

Many researchers have contributed to the development of PCK. However, a series of questions remain unanswered, a situation that resulted in a group of experts coming together for the first PCK summit in 2012. The intention of this summit was to cultivate a further understanding of PCK, its construction, and to produce an agreed definition and a new version of the PCK model. The following section involves a discussion of the impacts and outputs of this summit on the concept of PCK.

2.3.4 *Influence of first PCK summit on PCK notion*

Some researchers (for example Grossman, Magnusson) have presented models of PCK that have considered the transformative nature of PCK. However, others hold that PCK acts in an integrative way. PCK researchers have not formed a consensus on a single definition of PCK and its model because they cannot agree on whether PCK is *personal* or *canonical*. There has been no agreement among researchers about what components or (sub) categories should be included in PCK. Hashweh (2005) said that, in many PCK studies, several components have been described in an isolated or static way, leading to the concept being approached in a fragmented way. Therefore, the main purpose of the PCK summit was to bring PCK experts into one room to discuss the nature of PCK and to present a clear vision of PCK for future researchers. Below, I discuss the aims, outlines, and outcomes of the first PCK summit.

Despite three decades of research on PCK and the dissemination of invaluable educational documents all over the world, there remains a long-standing debate on some questions regarding PCK. For example, is PCK canonical, collective, or personal? Does PCK have a transformative or integrative nature? Is it tacit or explicit? The first PCK summit was convened in order to find the answers to such questions. The summit was held in Colorado Springs, Colorado, USA, and brought together 22 experienced PCK researchers from all over the world. These researchers presented their studies and understanding of the key concepts over six days at a retreat that examined the notion of PCK with the intention of "explore[ing] the potential for a common model for how PCK research was to be understood, conducted, and interpreted" (NARST, 2013). The following questions were discussed:

1. What is PCK? A knowledge base, a skill set, a disposition, or some combination? Can it change?
2. What are the elements of PCK? How are they related to each other and the other professional knowledge bases for teaching?
3. How can PCK be measured/captured? Paper and pencil? Observation? Interview?
4. Where should the emphasis on PCK research lie in the future? As a teacher characteristic? PCK development? PCK to teaching? PCK to student outcomes. (NARST, 2013)

The PCK summit began with a presentation made by Shulman – the founder of PCK, in which he provided a reflective trajectory about the "birth of PCK" (Shulman 2015, p. 3). At that time, Shulman described the principal limitation of the primary notion of PCK and drew the attention of the summit participants about the development of a political and ideological movement to identify the teaching activity as a profession, with the purpose of "combatting the missing paradigm" (p. 9). Following this opening presentation, most participants presented their own research and perceptions of PCK, following which the summit participants divided into groups and discussed the previously articulated questions. All possible answers to the above listed four questions were the outcomes of the first summit. The remaining paragraphs of this subsection discuss the key outcomes from this first gathering on PCK.

A noteworthy outcome of this summit was that the experts present agreed on a definition for PCK. According to Gess-Newsome (2015):

> Personal PCK is the *Knowledge* of, the *reasoning* behind, and *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)
>
> Personal PCK and Skill is 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). (p. 36)

These definitions are complex but give a clear direction to researchers for the definition of individual aspects of PCK they are observing or measuring (Gess-Newsome, 2015). These definitions highlight three aspects of PCK: Firstly, PCK is an internal and personal construct, and therefore it is context-specific and cannot be generalized. Secondly, the times during which PCK is employed can be divided into two phases: PCK in planning and PCK in the classroom. The first period refers to when a teacher prepares and considers teaching strategies for classroom practice. The second period occurs during classroom practice, which is a more dynamic phase of teaching, where teachers adjust their knowledge components and skills according to students, the level of engagement of students, their questions, and the problems that arise during practice. The third aspect of this definition is produced by the way it clearly distinguishes itself from previously established definitions; it indicates the purpose of PCK for teachers is to *enhance the students' outcomes*. More significantly is the addition of skill in PCK [PCK&S], for instance, a teacher may have good content knowledge but may not have the skill to apply it, or the teacher may not have the aptitude to use feedback from classroom practice or know how to modify their own teaching practice when planning the next class.

The second most fruitful outcome of the summit was the consensus model of PCK grounded on the agreed PCK concept that is shown in Figure 2.8. This consensus model is discussed by Gess-Newsome (2015) in *Re-examining of pedagogical content knowledge in Science Education*, which was edited by Berry, Friedrichsen, and Loughran, and which is popularly known as the *Blue Book* in the PCK community. This model included different components: a set of teacher professional knowledges, skill, a teacher's amplifiers and filters, classroom practice, students' amplifiers and filters, and student outcomes. Each component of the model is interconnected with each other, with some components maintaining a static relationship with others, for example, teachers' professional knowledge, while contrarily, some components are dynamic in nature, for example, classroom practice.

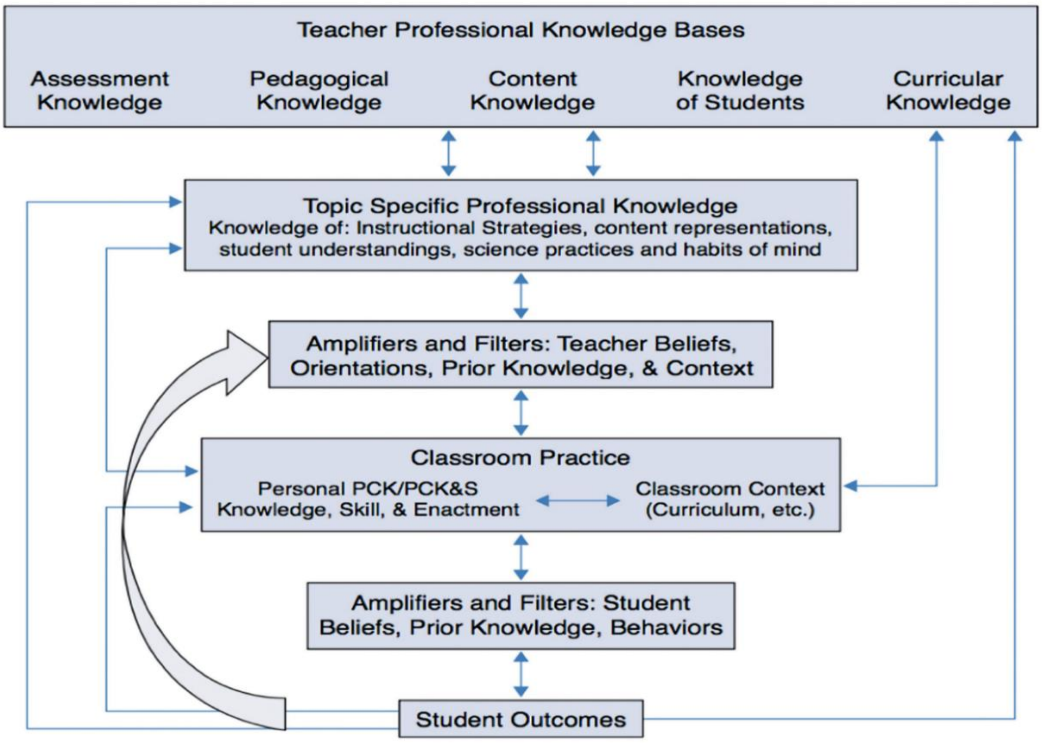
The point from which we should initiate our understanding of the model begins where the basis of teachers' professional knowledge informs topic-specific professional knowledge. When the teacher brings their base knowledge into a classroom, their interactions with students can have the potential to cause adjustments in the teacher's professional knowledge-base. In that classroom, amplifiers and filters of teacher beliefs, orientations, prior knowledge, and context, which can enhance or reduce the topic explanation and content, affect practice. The model also identifies that students come with their own understandings of some concepts, a reality which might also act as an amplifier or filter, and which might influence how students understand their teacher's knowledge. Student outcomes are not automatically the result of teacher instructions. Nevertheless, student outcomes can have the effect of mediating a teacher's thinking on classroom practice, topic-specific professional knowledge, and curricular knowledge. This model is discussed in detail in the next section.

2.3.5 *Model of Teacher Professional Knowledge and Skills including PCK*

The first PCK summit opened with a keynote by the founder of PCK, who presented some of the shortcomings related to the classical notion of PCK. This was followed by presentations of PCK experts from across the globe. The ensuing discussion, in the aftermath of the opening keynote and the presentations that followed, embraced different understandings of PCK and the possibilities of using several models to probe teachers' knowledge. During the summit, a group of experts gathered all the ideas which were nurtured in the summit. That group brought all those ideas into one model and portrayed the relationships between teaching knowledge, teaching practice in the classroom, and the students' outcomes. This model (shown in Figure 2.8) clarifies previous confusion of ideas about PCK. According to Gess-Newsome (2015), "…many previously competing or confusing ideas have been unpacked. The model identifies the overarching role of teacher professional knowledge" (p. 30).

Figure 2.8

Model of TPK&S including PCK



Note: This model was produced by PCK experts in the 1st PCK summit in 2012, and discussed by Julie Gess-Newsome (2015, p. 31). The figure is reprinted with the permission of the publisher.

This model came to be called ‘A model of Teacher Professional Knowledge and Skill (TPK &S) including PCK’. Later on, this model came also to be known as the PCK Consensus Model (Gess-Newsome, 2015). Significantly, this model provides a predictive form of thinking, enabling researchers to investigate teachers’ knowledge and their actions during the teaching process (de Sá Ibraim & Justi, 2019). Overall, the model is grounded in four foci: teacher professional knowledge bases, topic-specific professional knowledge, classroom practice, and student outcomes. All components of this model and their connections with each other are briefly described in the remainder of this section.

The top block in Figure 2.8 provides a breakdown of the generic teacher professional knowledge bases TPKB; which includes curricular knowledge, knowledge of students, content knowledge, pedagogical knowledge, and assessment knowledge. These knowledge components had already been discussed as components of PCK in previous models, but here TPKB is not a set of knowledge bases just in name but is rather a teacher’s knowledge of the practice (Gess-Newsome, 2015). From Gess-Newsome’s point of view, this would mean that assessment knowledge comprises teachers’ knowledge that contributes to the design of student assessments. In addition to this, assessment knowledge also becomes important for a teacher with respect to the need to know how to use assessment results to design or improve the next teaching practice. Pedagogical knowledge might include classroom management or student engagement, for example, teachers use instructional strategies in teaching and mobilize teaching strategies according to students' needs. Furthermore, pedagogical knowledge also encompasses knowledge of how to design a lesson plan using this knowledge.

In addition to the above, content knowledge in TPKB is understood as knowledge of the academic content of a discipline. Content knowledge also embraces how to generate knowledge when creating examples or explanations that enable a connection with core ideas in the discipline, and the recognition of crosscutting concepts. Knowledge of students includes students’ cognitive and physical development, understanding student differences, and the problem of how to enrich instructional differentiation through the use of this knowledge. Curricular knowledge might include the knowledge of curriculum goals and objectives, the role of scope, and teachers’ ability to assess a curriculum for the implications (Gess-Newsome, 2015). The aforementioned linkage between the components of TPKB shows that the concept is both an influence and is influenced by the topic-specific professional knowledge base and classroom practice. Besides, in the model, TPKB shows an indirect relationship with student outcomes, on the other hand, student outcomes have a direct influence on TPKB.

Topic-specific Professional Knowledge (TSPK) refers to teachers' knowledge about the teaching of a specific topic. Gess-Newsome (2015) describes this category of knowledge as one that encompasses teachers' identification of what will be effective instructional strategies. For instance, the teacher might identify such strategies as selecting valid content representations, organizing content to use as specific examples to build ideas, teachers' understandings about students' understandings of particular science concepts, and the nature of science within a particular scientific concept or topic. By nature, TSPK is canonical and developed from professional experience. Furthermore, it consists of personal knowledge and skills that make this model distinctive from other models. Canonical PCK refers to the same as canonical science knowledge that exists external to a teacher and available in books and other forms [for example, lesson plan, textbook, teacher notes] (Smith et al., 2017).

This model attracts attention to bringing TPKB and TSPK under one umbrella (PCK) and they may combine to create implications in the classroom. TSPK has a direct influence on, and is influenced by, TPKB in instances that have to do with, for example, teachers' amplifiers and filters, and classroom practice. For this reason, double-headed arrows are drawn between them. TSPK has a direct relation with classroom practice which shows that specific lesson teaching is based on the abstraction of TSPK from TPKB. According to this model, classroom practice contributes to developing teachers' TSPK and TPKB. Arrows show that student outcomes also play a role in the development of TSPK and TPKB.

TSPK is linked to classroom practice as a consequence of it passing through teachers' amplifiers and filters and those agencies or stimuli that may amplify or filter the concept in the teachers' experience. According to Gess-Newsome (2015), teachers can accept, reject, or modify new knowledge or skills and practice as a free agent in the classroom. Teachers' amplifiers and filters included teachers' beliefs, orientations, teachers' schooling or prior knowledge, and the context in which they are teaching. These aspects of teacher knowledge might amplify or filter the teaching practice in the classroom, which explains why it is located just above the classroom practice. Teacher orientations and beliefs also appeared in some previous PCK models (e.g. Magnusson et al., 1999; Mavhunga & Rollnick, 2013) but here, teacher orientations and beliefs include a wider range of factors and are conceptualized as teachers' amplifiers or filters might be considered as a contribution of this model.

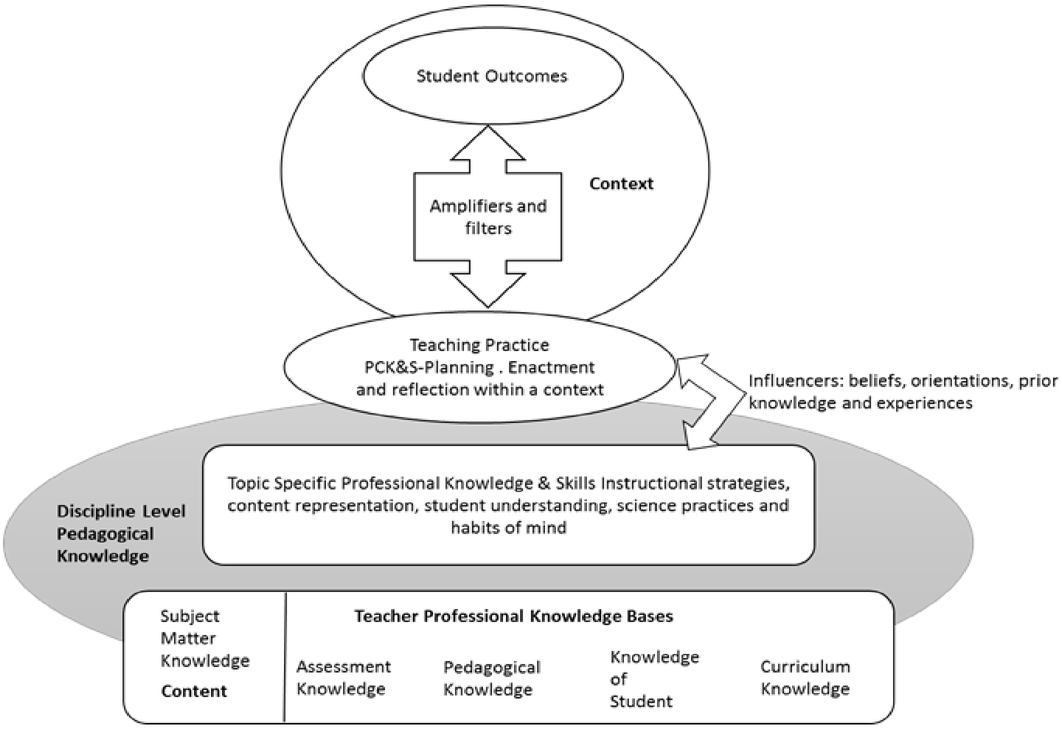
In this model TPKB and TSPK seem context-free, visible, clearly identified as knowledge bases, and relatively static; contrary to dynamic classroom practice and a contextually-bound component. For example, teachers' personal PCK interacts with classroom contexts, meaning it might be possible for teachers' actions to be planned or stimulate responses to something unexpected in the classroom. The location of this element (classroom practice) in the model indicates the existence of direct interactions with each element. Many researchers have argued that teachers' PCK was developed by experience in the classroom (e.g. van Driel et al., 2002; Magnusson et al., 1999; Neumann et al., 2019; Park et al., 2018).

Classroom practice influences student outcomes and vice versa, while students' amplifiers and filters play a role in students' own achievement or learning. These amplifiers and filters include students' beliefs, prior knowledge, and behaviors, such as those mentioned in this model. My point of view as a teacher is that these factors that influence student outcomes may be either external or internal. The external factors may include socioeconomic status, parental involvement, peer relations, etc., while internal factors may refer to memories, motivation, the ability to pay attention in the learning context, etc. The two-headed arrow between classroom practice, and students' amplifiers and filters shows that these amplifiers and filters not only affect the student learning, but they also influence what occurs in classroom practice, for instance, student behavior and learning, whether student attitudes are supported or suppressed by teachers' motivations, teaching strategies and the selection of the instruction method.

In 2016, a group of researchers who were part of the first PCK summit, met again to renew their discussion on their understanding of PCK. The underlying intention of this meeting was to interpret or revisit the outcomes of PCK summit of 2012, including the consensus model. Berry, Nilsson, van Driel and Carlson presented these revisions of the PCK consensus model, in 2017, at the International Conference of the European Science Education Research Association (ESERA) in Dublin, Ireland. This revised version is shown in Figure 2.9, which organizes the elements of the consensus model in a clearer way. The position of student outcomes was interchanged with the position of TPKB and TSPK, in other words, student outcomes were put on the top of all elements while TPKB and TSPK moved to the bottom. A second change was occurring in the way the concept of amplifiers and filters were coming to be known as influencers. These changes made the first consensus PCK model more dynamic because it emphasizes the relationships among components. The TPK&S model and its revision bring a valuable change to PCK research in the classroom because this model draws attention to teachers' knowledge in real teaching situations (de Sá Ibraim & Justi, 2019).

Figure 2.9

The refined version of the PCK Consensus Model



Note. This model was developed at the 2nd PCK Summit-2016 and discussed at the ESERA-2017 conference by Berry et al. This figure prints here with permission of the presenter [Amanda Berry].

The revision of the consensus model brought some significant changes in the model. The PCK experts again came together in a second PCK summit and developed a new consensus model [The Refined Consensus Model] that is discussed later in this chapter [see section 2.3.9]. TPK &S, including the PCK model [first consensus model], was a product of the first summit and had not lost its identity after the revision and the introduction of the new consensus model, as the participants at the second PCK summit acknowledge that The Refined Consensus Model (RCM) is not a replacement of TPK&S (Carlson & Daehler, 2019).

This study intends to examine teachers' use of PCK in their classroom practice when they were teaching a chemistry topic and for this purpose, the upcoming section discusses the PCK and skills. The idea that teachers' teaching skills are part of teachers' PCK was a novel one. According to the consensus model, PCK&S includes teachers' actions during classroom practice. The next subsection discusses the concept of teachers' PCK with teaching skills, hence PCK&S.

2.3.5.1 PCK and Skills (PCK&S)

The debate about whether PCK is a piece of knowledge or practice is still under discussion but most previous models define PCK as knowledge that concerns teaching rather than concerning skills. PCK researchers have tried to connect teachers' skills to PCK. Interestingly, skills connected to PCK (PCK&S) appeared in the classroom practice block of the consensus model, but there is no indication about what particular skills. This model indicates that PCK and its related aspects may not completely unpack the nature of this concept. The reason for unpacking this concept should then concern the need for PCK researchers to conceptualize (as a set of knowledges) and operationalize PCK (in action) differently (Chan & Hume, 2019). The remainder of this subsection involves a discussion of teachers' skills and their connection with teacher knowledge, after which the potential connection of PCK and skills in the teaching process is explained.

PCK&S is conceptualized very broadly in the consensus model as 'all acts of teaching' in the teaching process. Putting it succinctly, "we recognized that what a teacher does in the classroom is also based on their PCK" (Gess-Newsome, 2015, p. 36). For clarification between skills and teachers' actions in the classroom, some questions were in my mind as a PCK investigator. For example, what teachers' actions are based on skills in their classroom practice? OR are all actions based on their skills? It might be that teachers' actions are based on teaching skills even if not *all* their actions are based on teaching skills. A review of the literature reveals that teaching skills may not embrace all acts of teaching and that besides, teaching skills are narrow and more valuable than all actions in a teaching process. For instance, in 1960, competency-based teacher education gained credibility, after that teacher competencies were tried to be related to effective teaching, and slowly the idea of teaching competency was mixed with the notion of teaching skills (Kerry & Wilding, 2004). Competencies have different features than skills, Kerry and Wilding (2004) described the skill features of an individual:

> First, skills suggest that the practitioner not only can 'perform the operation' implicit in the skill but that he/she understand the rationale for the operation. Second, to operate at a skills level suggests that the practitioner undergoes a continuous process of reflection on the effect and effectiveness of the skills being practiced. (p. 29)

Additionally, Kerry and Wilding (2004) provide a descriptive continuum that creates a cleavage between competencies and skills. They went on to state that competencies include physical processes, ends in themselves (focused on a product), self-sufficiency, isolated actions, and behaviors (behaviouristic). On the other hand, skills reflect individual intellectual processes, means to an end (understand the process), reflective, integrated actions, and constructivist phenomenon (Kerry & Wilding, 2004). This set of continua helps filter the teaching skills from all acts in the teaching practice. A teacher's use of a computer, a whiteboard, video projectors, and practical apparatus in the science laboratory falls into teaching competencies. It might be possible that teacher assistants or lab attendants use these things more accurately than science teachers. Teaching skills might also include teachers' use of rational explanations to estimate the effect of actions that might help construct concepts and influence student outcomes. The teacher skills might be visible when teachers explain concepts, generate questions to assess students, conduct observations to evaluate the context for teaching, set lesson objectives, choose the best teaching style to transform content, make constructive use of biotic and abiotic contexts, engage in decision-making, take assessment actions, provide feedback, and undertake classroom management. Therefore, teachers' actions are related to the intellectual processes involved in the construction of a concept in a specific context. Science teachers' intellectual actions for particular students, for particular contexts, for particular situations in teaching by using their PCK are indicating their PCK&S. In other words, PCK&S is an operational form of PCK; which is to say, PCK&S highlights "[a]n implication for insights into teachers' pedagogical content knowledge is that teachers' interactive cognitions display how teachers use elements of their practical knowledge in specific contexts and situations" (Meijer et al., 2004, p. 174).

There is no agreement among writers and researchers about what types of skills are necessary for teaching as it would seem "difficult to reach consensus on exactly what knowledge and skills are unique to the teaching profession, … [even though] most educators would agree that special skills are necessary and do exist" (Cooper, 2010, p. 3). Therefore, it is difficult to make a strong claim about what teaching skills are necessary skills when it comes to understanding teaching practice. Cooper (2010) considered three broad categories of teaching skills: planning, implementation, and evaluation. A plan includes teachers' skills related to the writing of instructional objectives and planning. Implementation involves teachers in teaching, possibly using questioning, differentiating instructions, culturally responsive teaching, classroom management, or cooperative learning approaches. The evaluation includes reflection on teaching action, feedback, and other forms of student assessment. All three broad skills categories involve an intellectual process and are the result of the integration of teachers' own knowledge of teaching. These three broad teaching skills are indicating the teachers' PCK&S. Cooper (2010) further elaborates:

> Teacher[s] who possess PCK can translate the content knowledge they possess into forms that have great teaching power and that meet the needs and abilities of students. Such teachers understand the central topics in each subject, those aspects that are most difficult for students to learn, and what students' preconceptions are likely to get in the way of learning. These teachers draw on powerful examples, illustrations, analogies, demonstrations, and explanations. (p. 6)

Examining the above quote more closely, a teacher with strong PCK will have a powerful ability to practice their knowledge in the teaching process, which makes a difference to teachers' expertise. Thus, PCK can be considered the key to understanding knowledge when teaching and as such the key to developing a skillful teacher in the classroom, which of course should also be seen in student outcomes. van Driel et al's (1998) study of teachers' PCK revealed that "providing teachers with a knowledge base which enables them to teach specific topics effectively and flexibly in situations … are subjected to different contextual, situational, and personal influences" (van Driel et al., 1998, p. 691). Unfortunately, previous studies on PCK focused on teachers' knowledge and beliefs and were more focused on *knowledge on use* rather than *knowledge in use*. Meijer et al. (2004), for their part, stress that teachers' interactive cognitive capacities can be useful to investigate their integrated "knowledge in use" (p. 174).

According to Cooper (2010), the planning of teaching is a skill and this is a pre-instructional skill and is considered as a key to effective teaching (Moore, 2007). While teachers plan in a variety of ways, they often engage in four basic types of planning: annual planning, topic planning, weekly planning, and daily planning (Morine-Dershimer, 2010). In addition to this, Moore (2007) explains that there is a basic seven-step planning process: determine content, write objectives, plan introduction, select instructional strategies, plan closure, plan evaluation, and re-determine content. A single teaching plan contains a set of skills to manage the teaching in advance, which need to address the following questions: What content should be taught? What are the desired learner outcomes? What is a suitable pedagogy for specific content? How to assess learning during the class? How should the lesson finish? The teaching-planning steps, as discussed by Moore (2007), reveal that teachers use different skills to plan a lesson, and undertake decision-making when planning and that these skills are purely based on the set of knowledges that teachers have. Teachers might use their PCK when making a single planning-decision, for example when a teacher decides what is the best way to introduce a particular concept to a particular group of students. To achieve the desired student outcomes in this process, the teacher uses content knowledge, pedagogical knowledge, knowledge of their students or context, and the results of previous instructional experience. All such pre-instructional skills in the planning are part of teaching skills and these pre-instructional skills rely on teachers PCK&S rather than only on teachers' knowledge.

In addition to the above, once a teacher has set a teaching plan, the next step is to implement the plan in the classroom to achieve students' learning objectives. That is a difficult task that requires special skills [or integration with teaching competencies] essential to all teachers (Moore, 2007). A teacher uses a variety of skills in the classroom to increase the effectiveness of teaching and to meet the objectives. Teachers are unable to carry out well-planned lessons without skills, and teachers have a minimum portfolio of skills for classroom practice, including: establish cognitive sets, communicate, use stimulation variation, use reinforcement effectively, use questioning techniques, establish lesson closure and evaluate objectives (Moore, 2007).

The classroom observer might observe some teaching skills in the teacher's lesson planning, and skills that appear with teachers' actions in the classroom setting. For instance, questioning skills assist with monitoring the students' understanding and measure the success of teachers' own planned instructions (Cruickshank et al., 2009), while in the teacher's lesson planning, an observer cannot easily notice the teachers' assessment actions during an assessment. This involves asking questions that involve students in the learning task, measuring their understanding during class, evaluating the effectiveness of one's own teaching practice and this kind of art-craft of teaching has been described as one of the major teaching skills (Zahorik, 1986). The monitoring of a student's behavior as a specific action associated with the instruction is mentioned in teaching skills by Rosenshine (1976). All these skills in the classroom indicate the presence of teacher cognition, meaning these skills should have a strong connection with teachers' enacted PCK:

> …the insights from research on teachers' pedagogical content knowledge provided a useful starting point to investigate teachers' interactive cognitions. However, we considered the categories that were added when we analyzed teachers' interactive cognitions – thoughts about the particular class, about teacher-student interaction, and about process regulation – as specific to this kind of cognition, taking into account the fact that these categories concern aspects of teaching that are directly related to the actual teaching situation. (Meijer et al., 2004, p. 176)

During planning, a teacher can imagine the classroom context and draws on previous experience, their knowledge of students, their experience of particular students, and use of their own prior knowledge to develop a lesson plan, and yet the actual teaching situation is different from that in which the teacher does their planning. In the classroom, many factors may influence that which cannot be planned for in advance, for example, student attitudes toward learning, students' mode, and student motivation levels toward the specific concept. These aspects of classroom practice are more related to students and have been included under the umbrella of students' amplifiers and filters that are a vital part of classroom practice. Likewise, teachers' attitudes toward respective students, teachers' emotions, or feelings can be altered due to any reason and all these features of teaching are important for classroom practice. For instance, "virtually all educators are convinced that teacher attitudes are an important dimension in the teaching process" (Cooper, 2010, p. 4). Overall, teachers' use of skills in the classroom will be in accordance with the teaching situation and the context. Teachers need to set an environment in the classroom for learning (Kind & Chan, 2019) by organizing and managing the situation.

The consensus model of 2015 illustrates how student outcomes influence teacher professional knowledge base via an arrow. Moreover, student outcomes are also shown linked with classroom practice. These linkages indicate teachers need some special skills to utilize student outcomes for knowledge development and teaching planning; such teachers' intellectual actions after teaching practices are represented as post-instructional skills (Moore, 2007). Furthermore, Moore (2007) explains that there are two essential post-instructional skills: (1) the capacity to analyze the collected evaluative information and (2), the capacity to make judgments regarding this analysis. The teacher would use analytical skills to decide what types of changes are required for the next classroom practice because one of the purposes of teaching planning is to relate students' prior knowledge to content material (Shostak, 2010). In the light of these argumentations, I can say that PCK is knowledge for teaching and when this knowledge is in action for teaching, then it can be referred to as PCK&S. Furthermore, teachers' ability to put into practice their knowledge in the teaching process depends on their PCK.

Classroom practice is a dynamic aspect of the consensus model (CM) model and it may be possible to observe science teachers' PCK along with other knowledge components in a classroom. PCK&S is a newly added concept in the PCK and the next section elaborates on this in practice.

2.3.6 *PCK/PCK&S in classroom practice*

A classroom is a place where teachers construct concept(s) in students' thinking by using their knowledge components and skills. Furthermore, the classroom consists of biotic and abiotic contexts; the biotic context including the teacher(s), teacher assistant(s), teacher aide(s), lab attendant(s), and students, while the abiotic context encompasses the teacher's table, the students' desks, a whiteboard, a projector, technological teaching aids, etc. Student learning in the classroom is likely to be reliant on the quality of delivery of content knowledge, and that, itself, will require other teaching knowledge through the effective utilization of the biotic and abiotic contexts. On the other hand, teachers get a chance to enhance and develop their professional knowledge and skills during or after each teaching practice. There are many ways for teachers to develop their knowledge and skills after each class, for example through self-evaluation, peer evaluation, and discussion with colleagues. The main purpose of using PCK during classroom practice is to enhance student outcomes, as shown in the consensus model of PCK.

A teacher can nurture the development of their own PCK through classroom practice and, as such, experienced teachers are likely to have more developed PCK than novice teachers would have. Hashweh (2005) found that pre-service science teachers had limited PCK in their knowledge repertoire due to their lack of classroom practice experience. Furthermore, the interactions of novice teachers' CK and PCK started during their pre-service professional education, and maturity in this relation comes through classroom practice (Kind & Chan, 2019). Shulman (1987) reported that the development of teachers' PCK shifts their understanding of subject matter, enabling them to present subject matter in new ways. Through this, they can reorganize and divide knowledge of subject matter and convert this knowledge into activities, demonstrations, and images, etc. PCK is the knowledge that brings mastery to teaching and makes content understandable for students rather than transferring subject content from book material to students. Besides, teachers' interactions with students in classroom practice can develop teachers' PCK.

In the classroom, the teacher must create for students a situation or circumstance in which the construction of specific concepts can occur (Kind & Chan, 2019). This construction results from the use of pedagogical knowledge and other knowledge components that elevate the students' learning, without which content knowledge would not impact student learning. This process of concept construction includes organizing specific content such that it is sequenced, enabling connections to be made, the formation of relationships between concepts through the use of examples to occur and so forth (Nilsson & Vikström, 2015). Therefore, PCK can be considered a system of understanding the complex relationship between pedagogy and content, the integrated process of which is rooted in classroom practice (van Driel, Jong & Verloop, 2002). These relationships explore the implications of PCK in the classroom, reconstructing of PCK, and teaching purposes. Moreover, these relationships are increasing the understanding of researchers about why teachers use certain PCK to make classroom decisions (Lee & Luft, 2008).

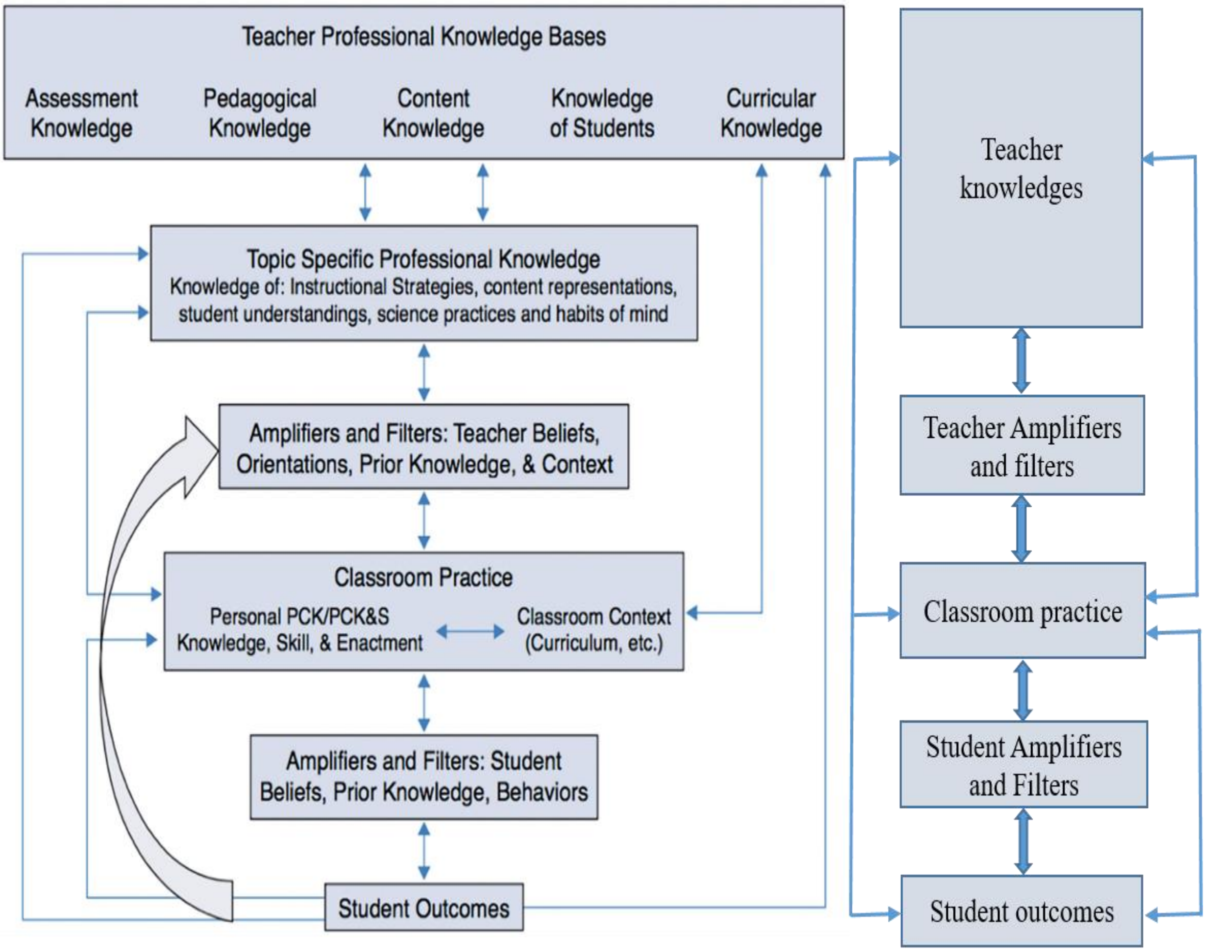
Additionally, Ball, Thames and Phelps (2008) stress that PCK underlies teachers' development and the selection of teaching tasks, the choice of representations and explanations, the facilitation of productive classroom discourse, the interpretation of student responses, the checking of student understandings, and the swift and correct analysis of student errors and difficulties. An interesting tension that accompanies our understanding of PCK has to do with the consequences these tasks have for teachers' professional development. On the one hand, PCK is static knowledge, something that teachers know about teaching as a way that promotes students' understanding; on the other hand, PCK refers to dynamic knowledge or a skill that indicates the presence of the teaching process in the classroom (Nilsson & Vikström, 2015). It has been claimed that "Nonetheless, providing teachers with support to create PCK from baseline knowledge and facilitating its deployment in a teacher's classroom to ensure quality instruction and positively impact student learning outcomes seems essential" (Kind & Chan, 2019, p. 975). Consequently, it can be said that teachers develop or shape their PCK after each teaching experience and its effective usage in benefitting student learning.

This consensus model is not a model of PCK itself because it does not explicitly do what PCK may comprise (Neumann et al., 2019), but it attempts to describe the flow of teachers' knowledge components in the form of PCK with skills in the classroom and its effect on student outcomes. Therefore, PCK can be divided into three phenomena based on the flow of teachers' knowledge: teacher knowledge, classroom practice, and the influence of classroom practice as shown in Figure 2.10. Teachers' professional knowledge includes Teacher Professional Knowledge Base (TPKB) and Topic-Specific Professional Knowledge (TSPK), and teachers' amplifiers and filters. Classroom practice can be understood as a process in which teacher knowledge and skills are interrelated in the classroom context for the enhancement of student learning. Finally, the influence of classroom practice includes the results of teachers' knowledge and teaching process in the form of student outcomes. It might be possible that students' amplifiers and filters would affect their outcomes. Students' amplifiers and filters can also directly influence teacher knowledge components and classroom practice, as shown in the consensus model.

Teachers use and develop their knowledge for the betterment of student learning in classroom practice. However, the classroom is a dynamic, and observable situation where a teacher's knowledge and skills enable an interaction with students that makes classroom practice more vibrant than other dynamics in the CM of 2015.

Figure 2.10

The Consensus Model with focus on three sections



Note. The left side of this figure presents the CM-2015. The right side represents a simplified version of this model produced by me for this project.

Imaginatively, if the classroom practice block was removed in Figure 2.10, then there would be no direct relationship between teacher knowledge and student outcomes, and therefore teachers' knowledge cannot play any role in student outcomes without classroom practice. It is for this reason that I have chosen to explore teachers' PCK in classroom practice as a key component of this model.

A teacher comes from a society in the teaching situation and may bring into the teaching process various attributes and traits that form the society. These attributes and traits affect teachers' planning, which inevitably leads to classroom practice affecting student outcomes. In the 2015 consensus model, these aforementioned phenomena underpin the teachers' amplifiers and filters. In the next subsection, I discuss these amplifiers and filters.

2.3.7 *Teachers' Amplifiers and Filters*

Teachers enter the classroom with a variety of experiences, knowledge, beliefs, academic background, professional experiences, and personal traits. It is difficult to imagine these aspects of life not influencing their teaching practice. Fang (1996) notes that factors outside of the classroom (for example, school context) and teacher attributes (for example, beliefs, prior knowledge) also impact teaching practice. Theoretically, amplifiers and filters are mentioned at two different places in the CM: teacher amplifiers and filters may be theoretically situated above classroom practice while student amplifiers and filters may be theoretically situated below classroom practice. According to the CM diagram, these amplifiers and filters directly or indirectly impact student outcomes, in that they both are shown to directly affect classroom practice. This study focuses on teachers' PCK and skills in classroom practice. The literature on teachers' amplifiers and filters is discussed next

Teacher amplifiers and filters are understood in this model to be agencies from teachers which can amplify or filter their knowledge for particular classroom practices (Gess-Newsome, 2015). Teacher beliefs, Orientations, Prior knowledge, and Contexts are thought of in the model of TPK&S as teacher amplifiers and filters. Berry et al. (2017) at the ESERA-2017 conference presented a revised version of this CM of 2015, this revised model added teachers' *experiences* instead of *context*.

Orientation to teaching was considered to be part of teachers' PCK by some researchers (e.g. Grossman, 1990; Magnusson, Krajcik & Borko, 1999). However, Grossman (1990) discusses this term in relation to the purpose of teaching subject matter, while the Magnusson et al. (1999) model identifies teaching subject matter as the major element of PCK which shapes the other knowledge components of PCK. Kind (2016) explains the work of Anderson and Smith (1987), who used the terminology "orientation" to define a teacher's "general patterns of thought and behaviour" (p. 99) and an "orientation" discussion as a flexible stance that is changeable in a particular situation. The removal of teacher orientation and beliefs from teacher knowledge bases and the placing of it in the broad feature of teaching (teachers' amplifier or filter) is a contribution of the first consensus model (Gess-Newsome, 2015). Unfortunately, there is no definition or explanation of teaching orientation as an amplifier and filter in the consensus model. According to Magnusson et al. (1999), "[a]n orientation represents a general way of viewing or conceptualizing science teaching" (p. 97). There is no clear agreement among researchers about what should be a particular orientation toward teaching; the reason being that teachers set goals, provide strategies, and plan according to context and content.

According to the CM, teacher beliefs can function as an amplifier or filter during classroom practice but there is no consensus among researchers as to what teacher beliefs are, leading to educational researchers discussing teacher beliefs according to different perspectives. Luft and Roehrig (2007) deliberated over the points of view of some researchers, dividing these perspectives into clusters: some researchers considered individuals' beliefs and attitudes together; some researchers interchange terms such as theories and philosophies with beliefs, and they acknowledge that these attributes are individuals' constructions. Other schools of thought associated beliefs and knowledge as that which guides individuals in their decision-making processes. Smith and Siegel (2004) tried to clarify the distinction between knowledge, and beliefs, firstly by treating individuals' beliefs and knowledge as separate constructs with reciprocal impact, and then by treating beliefs as subsumed phenomena within knowledge.

These different points of view about beliefs indicate that personal beliefs are unique attributes to an individual when accepting or rejecting ideas, knowledge, innovation, etc. Importantly, "as a free agent, a teacher has an opportunity to embrace, reject, or modify new knowledge, skills, and practice" (Gess-Newsome, 2015, p. 34). Theoretically, the interpretation of this model provides some examples of how a teachers' beliefs work as filters or amplifiers during teaching practice:

> [A] teacher who believes that teaching is telling might reject conceptual change learning strategies that begin with an understanding of what a student knows in order to design instruction to challenge this understanding… [a perceptional example of amplifier] a teacher might enthusiastically infuse their curriculum with instruction about nature of science. (Gess-Newsome, 2015, p. 34)

Teacher beliefs can amplify and filter topic content and classroom practice. Wallace and Kang (2004) investigated the connection between teachers' beliefs and their classroom practice and found that teachers' beliefs amplify their science teaching practice (inquiry-based laboratory practice was extensively used). Significantly, teachers' beliefs are responsible for their actions in the classroom:

> Strong like and dislikes of particular pupils, biases toward or against particular ethnic groups, low learning expectations for poverty-level children, and biases in favor of or against certain kinds of student behaviour … all [these phenomena] can reduce teaching effectiveness [and act as filters]. Self-awareness of such attitudes toward individual pupils or classes of children is necessary if teachers are to cope with their own feelings and beliefs. (Cooper, 2010, p. 5)

For the most part, educators are convinced that teachers' attitudes are important factors that set the direction in the teaching process (Cooper, 2010). In the New Zealand teaching context, Garbett (2011) reported that "…in our haste to deliver subject-specific content knowledge and model constructive-based teaching approaches, we presented science teaching as unproblematic. In effect, our teacher education pedagogy was based on 'do as we say, not as we do" (p. 37). Sometimes terms such as attitude are confused as a separate construction from the term belief. More than 500 operational definitions of attitude were reported by Fishbein and Ajzen (1972) in their review (as cited in Bergman, 1998). Jones & Carter (2007) conclude that after discussing different research findings on attitudes and beliefs "…beliefs are part of belief systems and attitudes are components of this larger system" (p.1070). Therefore, teachers' attitudes about context or object, teaching content, adoption of teaching strategies, etc. are also influenced by their beliefs.

Gess-Newsome (2015), when providing us with her interpretation of the CM, does not describe what her understanding of *teachers' prior knowledge* is. Furthermore, she does not provide an example of how *teachers' prior knowledge* could potentially filter or amplify teaching practice. In my perception, it might be developed through teachers' interaction with the particular group of students, in the particular subject, in the particular context, in that sense teachers have a clear idea of how to shape [amplify or filter] the content or practice for those particular students. Interestingly, Gess-Newsome (2015) discusses how *teachers' personal knowledge* might act as an amplifier and filter in the teaching process. According to Borko and Livingston (1989), beginner teachers apply knowledge and skills to instructional planning differently as compared to senior teachers, inferring that teachers use their personal knowledge and experience to enhance their teaching.

Another component in the teacher's amplifiers and filters is 'context'. In Gess-Newsome's (2015) words:

> …contextual variables can influence what a teacher knows and how knowledge may or may not be used. Access to high-quality professional development at the pre-service levels can influence practice, as well as the nature of the professional development and whether it is focused on generic or topic-specific knowledge and skills. (p. 35)

Teachers' adaptability of the (developmental) program is also a contextual variable along with institutional support (Shernoff & Kratochwill, 2007), school status, class-grade-level, the pace of lessons, and the size of the group (Brophy & Evertson, 1978). For instance, at a high-status school, the teacher concentrates on teaching to an established curriculum, asking more difficult and critical questions, and covering content at a faster pace as school and parent expectations may dictate this (Brophy & Evertson, 1978). Gess-Newsome (2015) also provides research findings that elaborate the impact of the contextual variables on teaching practice: for example, she claimed that teachers' generic professional development has a negative impact on teaching effectiveness. Therefore, a teacher's context or background can amplify or filter the teaching process, according to the teaching context. A teacher's context may include professional development, experience, schooling, relevant qualification, etc.

These contextual variables directly and indirectly impact classroom practice and modify teaching in response to the students, the number of students, the grade level, and the school status. Contextual variables act as amplifiers or filters of teaching in relation to asking questions, the pace of content, the decision-making process, evaluation criteria, etc. Therefore, "the variability imposed by teacher amplifiers and filters, the impact of context on teaching, and the decisions that teachers make about instruction all increase the uniqueness of each teacher" (Gess-Newsome, 2015, p. 35).

The consensus model added science teachers' orientations in the diagrammatic model as an element of teacher amplifiers and filters. The writer did not explain how orientations act as amplifiers and filters. It was important to define orientations for my study along with other elements of amplifiers and filters: Belief, Context, and Prior Knowledge.

Ideas about teaching orientations and beliefs are overlapped in literature. Teaching orientation was actually first time introduced as an aspect of teachers' PCK in Magnusson et al's (1999) model. Interestingly, Magnusson and her colleagues also did not explain how teacher orientation shaped their understanding of PCK. According to Magnusson et al., the orientation to teaching science has to do with "the knowledge and beliefs possessed by teachers about the purposes and goals of teaching science at a particular grade level" (p. 97). In their point of view, teachers' beliefs act as a part of teachers' orientation. It could have been a challenge in this research during data collection, for instance, if teachers were observed in their classrooms motivating students for learning whether to discuss it under either orientation or belief. It seemed that a decision was needed to remove one of orientation or belief from amplifiers and filters.

Before taking that decision, I further investigated the roles of orientation in teaching practice from established literature. For example, Friedrichsen and Dana (2005) point out that teachers have multiple goals in their teaching, so investigating teaching orientation is convoluted in teaching practice. Magnusson et el. (1999) also identified nine orientations in their study and did not explain which ones impact or shape teachers' PCK. This shows orientation is complicated to capture during teaching practice.

Later, Friedrichsen et el., (2011) focused on three dimensions of teaching orientation which included '[1] beliefs about the goals and purposes of science teaching, [2] beliefs about the nature of science, and [3] beliefs about science teaching and learning' (Friedrichsen et al., 2011. p. 373) to verify how these dimensions come together in how teachers view and shape their teaching. These researchers examining science teaching orientations (STOs) may not have considered that a given teacher might have more than one orientation to teaching science. Instead, researchers have assumed that a given teacher has a single orientation to teaching science, regardless of the content or topic being taught, and that this orientation informs their teaching practice. Campbell et al.'s studies (2013, 2014) developed science teaching orientation profiles to consider how dimensions of STOs push or pull on one another to shape teachers' beliefs (Campbell et al., 2013, 2014). This reflects that dimensions of teacher orientation interact to shape their beliefs. Therefore, orientations and beliefs seemed to overlap each other.

I have reached the conclusion in the light of literature that teachers have more than one orientation during teaching which a complex process. Second, dimensions of orientations push and pull one another to shape teachers' beliefs. Therefore, I kept teacher beliefs in amplifiers and filters and left out teaching orientations to examine teachers' PCK in more detail. In addition, the refined consensus model of PCK 2019 also did not consider orientations as part of amplifiers and filters. I think it is not part of the Refined Consensus Model of PCK because in literature there is no solid scholarly foundation of orientations as amplifier and filter.

Recently, PCK experts have revisited the concept of PCK and have proposed the 2019 consensus model; the model which is discussed in the next subsection.

2.3.8 *The Refined Consensus Model of PCK in science education*

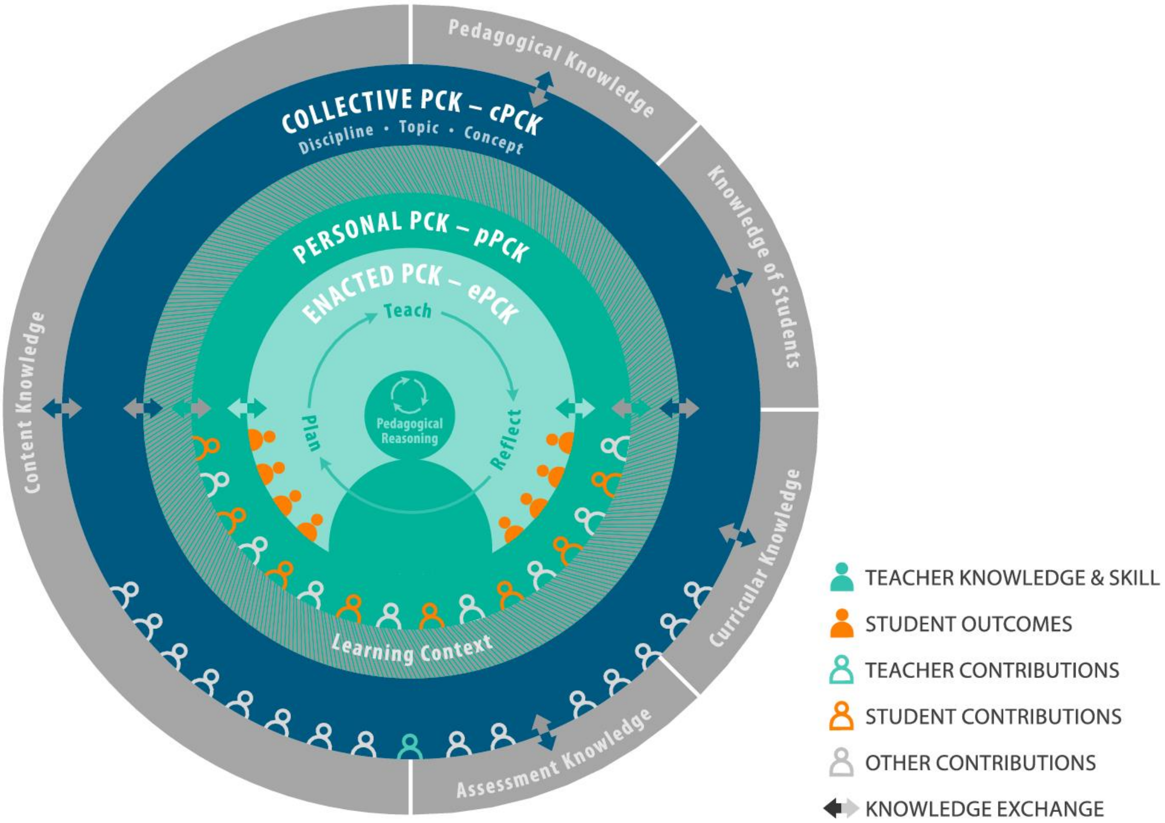
A 2nd PCK Summit was held in 2016 with both participants from the first summit and other active PCK researchers from around the globe taking part. One purpose of this intellectual gathering was to meaningfully review the CM presented at the 1st Summit (Carlson & Daehler, 2019) and one of the final products was the Refined Consensus Model (RCM). What follows is an explanation of the RCM and its components.

The 2nd summit attendees discussed certain limitations of the CM of 2015. Firstly, the CM provides limited detail about PCK. Secondly, this model illustrates the flow of teachers' professional knowledge including PCK in the classroom, and its lack of effect on student outcomes. Thirdly, the concept of PCK suggests a dynamic essence while the CM encompasses static knowledge components, and personal PCK and skills (PCK&S) could and should be separately expressed for more canonical Topic-Specific Professional Knowledge (Carlson & Daehler, 2019). The major issue of the CM was that it contained more static components than dynamic components and, as such, presented CM as having a static nature. One goal of developing the RCM was to provide researchers, by focusing on teachers and classrooms, a means of locating student and science learning interrelationships to PCK. In the RCM shown in Figure 2.11, it places enacted PCK at the center.

In order to develop the new version of the consensus model, 2nd PCK Summit participants sought to add more specificity to the CM by addressing the role of the grain sizes of the PCK (e.g. discipline, topic, and concept) of science teachers. The purpose of adding this grain size of PCK is to show how PCK evolves dynamically for individuals through feedback mechanisms that relate to classroom teaching experiences. The existence of grain size also elaborates the concept of PCK through the application of PCK by science teachers during the pedagogical reasoning cycles of instruction (planning, enacting, and reflecting); and by contextualizing this PCK practice within the wider context of the personal PCK of a teacher and the greater collective PCK. It is these ideas that gave birth to this new PCK model (see Figure 2.11) instead of refining the CM as its name suggests. Hence, "while this updated model highlights various aspects of PCK, the group … the PCK expert participants … did not see it as a replacement of other models such as the Magnussen Model or the 2012 CM" (Carlson & Daehler, 2019, p. 80).

Figure 2.11

Refined Consensus Model of Pedagogical Content Knowledge (RCM of PCK)



Note: This model was produced by participants at the 2nd 2016 PCK Summit, and discussed by Carlson and Daehler (2019, p. 90). This figure has been adapted from the original of Carlson and Daehler (2019). The figure is reprinted with the permission of the publisher.

The outermost layer of the Figure identifies the professional knowledge base of teachers (TPKB). According to this theoretical model, the Content Knowledge of teachers seems to cover half of the outer rim, and the remainder is covered by four Knowledge components (Pedagogical Knowledge, Knowledge of Students, Curricular Knowledge, and Assessment Knowledge), which suggests that teachers should require before teaching both a content degree and a relevant professional degree. Content Knowledge is viewed as both the academic content and teaching expertise: academic content includes the knowledge of the discipline (for example Chemistry, Physics, Biology) and the teaching expertise contains discipline-specific knowledge and skills. For example, Content Knowledge refers to both teachers' understanding of the nature of science and how scientific explanations should be written, an understanding of a given domain within the discipline, and the relationship between the discipline areas.

The other knowledge-bases help teachers to teach the particular content in the classroom and its purpose is to teach or “what it (Content Knowledge) means to teach” (Carlson & Daehler, 2019, p. 91). Additionally, science teachers need to understand their students' willingness to learn, the nature of the curriculum, the assessment types, and a variety of pedagogical skills and strategies. Often these knowledge-bases are developed through more formal routes, such as teacher preparation training, professional upgrade sessions, and then strengthened through interaction with students during classroom teaching and professional learning.

The second layer in Figure 2.11 refers to collective PCK (cPCK) and this knowledge refers to what is generated by the contributions of multiple science teachers, therefore, cPCK is not private knowledge (Boz & Belge-Can, 2020). In simple words, cPCK embraces knowledge possessed by more than one person, meaning knowledge that is not private, but rather is public and collectively held (Carlson & Daehler, 2019). This specialized knowledge in science teaching, as shown in Figure 2.11, can range from discipline-specific knowledge to topic-specific knowledge to concept-specific PCK in grain size.

In this model, the learning context is located between the teacher’s cPCK and personal PCK (pPCK). This circle signals how vital it is for science teachers to have an extensive understanding of the learning context in which they teach. Here, learning context is conceptualized in the wider sense. For example, it includes educational climate (for example, federal policy), particular learning environment (for example, school, classroom), and individual students’ attributes (for example, learning attitude) (Carlson & Daehler, 2019). From the PCK lens, student attributes are perhaps the most significant component of the learning context. The learning context also includes students’ factors such as age, grade level, prior experiences, language skills, and cultural beliefs (Carlson & Daehler, 2019). The learning context is also perceived as amplifiers and filters of teaching practice, “[a] context that serves to both amplify and filter each teacher’s knowledge and skills and to mediate teachers’ actions” (Carlson & Daehler, 2019, p. 87).

The personal PCK (pPCK) acts as a reservoir of knowledge and skills that the teacher can draw upon during the practice of teaching. When facets of the larger realm of pPCK are accessed and utilized, it becomes enacted PCK (ePCK). The two-headed arrow between ePCK and pPCK indicates the knowledge exchange between them, resulting in ePCK informing and being informed by pPCK. Furthermore, this arrow suggests a science teacher brings pPCK into the classroom for specific science learning that depends on its translation into practice (ePCK).

The concept of ePCK reveals the key ideas that were articulated during the 1st PCK Summit. In particular, it reveals the importance of 'personal PCK' in science education. ePCK refers to the specific knowledge and skills utilized by a teacher in teaching-learning settings in the context of students achieving learning objectives in relation to the acquisition of a specific concept. The PCK enactment in this model not only applies to the set of knowledge of, and reasoning behind, the act of teaching when interacting directly with students (reflection in action), but it also applies to the acts of teaching planning and the act of reflecting upon instruction and student outcomes (reflection on action). Simply, ePCK can be discussed as enacted PCK in planning (ePCKp), enacted PCK in teaching (ePCKt) [alternate form of PCK&S] and enacted PCK in reflection (ePCKr) (Alonzo et al., 2019). The model's center circle identifies that the pedagogical cycle of teaching is dynamic and that pedagogical reasoning takes place in all aspects of teaching, making the pedagogical cycle unique to each teacher and every moment of teaching (Carlson & Daehler, 2019). Student outcomes offer one means of evaluating the efficacy of teacher instructions. Thus, one way of measuring a construct's utility (such as PCK's), is to decide if that construct predicts the learning outcomes. The student icons at the center of this model represent teacher interactions with students in the context; the student outcomes would be the result of these interactions.

In summary, while PCK has emerged in educational research as key knowledge for teaching, it is still in the development phase. In 1986, Shulman has presented PCK as an amalgam of content knowledge and pedagogic knowledge. Following the development of this nascent concept, Grossman (1990) went on to explain these components and their relationship to the PCK in a diagrammatic model. A considerable amount of literature attempts to explain PCK components, nature, types, and levels. The uniqueness of Magnusson's model (1999) is the addition of two new components to the classical concept of PCK and the description of each component at the level of its specification. In the same year, Veal and MaKinster (1999) published a PCK taxonomy that explains its hierarchy in the educational context. From 1986 to 2012, different researchers understood this concept from different perspectives. This lack of consensus resulted in PCK intellectuals at the first PCK summit seeking and reaching an agreement on the definition of the concept of PCK and its model. Gess-Newsome published the resulting PCK Consensus Model in 2015. This model provides a broad picture of the use of teacher knowledge, including PCK, during the teaching process. Furthermore, it illustrates how the interaction with students influences student outcomes during classroom practice; teacher and student amplifiers and filters influencing that interaction; something illustrated by all components of this model, being directly or indirectly interlinked. Classroom practice would appear to be a dynamic part of this model and it is for this reason that this study focuses on classroom practice as a means of examining the PCK of science teachers. To review this consensus model, a 2nd PCK Summit was organized which produced another consensus model, later published by Carlson and Daehler (2019), known as the Refined Consensus Model (RCM) of PCK. The RCM diagram consists of complex layers of knowledge components and aspects of teaching that shape and informs teachers' enactment and facilitate student outcomes.

This study was anchored in the classroom aspect of the Consensus Model of 2015 and it entails teachers' PCK in their classrooms. The first consensus model has some unique features which make it more applicable in this study. To this effect, the next section justifies the characteristics of this model that relate to the focus of this study.

2.3.9 *Why the first PCK Consensus Model was selected for this study*

This study aims to examine PCK and the skills of science teachers in their chemistry classroom practices. For this purpose, the research needs to focus on the most relevant PCK model as a foundation. After examining the PCK models that have been produced over time, as discussed earlier in this section, I was able to select the most appropriate model for this study. The suitability of the most relevant model depends on the components that embrace the requirements of the nature of the data analysis, for instance, the selected model would need to have the classroom practice component. The following paragraphs elaborate on the justification for adopting the first CM for this project.

The established PCK models have been developed by both individual researchers (Grossman, 1990) and by groups of researchers (Magnusson et al., 1999)) in the last three decades. More recently, two consensus models (Carlson & Daehler, 2019; Gess-Newsome, 2015) have been presented by the experienced PCK experts at the PCK summits. Each model is important and provides a unique way of understanding the concept of PCK and its development. Numerous studies of these previously developed models have been made with most PCK studies focusing on Magnusson et al.'s (1999) model of science teaching, while very few studies have focused on the PCK consensus models, due to their relatively recent emergence. Recent developments in the field of PCK have led to a renewed interest in the examination of the PCK of science teachers in classroom practice. My project began in 2017 with data being collected in mid-

2018, which is to say before the 2019 publication of the refined version of the consensus model. For this reason, the data was gathered on the basis in accordance with the first version of the consensus model, so it was difficult to modify the direction of the research, the conceptual framework, and the nature of the data in accordance with this more recent PCK model (RCM).

Overall, the requisite features of the elements of the CM, for example, the interaction between teacher knowledge and classroom practice, and their results (student outcomes) are seen as the main objective (student learning) of teachers' PCK. The second significant feature is the addition of non-cognitive aspects such as emotion and motivation; it highlights the role of amplifiers and filters in this model.

The overarching contribution to teaching practice in the classroom involves the introduction of the concept of PCK&S; which has attracted the attention of PCK researchers. PCK&S encompasses all teaching actions that are based on PCK where these skills include the ability of teachers to use feedback to improve the quality of their practice. In the CM of 2015, an arrow is shown from student outcomes to classroom practice. Most importantly, the PCK&S model involves a discussion of student outcomes as a product of PCK. Such theoretical features in this model are both, directly and indirectly, related to the development of my study. These elements are described one-by-one and their relation with my study later in this subsection.

After reviewing all components in the PCK model, I have concluded that the ideas in this model have mostly been developed in recognition of the limitations highlighted by Lee Shulman (2015) when speaking to his original PCK concept at the 1st PCK Summit. Shulman identified four main limitations to his classical idea of PCK that appear to generate the four new elements in this model (the top block already discussed in the previous models). These are: non-cognitive aspects of teaching practice, teachers' skills, social and cultural contexts, and products of PCK (Student outcomes).

Student outcomes are the goal of the educational process. In this CM, there is a complex relationship between classroom practice, teacher knowledge components, teacher's personal PCK and skills, the classroom context, and student outcomes. Student outcomes also play a role as a modifier/developer agent of teacher knowledge and classroom practice. Moreover, the big curved arrow indicates that student outcomes influence teachers' amplifiers or filters, thus, assisting in the improvement or modification of teachers' amplifiers or filters.

On the other hand, according to the CM, classroom practice has a direct connection with student outcomes through students' amplifiers and filters. In the classroom practice situation, teachers'

PCK/PCK&S looks like a more vibrant element in the teaching-learning process because it is a valuable source of concept construction in the classroom to the extent that it might be well planned, well-structured, and involve the classroom context. To this effect, this study aimed to examine science teachers' set of knowledge, including PCK and skills in their chemistry topic teaching of Year 10 students in the New Zealand classroom.

The CM is the result of researchers' discussions at the 1st PCK Summit and this diagrammatic model had as yet no research foundation. At the 1st PCK Summit, it was declared that overall PCK is a theoretical construction to facilitate science education (NARST, 2013). While the theoretical value of the PCK model is strong, despite it being without an explicit research base, the concept of PCK appears to provide impetus to researchers to conduct new research. This study examined one aspect (classroom practice) of the PCK model with the purpose of investigating the PCK of science teachers in secondary school chemistry classrooms in New Zealand. The location of classroom practice is sandwiched between the teachers' and students' amplifiers and filters in the CM model, linked with TPKB and TSPK, and influenced by student outcomes either directly or indirectly. These interconnected links between elements make classroom practice become a dynamic part of the model, making classroom practice more practicable to examine.

Additionally, the CM model and its revisions have brought valuable change to PCK research on classroom practice on account of these models drawing attention to teachers' knowledge in real teaching situations (de Sá Ibraim & Justi, 2019). The previous versions of the PCK model understood teachers' professional knowledge-base as knowledge for teaching. The CM was not adopted as a set of knowledge components just by name, moreover, these sets of knowledge components include teachers' knowledge for practice (Gess-Newsome, 2015). The top block of this model spoke to a set of teacher knowledge components as well as teachers' abilities to utilize these knowledge components effectively in a teaching process. For instance, curricular knowledge might include curriculum goals, the role of scope and sequence, and the ability to assess a curriculum for coherence and articulation (Gess-Newsome, 2015). *The New Zealand Curriculum* (NZC) also emphasizes the utilization of feedback on teaching, asking "[w]hat happened as a result of the teaching, and what are the implications for future teaching?" (Ministry of Education, 2007, p. 35).

While all previous models and understandings of the concept of PCK were emotionless and ignored the non-cognitive aspects in the classroom of teachers' and students' experiences, this issue was addressed by the CM with the conceptual creation of teachers' and students' amplifiers and filters. Gess-Newsome (2015) claims that teachers can accept, reject or modify knowledge, skills, and practice as they are free agents in the classroom. These non-cognitive aspects of individuals are also implicit in interactions in classroom practice and, as such, have an impact on students' learning, attitudes, affiliations with school, etc. These impacts have been both observed internationally by researchers (e.g. Cowie & Summers, 2020) and in the New Zealand teaching context (Bishop et al., 2007). To this effect, this study examines the science teachers' amplifiers and filters in their chemistry topic practice.

Furthermore, the previous PCK models did not give attention to classroom practice. It appears that one of the big limitations of the previous models was that they ignored the classroom context (students, teacher aides). Recently, Cowie and Summers (2020) found that "we attend to the affective aspects of teaching and learning by regularly acknowledging common emotional responses, which helps to normalize students' feelings" (p. 45). To achieve lesson objectives, teachers need to teach according to the classroom context (Parr & Limbrick, 2010), which is to say, effective teaching practice varies from context to context. Therefore, the teacher needs to set the classroom environment (Kind & Chan, 2019) according to the context. This study gathered data in the classroom to examine teachers' PCK and skills, amplifiers and filters, in the particular classroom context in which teaching was practiced.

In a nutshell, the CM model has new components that are research-alluring for PCK researchers. This study aimed to examine these overarching aspects of the CM in science teachers' chemistry topic teaching to their Year 10 students in the New Zealand classroom. For this reason, science classroom practice and learning in the New Zealand science classroom needs to be accounted for in the literature. With this thinking in mind, the upcoming section discusses science classroom context and teaching practices in New Zealand.

2.4 Science Classroom Context and Teaching Practice

A meta-review of 10,000 studies done by Dunkin & Biddle (1974) highlights the importance of classroom context on classroom teaching. In this research, Dunkin and Biddle state that process-outcome relationships are weak in discussion studies because these studies ignore the classroom context. Brophy and Evertson (1978) argue that "… process-outcome relationships will become both more orderly and more powerful if important context variables can be identified and taken into account in research design and analyses" (p. 310). This study incorporates the importance of teaching practice context variables in the classroom. The upcoming paragraphs present the roles of classroom context in teaching practice.

The science classroom context is an important variable for science teaching that may influence the teachers' utilization of knowledge (Gess-Newsome, 2015). In this study, the classroom context is divided into two fragments: biotic and abiotic. For instance, science teachers use scientific images, graphs, and scientific symbols in their classes more frequently than language teachers do in their classes. Gilbert (2010) explains the importance of the non-verbal context in the following way: verbal information and non-verbal information make associate structures that are capable of "cross-linkages" that form "referential connections" in student learning (p. 3). For example, 'hearing' about Rutherford's atomic model and 'seeing' the actual model or the model in the photograph will enable two sources of understanding that reinforce each other (Gilbert, 2010). Moreover, visual representation in the classroom plays a role, as a tool, that supports cognitive understanding in science (Evagorou et al., 2015); visual and physical representations in the classroom afford complementary advantages when learning a concept (de Jong et al., 2013) because many science concepts cannot be directly observed (Gilbert, 2005).

Science classrooms are designed to facilitate the specific discipline of teaching science. For example, a chemistry classroom may be decorated with periodic table charts, atomic models, science pictures, scientific information, experimental apparatuses that are different from what one finds in a biology classroom. This is to say the resources used in a science classroom have a significance that is particular to the teaching of science (He & Forey, 2018). Teachers use accessible resources to teach particular concepts to enhance the student learning and learning atmosphere through utilizing their knowledge components and skills. A teacher needs a variety of semiotic resources in a science class, such that each resource can be used to teach particular content in a particular style, since a certain level of readiness is needed in the learning situation (Lemke, 1998). Science teachers use scientific vocabulary, particular instructional strategies, resources, and substantive knowledge to construct concepts for students in the classroom. Halliday and Martin (1993) noted that science teachers use technical taxonomies, abstractions, and nominalization in the classroom that has an impact on the learner.

Different dimensions of effective practice are discussed in the literature but "we do not know what dose of each treatment is optimal, how these treatments are best combined, and what combination of treatments work best for which [students]" (Graham & Perin, 2007, p. 328).

Some research only focuses on one dimension of teaching practice, for example, the personal teaching dimension (Rowe, 2011), the ethical dimension of teaching (Bárcena et al., 1993), or the emotional dimension of teaching (Bahia et al., 2013), while some research discusses more than one dimension in a single study (for example Bartholomew et al., 2011; Gadd, 2014) to elaborate classroom practice.

Science teachers have adopted a variety of teaching methods according to well-established science teaching styles while considering particular content, choices, modifications, and particular contexts. From my point of view, science teachers select pedagogies according to the context and content in place of following a recommended pedagogy. For instance, some educators recommend the use of an inquiry-based teaching method for reasons that they believe it is one of the best pedagogies used when teaching science. Alternatively, Cairns and Areepattamannil (2019) found, when analyzing the Programme for International Student Assessment (PISA) data from 54 countries, a significant negative relationship between inquiry-based teaching and student achievement. The adoption of pedagogies by science teachers is more reliant on context and available resources; for example, New Zealand public school science teachers can adopt discourse teaching instruction or animation or visualization techniques to explain chemical reactions at the micro level because of available resources, but the average public school in Pakistan cannot do this due to lack of proper resources.

The other factor which affects the teacher to adopt pedagogy in the classroom is their students' cultural background. This culturally-responsive pedagogy includes "cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students" (Gay, 2010, p. 31). Nuthall (1999) discusses five studies of science and social studies classrooms that found similarly significant effects on learning due to the social and cultural factors that influence the intellectual climate of the classroom. Averill and McRae (2020) noted in the New Zealand context that culturally sustainable teaching practices are advocated to enhance the learning experience of indigenous Māori learners. Moreover, it is noted in *The New Zealand Curriculum* that, "[d]ifferent cultures and periods of history have contributed to the development of science" (p. 28). Also, the ERO (2020) argues that some effective teaching practices in schools lift Māori achievement. The pedagogies recommended by *The New Zealand Curriculum* and science teaching practices in the New Zealand classroom are discussed in detail in Section 2.6.

The Ministry of Education of New Zealand supports the development of modern teaching practices through the provision of infrastructure, both physical and digital (ERO, 2018). I think, in this modern technological era, science and its associated technologies have arguably become the backbone of a country's economy, supposedly as a result of a good education system producing good scientists. According to Sir Peter Gluckman – chair International Network for Government Science Advice (INGSA) and Chief Science Advisor to the Prime Minister in New Zealand – "[t]he key is to create an effective brokerage system between national and international policy communities and between the multiple disciplines of science and technology" (Gluckman, 2017).

The New Zealand education system places significant value on science education; something that can be seen in the educational goals of the practice of teaching science in the classroom. The next subsection involves a discussion of the New Zealand Ministry of Education's science education goals and objectives. This discussion provides a snapshot of educational goals, educational objectives, science learning areas, secondary schooling, and the current array of schools that make up the New Zealand secondary school system. Finally, this subsection outlines the New Zealand science classroom practice and assessment system.

2.5 Science Education in New Zealand

The New Zealand Government has a clear strategic direction for the improvement of student outcomes and the creation of stronger economic growth (Ministry of Education, 2014). This strategic initiative involves the raising of teaching quality and the development of teaching leadership. In recognition of the importance of education, the New Zealand Government has established *The National Education Goals* (NEGs). These NEGs will be revised in the near future, commencing in 2023. The following current NEGs are related to this study and its interest in enhancing science education:

- Development of the knowledge, understanding, and skills needed by New Zealanders to compete successfully in the modern, ever-changing world.
- A broad education through a balanced curriculum covering essential learning areas. Priority should be given to the development of high levels of competence (knowledge and skills) in literacy and numeracy, science and technology, and physical activity.
- Excellence is achieved through the establishment of clear learning objectives, monitoring student performance against those objectives, and [the provision of] programs to meet individual needs.

- Success in their learning for those with special needs by ensuring that they are identified and receive appropriate support (NZ Govt, 2020).

The next part of this section provides a short description of the history of secondary education in New Zealand.

2.5.1 *Secondary schooling in New Zealand*

New Zealand's public education system was set up in the late 19th century (Bull et al., 2010). These authors describe how the Education Act of 1877 made provision for a nationwide secular system of compulsory, and *free* schooling for everyone between the ages of 7 and 14. These public secondary schools charged fees for attendance until 1914. Usually, only the students of rich families attended secondary schools at that time. In the early 20th century, a parallel system of technical high schools offering a more 'practical' and 'relevant' curriculum was set up but there was a serious drawback to this form of schooling in that they produced students who were only able to secure working-class jobs. In response to this situation, *The Thomas Report* (New Zealand Department of Education, 1944) outlined a new direction for secondary education, introducing school certificates and university entrance examinations (Bull et al., 2010). This development required a new and more advanced curriculum and a broad and balanced education for all.

The current New Zealand schooling system is divided into 13 Years. Primary education begins at Year 1 and goes to Year 8 (that is from approximately 5 to 12 years of age) while secondary education goes from Year 9 to Year 13 (around 13 to 17 years of age). There are currently three types of schools, each category emphasizing one or more of the following: language/culture, level, gender-separated, and/or co-education. These schools are classified as state schools, state-integrated and private schools, single-sex or co-education, and Māori-medium education. Those schools funded by the state are known as state schools, while those funded partly by the state are called state-integrated schools. Those schools owned by private bodies are called private schools. State schools teach the national curriculum and are secular (non-religious). State-integrated and private schools also teach the national curriculum but may have their particular aims and objectives that reflect their values, for example, they may teach according to a specific philosophy or focus their provision of education on a particular religion. State or state-integrated schools are co-educational or single-sex institutions, while most religious schools are single-sex schools.

Māori schools focus their system of education on Māori culture, values, and the use te reo Māori (the Māori language) as the medium of instruction. These schools are known as Kura

Kaupapa Māori. Kura Kaupapa Māori schools are funded by the state, and are mostly composite schools, with primary and secondary departments within a single institution. The Maori-medium schools follow *Te Marautanga o Aotearoa* (ERO, 2018). All other schools follow *The New Zealand Curriculum* and, as such, focus on the achievement of national education goals. The following section provides a snapshot of *The New Zealand Curriculum,* which was followed in the school in this study.

2.5.2 ***Science education in The New Zealand Curriculum***

Since 1877, New Zealand has had its own national curricula and schooling policies and in the last 30 years, has had an emphasis on developing school-based curricula that abstract from national curriculum frameworks (Cowie et al., 2011). The New Zealand national curriculum is a mandated document designed to ensure a common program of study is presented nationwide with some uniformity of content and standards in education (Ministry of Education, 2007). Its main purpose is to develop the skills in young people such that they learn to study and prepare for work and life in a manner that they realize their potential. The two documents that make up the national curriculum are *The New Zealand Curriculum* (NZC) and *Te Marautanga o Aotearoa. The New Zealand Curriculum* is in English and is delivered by all New Zealand schools except Māori language medium schools. *Te Marautanga o Aotearoa* is in te reo Māori and has objectives that are different in that they relate specifically to the philosophy of Kura Kaupapa Māori. This study is concerned with *The New Zealand Curriculum*, firstly, because most schools in New Zealand use this curriculum and secondly, because this curriculum was in use in my study school.

The vision of *The New Zealand Curriculum* is to produce young people who will be creative thinkers, actively involved, lifelong learners, with an ability to understand new knowledge and technologies to create a sustainable social, cultural, and environmental future for all New Zealanders. *The New Zealand Curriculum* describes values and key competencies for all learning areas. For instance, in *The New Zealand Curriculum*, values related to science encourage students to pursue innovation, inquiry, and curiosity, by thinking critically, creatively and reflectively, while caring for the New Zealand environment (Ministry of Education, 2007). These values and competencies are knitted into eight learning areas: English, The Arts, Health and Physical Education, Learning Languages, Mathematics and Statistics, Science, and Social Sciences, and Technology. Each learning area is divided into levels. There are eight levels in the National Curriculum that stretch from year 1 through to year 13, one level typically covers about two years of learning, with a single level representing a learning stage in that learning area. To determine science learning in the New Zealand classroom, *The New Zealand Curriculum* sets science education objectives. The subsection that follows describes the science education objectives the Ministry of Education has for New Zealand students.

2.5.3 ***Science achievement objectives***

Science objectives are expressed in the *The New Zealand Curriculum* in a way that clarifies to learners what they should try to achieve as they learn. These objectives involve the meeting of relatively short-term goals that effective learners should be capable of achieving within the scope of the course. Four points are listed in *The New Zealand Curriculum* (Ministry of Education, 2007) which highlight what science students should be able to do when studying science, under a banner of Nature of Science:

- develop an understanding of the world, built on current scientific theories;
- learn that science involves particular processes and ways of developing and organizing 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. (Ministry of Education, 2007, p. 28)

These science objectives mainly focus on preparing students for a scientific world in which they would face science-related issues that are part of students' everyday lives. Overall objectives for science suggest that "By their senior years the achievement objectives signal that they should understand the dynamic nature of the relationships between investigative activity and the theories and models of science" (Hipkins, 2013, p. 226). To this effect, science education at secondary schools are supported by the report *Science Education for the Twenty-First Century* (Gluckman, 2011), produced by the Office of the Prime Minister's Science Advisory Committee in April 2011. According to this report, science education at the secondary school level has two distinct purposes - that it be: Pre-professional education, and Citizen-focused (Gluckman, 2011, p. 5). Traditionally, the first purpose of secondary education in New Zealand is for careers needing science and is organized around specific subjects like mathematics, physics, chemistry, biology, and perhaps general science. The second purpose as citizen-focused is the need for all students over the next 60 years of their lives to have knowledge and understanding of the modern world of science that will impact them as a citizen (Gluckman, 2011, p. 5). The upcoming subsection discusses the role of the science learning area in science education.

2.5.4 *Science learning areas*

The New Zealand Curriculum provides scaffolding for school-based curriculum development in New Zealand from 5 to 18 years of age (Hipkins, 2013). The purpose of science in *The New Zealand Curriculum* is described as concerning the development of scientific knowledge, understanding, and a capacity to explain the natural worlds such that students can solve problems and make decisions drawing upon such knowledge and skills; the NZC discussed these things under “enhancing the relevance of new learning” and “encouraging reflective thought and action” (Ministry of Education, 2007, p. 34). Science achievement objectives are set for students so that they learn to manage the challenges that they confront in the world – challenges that need to be approached from a scientific perspective. The science achievement objectives in schools (see subsection 2.5.2) can perhaps be better understood when we look at how these objectives are thought to be achieved.

For achieving these science achievement objectives, this learning area is organized into the following five ‘strands’:

- Living world
- Planet Earth and Beyond
- Material World
- Physical World
- Nature of Science

The Nature of Science strand is an overarching and unifying strand and compulsory for all students up to year 10, while the other four strands cover a broad picture of what constitutes the canonical content of science (Hipkins, 2013). Moreover, these latter strands are intended to serve as contexts for learning while at the same time being woven together with the Nature of Science strand.

Each strand has specific achievement objectives organized according to the levels at which students are progressing in their learning. Hipkins (2013) highlighted the nature of science in

The New Zealand Curriculum based on the more visible outcomes of learning through the study of science: investigating in science, understanding about science, communicating in science and, participating and contributing. In simple words, students are expected to learn what science is and how scientists work, as in how scientists carry out their investigations. Students should develop the skills, attitudes, and values that are required to build a foundational understanding of the world. Students should also learn how scientific concepts are communicated and how to draw the relationship between scientific knowledge, and everyday decisions and actions.

My study focused on science teaching practice, so it ties with the Material World strand of *The New Zealand Curriculum*. The Material World strand deals with the properties of matter, composition, changes that occur in matter, and laws and principles that govern this change. In the Material World Strand, students develop an understanding of the composition of matter in terms of particles (atoms, molecules, ions, and subatomic particles), structures, and the interactions among atoms present in a molecule. Furthermore, they need to understand and use fundamental concepts of materials. The second aspect of this strand has to do with chemistry and society. This learning helps students create make connections between the concepts of chemistry and their applications. Studying the Material World should also lead to the development of an understanding of the role of chemistry plays in society (Ministry of Education, 2007).

This study involved science teachers teaching Year 10 students, meaning these students were learning at Levels 4 and 5. According to the (Ministry of Education, 2007), students in level 4 should have opportunities to understand the chemical and physical properties of different materials based on observations and measurements. This learning can help students to compare the properties and changes (physical and chemical) of different materials. The student should develop an understanding of the particle nature of matter and use this understanding to explain observed changes in matter. Furthermore, they should also be able to relate these observed chemical and physical properties of different materials to technological uses and the natural processes that occur in society.

During level 5, students should investigate the chemical and physical properties of different groups of substances such as acids and bases, fuels, and metals. These understandings can assist students to distinguish between pure substances and mixtures, elements and compounds, and mixtures and compounds. Students should learn to describe the structure of the atoms of different elements and be able to distinguish between an element and a compound at the particle level. This learning can help students to create a link between the properties of different substances (learned in school) that are naturally present in substances used in society.

Each objective in this strand is divided into two focuses; learning in the classroom and its application in society. The curriculum suggests that both students and teachers should be actively involved in the learning process. For achieving these objectives, a science teacher should act as a knowledgeable and skillful guide or facilitator so that they assist students in the construction of learning while enabling them to reflect on how this learning has implications for the function and nature of society. This study draws from already established literature about New Zealand science teaching practices and the recommended pedagogies relating to teaching a particular area of science. The next section discusses science teaching practices in New Zealand classrooms and the pedagogies recommended by *The New Zealand Curriculum*.

2.6 Science Teacher Practice in New Zealand

The educational context is a vital aspect of the teaching process, particularly, in adopting the pedagogy. For example, the science teacher would be able to demonstrate a flame test activity in the classroom to show the colors of salt, if the school has the required apparatus. To gain an understanding of New Zealand classroom practice, it then becomes necessary to examine the literature concerning classroom practice. This section therefore involves a discussion of science-teaching practice in New Zealand, the pedagogies recommended in *The New Zealand Curriculum*, and the learning trends of science students in New Zealand.

New Zealand is a multicultural country, the reflection of which can be observed in the New Zealand classrooms. To provide an example, in this project, the class of students that was observed was made up of Pākehā (non-Māori of European descent), Māori and Asian students (see Subsections 4.2.1 and 5.2.1 for more details). Teachers set up learning environments in response to the demographic of their students; which is to say, effective teaching practice is not absolute; teaching practice must vary from context to context (Parr & Limbrick, 2010), and therefore teachers need to modify their classroom practice according to the context. In a systematic review of effective literacy teaching, Hall and Harding (2003) found "effective teachers … have a wide and varied repertoire of teaching practices and approaches … and they can intelligently and skilfully blend them together in different combinations according to the needs of individual students" (p. 3).

Within the context of my study, “in Aotearoa New Zealand representation describes prioritizing Māori involvement at all stages to ensure suitable inclusion of Māori knowledge, expectations, and perspectives in all development” (Averill & McRae, 2020, p. 7). The involvement of each student in a science classroom during the construction of a concept reflects a teacher’s teaching expertise. This expertise signifies the effective management of the challenges in a multicultural context – such challenges as those faced by New Zealand science teachers. As argued, “improving NOS [Nature of Science] understandings is just one aspect of these challenges. Many New Zealand teachers will not feel confident that they have the necessary understandings of Māori culture and worldviews” (Waiti & Hipkins, 2002, p. 5). Besides, the science curriculum promotes a learner-centered approach in the classroom which acknowledges the New Zealand educational context (Hume & Coll, 2008). The management of the multicultural context requires teachers to have a sound knowledge of the cultural background and worldviews of their students so that their teaching practice is reflective of effective science teaching.

Additionally, Bishop, Berryman, Cavanagh, and Teddy’s (2007) research on Te Kōtahitanga discusses the New Zealand classroom and examines how New Zealand teachers should build a supportive, secure, and well-managed learning environment for their students (Te Whakapiringatanga). They can use a range of strategies to promote effective relations with their learners (Te Ako) which significantly contribute to the positive outcomes experienced by learners. Bishop et al. (2007) provide an image of New Zealand teachers in the classroom and their active participation in enhancing student learning. Furthermore, these researchers (Bishop et al., 2007) claim that positive teacher-student relationships and the quality of teacher-student interactions are the foundation of effective student learning. This view of the New Zealand context is supported by Averill (2009), as she found positive teacher-student relationships enhanced student achievement in mathematics.

In the New Zealand context, the positive teacher-student relationship is assisting classroom practice for raising student learning (Averill, 2009; Bishop et al., 2007), and it is also important to understanding the biotic context of the classroom in New Zealand. Gadd (2014) discusses several studies from around the world, including New Zealand, and reports that positive teacher-learner relationships are closely linked to high literacy achievement. Moreover, it is claimed that positive relations influence students in a multitude of ways such as better attendance, high achievement scores, and feelings of connectedness to the school (Ransom, 2019). How New Zealand teachers' actions promote learning in the classroom is discussed in Subsection 2.6.1. When discussing the nature of the relationship between effective teachers and successful learners in practice, some terms often emerge such as *positive*, *close*, and *caring* (Gadd, 2014). To this effect, teachers in the New Zealand classroom would seem to facilitate through caring and generating relationships with students that help them to improve their learning. Ualesi & Ward (2018), for their part, found that New Zealand science teachers have a positive attitude towards teaching science.

The New Zealand Curriculum also suggests that teachers should create positive relations with students to create a positive learning environment. According to Wentzel (1997), the indicators of positive student-teacher relationships in classroom practice are that the teacher "makes a special effort", "teaches in a special way", "makes the class interesting", "talks to me", "pays attention", "asks questions", "listens", "trusts me", "tells you the truth", "asks what's wrong", "talks to me about my problems", "acts as a friend", "asks if I need help", "takes time to make sure I understand", "calls on me", "checks [my] work", "tells me when I'm doing a good job" and "praises me" (p. 416). Such positive relationships are a benefit for students and teachers (Ransom, 2019; Wentzel et al., 2016). In the New Zealand context, ERO (2018) suggests that:

> Teachers who engage with their students in this way come to understand them better, gaining insight into their aspirations and the communities to which they belong. This makes it easier for them to meet their students' needs and ensure that learning is both relevant and challenging. (p.11)

It has been advocated for some time that New Zealand classroom practice be based on a constructive scientific approach where teachers are actively engaged to develop relations with students for enhancing the student outcomes (Garbett, 2011; Moeed & Anderson, 2018). To create such a learning environment such that science is made more understandable to students, *The New Zealand Curriculum* recommends that science teachers use particular pedagogical approaches. The upcoming subsection provides some detail on these pedagogies.

2.6.1 ***Pedagogies recommended in The New Zealand Curriculum***

The teacher converts the content into teachable content and practices this teachable content in the classroom by using their knowledge and skills. A teacher's subject matter knowledge and skills play a vital role in effective teaching. Bull et al. (2010) explain, stating that:

> [s]ubject matter knowledge is framed to meet educational goals rather than being taken directly from the discipline from which it is drawn. It is packaged and presented to students in ways that take account of learning theory as well as students' ages, interests, and abilities. (p. A-12)

There is not a surety about learning for each student in a single context, but there is some evidence about teaching approaches that promote students' learning. *The New Zealand Curriculum* has a section "Effective Pedagogy: Teacher actions promoting students learning" (Ministry of Education, 2007, p. 34) that recommends teachers' actions in the classroom. This document discusses teachers' seven broad actions to make classroom practice effective: teachers should create a supportive environment, encourage reflective thought and action, enhance the relevance of new learning, facilitate shared learning, make connections to prior learning and experience, provide sufficient opportunities to learn and inquire into the teaching-learning relationship (Ministry of Education, 2007). *The New Zealand Curriculum* describes teaching actions that have been shown to consistently have a positive effect on student learning (ERO, 2018). However, *The New Zealand Curriculum* (Ministry of Education, 2007) also emphasizes that teachers should improve their teaching by inquiring into their own effectiveness. This recommended teacher practice is seen in New Zealand secondary schools (Moeed & Anderson, 2018). The book *Learning through School Science Investigation: Teachers Putting Research into Practice* by Moeed and Anderson (2018) presented outcomes of the two-year classroom research project set in the New Zealand primary and secondary school context and funded by the New Zealand Ministry of Education Teaching and Learning Initiative. These researchers found that secondary school teachers in New Zealand have changed their practices through an iterative process of teaching reflection and teaching review (Henderson, 2020).

According to *The New Zealand Curriculum,* creating a supportive environment includes establishing good relationships between the student's culture, home, and school so that parents and Whānau (family) become actively engaged in the learning of their children. Teachers are advised to look for opportunities to directly involve students in their own learning decisions and facilitate shared learning: students learn when engaging in shared practices and conversations with others, including family members and any other community members (Ministry of Education, 2007). Teachers may encourage this process by cultivating the class as a learning community. By making connections to prior learning and experience, teachers can facilitate their students towards making connections across learning areas as well as to their prior learning. Providing sufficient opportunities to learn, it is important to include practical learning opportunities because if these opportunities are used properly, they can empower students, and enrich and expand their learning experiences. Inquiry into the teaching-learning relationship or teaching as inquiry, means here that good pedagogy allows teachers to examine the effects of their teaching on their students. For example, the ERO (2018) elaborates teachers' actions in teaching as inquiry: "formative assessment provides evidence for the learner and teacher about progress and about areas that need to be addressed, and suggests how the curriculum itself might be refined" (p. 12).

The science learning in *The New Zealand Curriculum* is underpinned by ideas of constructivism (Garbett, 2011). Constructivism, as a learning theory, emerged from cognitive science and attempts to explain how individuals construct new knowledge from personal experience, such that they can integrate their thinking with existing knowledge and, as such, make a sense of that knowledge (Tobin, 2007). Ferguson (2007) has reviewed different kinds of constructivism, including personal or cognitive constructivism, social constructivism, radical constructivism, critical constructivism, and contextual constructivism. Personal constructivism refers to the personal construction of meaning by an individual, where the student brings this knowledge into the classroom; something that highlights the importance of teachers' interest in students' prior knowledge (Moeed, 2010).

Social constructivism relates to the learning of an individual through interactions with people. This knowledge is constructed, as Bell and Gilbert (1996) note, through a variety of social interactions within society. Contextual constructivism describes how human knowledge and life are nurtured by the context (Bell, 2005). McDowall & Hipkins (2019) found, within the New Zeland context, that teachers who take an integrated approach across the curriculum, find benefits:

> In response to eight Likert-scaled items describing potential positive and negative impacts on their work, just under three-quarters of the teachers indicated that when teaching using an integrated approach they found it: easier to explore authentic issues and contexts (74%); more stimulating to work with another teacher (72%); or more engaging for them as a teacher (68%). (p. 2)

On the positive side of the above finding, teachers' work with a more experienced and skillful teacher may provide the teacher with a chance to develop their PCK. The observation of more experienced teachers can deepen their PCK (McDowall & Hipkins, 2019). This contextual constructivism in New Zealand schools has the effect of nurturing the teachers' knowledge and skills while also indicating what their direct impact is when developing and practicing PCK in classrooms. In this study, a social view of constructivism has been adopted as our understanding of this form of constructivism aligns with the CM, which in turn is influenced by social interactions in the classroom, teacher beliefs, and context in which these phenomena impact as amplifiers and filters of content. The teachers' adoption of pedagogies in the classroom and the overall central purpose of an educational process can therefore be said to be constructing learning in students. The upcoming subsection discusses the trends in science learning of New Zealand students.

2.6.2 *New Zealand science students: The trends in the learning of science*

The pedagogies recommended for science teaching in *The New Zealand Curriculum* have been based on constructivism, meaning science teachers use different practices in the classroom and according to the needs of the learners and the concepts being taught. Baviskar, Hartle and Whiney (2009) state that there are four characteristics to a constructivist pedagogy: eliciting prior knowledge, creating cognitive dissonance, the application of new knowledge with feedback, and reflecting on learning.

On the science teachers' end, they concentrate on students' learning by using constructive approaches as recommended by national documents. In constructivist teaching, the first step involves eliciting the accumulated prior knowledge of the learner (Baviskar et al., 2009) while focusing on identifying the current ideas of students (Garbett, 2011). The teacher can gather prior student knowledge through informal questioning, the use of portfolios, discussion, pre-tests, and concept maps. The second feature of constructivism is related to task selection, where the teacher assigns a task, leaving students to derive new ideas from the task. Using this approach, the teacher finds out how students make new links to their existing constructions of knowledge while clarifying the use of alternative conceptions (Baviskar et al., 2009).

It has been noted that students consider science subjects to be more difficult or sometimes boring when considering their learning in the arts and social science subjects (Delpech, 2002). In New Zealand, it has been observed that students have a variable interest in science during their schooling, and "some studies indicate that many New Zealanders' levels of understanding of and interest in science are not as high as they could be and the number of young people choosing to study science at school once it is no longer compulsory is steadily decreasing" (Bull, Gilbert, Barwick, Hipkins & Baker, 2010, p. A-11). On the other hand, New Zealand students have gained excellent results in science and mathematics, as can be seen in, for example, the Programme for International Student Assessment (PISA). According to 2018 PISA survey findings, New Zealand 15-year-olds scored above the average in each of the three subjects (Science, Mathematics, and Reading) among Organisation for Economic Co-operation and Development (OECD) countries and New Zealand ranked 7th out of 36 for science (OECD, 2018). Additionally, Bull et al. (2010) note that there is also a significant number of New Zealand students who do not do very well in science, moreover, many students in New Zealand have developed negative attitudes toward science during middle school years (Bull et al., 2010). It is within these contexts that science teachers are constantly challenged to make science teaching comprehensible and interesting for students. This highlights the need for teachers to give special attention to evaluating and assessing their students' learning and preparing them for achievement. The next section involves a discussion on the assessment system at the secondary level.

2.6.3 *Assessment in New Zealand secondary schools*

Assessment in schools is usually understood to comprise a mixture of formative and summative assessments. Formative assessment is a process in which teachers recognize and respond to student learning during teaching, for the purpose of enhancing that learning (Bell & Cowie, 2001). On the other hand, the purpose of summative assessment is to monitor educational progress as policymakers, educators, parents and the public want to know to what extent learners are meeting the current standards (Bell & Cowie, 2001). This type of assessment is often used at the end of a teaching period and can provide a teacher and their students with overall feedback about a student's progress in their learning. In this study, the focus will mainly be on examples of formative assessment, and how the teacher uses this assessment in the classroom, and what students do in response to the feedback they get.

Students in New Zealand need to attend school until they are 16 years old. The New Zealand secondary school is also known as high school or college. Secondary school education starts when students are 12 or 13 years old and lasts for 4 or 5 years, from Year 9 to Year 13. In New Zealand, all national secondary qualifications are monitored by the Government and education sector agencies. The main qualification that secondary schools offer is the National Certificate of Educational Achievement (NCEA), which is a standards-based assessment system. A student's grades in NCEA are dependent upon their level of knowledge or ability. Students in each of these years need to meet a set of standards offered that are set by their particular school.

There are both internal and external assessment standards. All standards assessment is managed by the New Zealand Qualification Authority (NZQA) with whom schools work in partnership to realize the assessment of students for national qualifications. The complete assessment consists of two major steps: the internally assessed standards are administered and assessed by schools with consent from NZQA. Secondly, there are external assessments of examination papers or portfolios, and this external assessment system is run by NZQA. Students are usually assessed during their last three years at school (Years 11 to 13). Students can achieve NCEA at 3 levels in a wide range of courses and subjects (NZ Govt, 2017).

Some schools prepare their students for other assessment systems, like the International Baccalaureate (IB), and Cambridge International Examination (CIE). The International Baccalaureate two years Diploma program (equal to NCEA levels 2 and 3) comprises six sections: language, second language, individuals and societies, experimental science, mathematics and computer science, and the arts. The Cambridge International Examination system involves three years of study across Years 11-13. Successful students in this examination are awarded the International General Certificate of Secondary Education (IGCSE). Both of these programs are recognized internationally.

Generally, the Year 10 assessment takes the form of tests, portfolios, and exams to prepare students for the qualifications they will be assessed for in Years 11-13. The Year 10 class students are involved in my study but their academic outcomes are not part of the research data. Nevertheless, an important aspect of this study involves the need to recognize how science teachers use their assessment knowledge and skills in practice.

The literature review provides a foundation for a conceptual framework to guide this study.

2.7 The Conceptual Framework of the Study

This study is focused on the classroom practice component of the first PCK consensus model because it is a dynamic component of this model in which teachers utilize their knowledge and skills as PCK in the classroom, when teaching for students to achieve their learning outcomes. The conceptual framework (Figure 2.12) has been based on the Consensus Model (CM) of 2015 (Gess-Newsome, 2015) and includes small changes to their components, for instance, teacher orientation is not considered part of teachers' Amplifiers and Filters for this study because the literature on the orientation of teaching provides different definitions which mostly overlap with other components of Amplifiers and Filters (see 2.3.7). The other change is the addition of Contextual Knowledge in the top box. During piloting of my method and instruments (see Section 3.4.1), I noted that teachers generated examples by using contexts, used classroom context to facilitate science teaching, and assigned contextual based projects that reflected their Contextual Knowledge. This knowledge has also been discussed by researchers as a PCK component (Grossman, 1990; Mavhunga & Rollnick, 2013; Shulman, 1986), therefore I considered Contextual Knowledge in this study to investigate this component in PCK. The remainder of the components are the same as presented in the CM of 2015.

According to the CM, there are two pathways between professional knowledge bases TPKB and classroom practice: the direct path and the indirect path. The direct path shows teachers' direct usage of these knowledge components in classroom practice without passing through the Topic-Specific Professional Knowledge (TSPK). For example, teachers may use Assessment Knowledge in planning and teaching. On the other hand, the indirect path insinuates that the teachers would combine their TPKB knowledge components with TSPK knowledge components. Then teachers apply these knowledge components into practice through passing through their Amplifiers and Filters (Beliefs, Prior Knowledge, and Context). My study examines both trajectories of teachers between their professional knowledge bases and classroom practice.

Classroom practice consists of two main components: teaching practice and the classroom context. When the teacher interacts with their students in the classroom, teachers' knowledge components and classroom context merge to become one process. In other words, teachers' PCK/PCK&S and the classroom context become a single process in the classroom where the boundary between them is no longer evident (Gess-Newsome, personal communication, July 18, 2017). The conceptual framework for this study illustrates this relationship with the use of a double-headed arrow between them (see Figure 2.12).

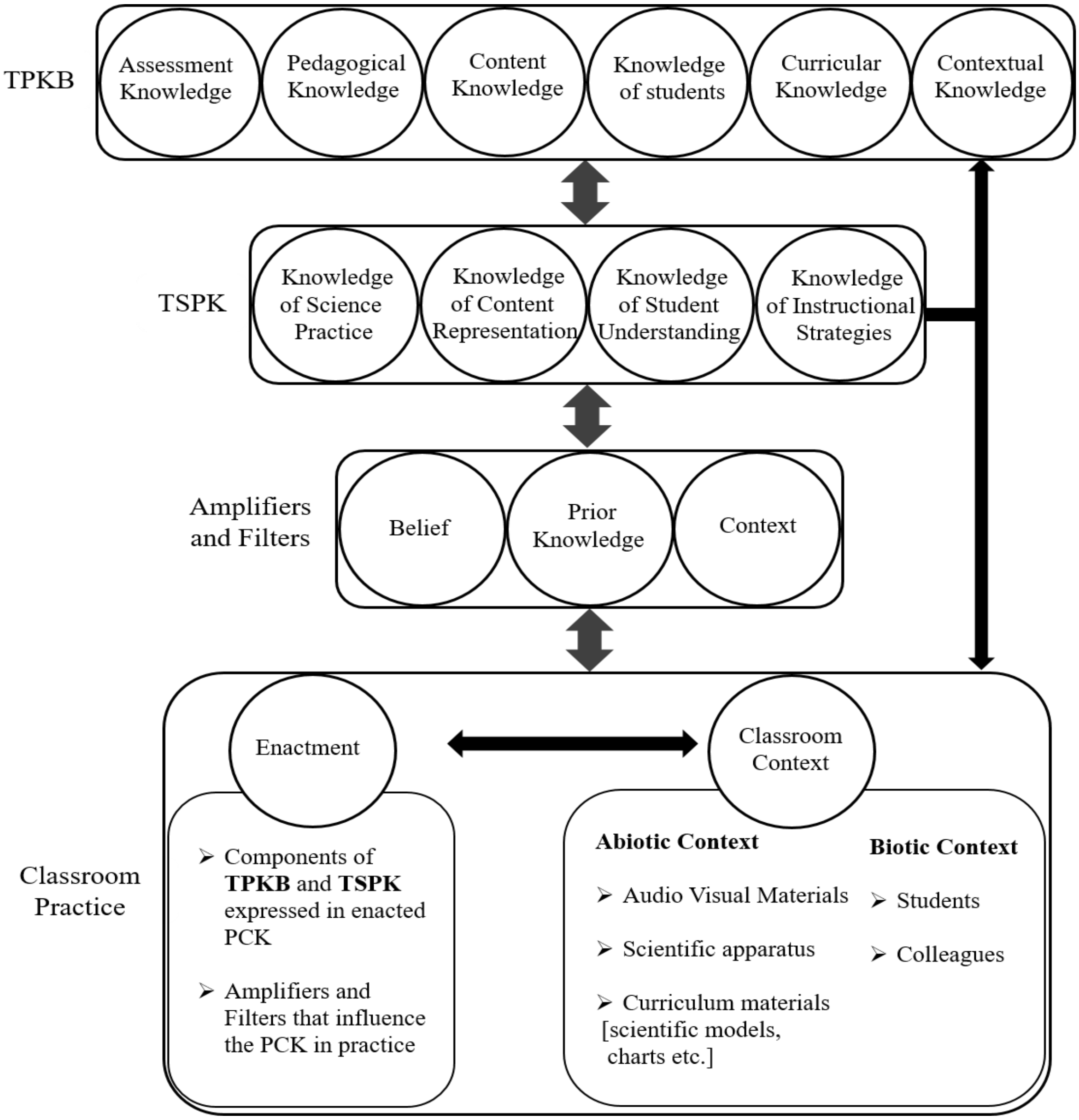
The teachers' actions in the classroom, grounded in PCK, have become known as PCK&S (Gess-Newsome, 2015). The enacted PCK signifies teachers' knowledge and skills for the transfer of specific knowledge components into practice by the involvement of available biotic and abiotic sources for the enhancement of student learning (Carlson & Daehler, 2019). Moreover, Alonzo et al. (2019) divided teachers' enacted PCK into three phases: enacted PCK in planning (ePCKp), enacted PCK in teaching (ePCKt), and enacted PCK in reflection (ePCKr). The combinations of knowledge components and skills (PCK&S) that are used by teachers for the enactment of PCK in their teaching process underpin this conceptual framework. The left-hand element in the bottom box of Figure 2.12 suggests all components of TPKB and TSPK may contribute to enacted PCK, and teachers' amplifiers and filters may influence their enacted PCK.

In the New Zealand context, in order to establish constructivist-based pedagogies, as recommended by *The New Zealand Curriculum* (Ministry of Education, 2007), a teacher should have strong PCK and skills to engage students in science learning. Garbett (2011) argues that "[t]eaching using a constructivist approach emphasizes the role of pedagogical content knowledge and a teacher's ability to engage their learners in knowledge construction" (p. 38). The CM model shows that teachers need knowledge and skills to update their knowledge-base after each classroom practice. Moreover, *The New Zealand Curriculum* emphasizes this aspect in "teaching as inquiry" (Ministry of Education, 2007 p. 28). The double headed arrows between blocks in Figure 2.12 show this relationship (i.e. teaching as inquiry) between classroom practice and knowledge bases.

The second component of classroom practice (classroom context) is not completely described in the Consensus Model, for instance, it does not explain what constituents are included in the classroom context, except when indicating that constituents are mere "curriculum, etc." (Gess-Newsome, 2015, p. 31), meaning they might include students, colleagues, teaching-related materials, etc. For this study, the New Zealand science classroom is divided into two main categories: the biotic and abiotic contexts, which are displayed in the right side box at the bottom. The biotic context embraces (observed) class students, teachers, and teacher colleagues of research participants. Students may be the most important element of the biotic context (for example, low ability, less motivation, etc., and students' cultural backgrounds such as Pakeha, Māori, Asian, etc.). If a teacher's colleagues (for example, teacher aide, other teachers, lab assistant, etc.) help and assist the research participant during teaching, planning, or teaching reflections, then they could be considered to be part of the biotic context. The physical context of the classroom and the science laboratory refers to the abiotic context, for example, audio-visual material, scientific apparatus, science models, science charts, etc. This study only focused on teachers' knowledge combinations in their classrooms and did not include its impact on student outcomes, therefore student outcomes is not a part of the framework. Teachers' PCK involved the knowledge components for teaching to enhance student learning. The CM suggested a relationship of teachers' professional knowledges with student outcomes that stretches its implication beyond teachers' PCK. The CM is not a model of PCK: it is a Model of Teacher Professional Knowledge and Skills including PCK. All previous PCK models indicate that examining teachers' PCK does not need to include student outcomes. This study had no aim to see the relationship of teachers' PCK and student outcomes so that a strong focus on the teacher could be maintained.

Figure 2.12

The conceptual framework for this study



The above Framework illustrates how practicing teachers may include TPKB and TSPK components into classroom practice. Teachers' amplifiers and filters were also noted during their utilization of this set of knowledges through using their skills. Biotic and abiotic contexts are also considered as an essential part of classroom practice and their influence on the transfer of PCK into practice.

2.8 Summary

A chronological review of the three decades of PCK studies showed the existence of some relations between different PCK models that enhanced my understanding of PCK. Now, PCK is a part of the consensus models: here PCK is linked to other elements of teachers' aspects (i.e. Amplifiers and Filters), teaching context (i.e. classroom practice), and impact of teaching (i.e. student outcomes). Beside this, it was perceived as a teacher knowledge (i.e. PCK) as well as a practice knowledge (i.e. PCK&S). These Consensus Models are theoretical constructions with novel ideas presented by a group of PCK experts in PCK summits. The PCK experts emphasized the need to test those consensus models in the classroom. These ideas created a gap to understand the dynamic behaviour of PCK. This gap motivated me to examine teachers' PCK in their classrooms. Therefore, the first Consensus Model is set as a framework of the study. The research involved a detailed examination of how teachers combined their knowledges to facilitate their teaching in the classroom.

The next chapter provides detail on the methodological aspects of this study the construction of research tools, the data collection process, the analytical framework used to examine the data and other research aspects.

Chapter 3
Methodology

3.1 Overview

This chapter describes the methodology of this study. Firstly, it reiterates the research questions that guided the study and this is followed by the theoretical considerations of the study. Secondly, the chapter deliberates the paradigm of the study and discusses ontological, epistemological, methodological, and axiological stances of this research. Thirdly, the methodology section explains the research tools and data collection procedure. Fourthly, it presents the analytical framework of this study. Finally, the chapter presents a brief description of the quality procedures of this study and the data analysis and ethical processes, followed by a chapter summary.

3.2 Research Questions

The question that guided this study is:

> RQ: How do science teachers combine the knowledge components within their Pedagogical Content Knowledge (PCK) in their classroom practice?

3.3 Theoretical Considerations

Educational research takes place in a complex environment by involving students and teachers with influences of other factors [e.g. school management, educational policy, personal beliefs] (Wiersma & Jurs, 2009), and such influences convert it into a vastly complex and demanding task in a context. To address this complexity, researchers approach their work from a variety of theoretical viewpoints and methodologies, when they aim to research in an educational context (Labaree, 2003). It is helpful for educational researchers to have a sound understanding of the philosophical bases that support educational research, so the upcoming subsections of this part discuss the paradigm choice, and its ontological, epistemological, axiological and methodological positions in this educational study.

3.3.1 *The paradigm of this study*

The research inquiry is interwoven with the dichotomy of objectivity and subjectivity, and within these different approaches, various researchers rely on a paradigm for its basic philosophy (Henry, 2015). The term *paradigm* was first used by American philosopher Thomas Kuhn (1962) in his book *The Structure Of Scientific Revolutions* and it indicates a philosophical way of thinking (Kivunja & Kuyini, 2017). A research paradigm is a set of beliefs that attempts to explain the individual's perception of the world and it serves as a thinking framework that guides the researcher (Jonker & Pennink, 2010). In educational research, it is referred to as a researcher's worldview (Mackenzie & Knipe, 2006), human construction (Denzin & Lincoln, 2000), and set of beliefs that guide the study (Guba & Lincoln, 1994).

Experts in the field of research have currently classified all proposed paradigms into four groups: positivism, interpretivism, critical, and pragmatic paradigm (Kivunja & Kuyini, 2017). The positivist paradigm is generally connected to scientific methods (Mackenzie & Knipe, 2006), and in this paradigm research proceeds on deductive logic, hypothesis, experimentation, calculation, extrapolation, and expressions to drive conclusions (Kivunja & Kuyini, 2017). In contrast, interpretivism deals with human actions in a real context (Ma, 2016), and the critical or transformative paradigm addresses the political, social, and economic issues (Kivunja & Kuyini, 2017). The pragmatic researcher focuses on the *what* and *how* of the research problem using methods that are seen to provide insight into the problem (Creswell, 2013).

To identify the locus of my study, method, and research tools within a paradigm, I examined research approaches, methodology, and data collection tools according to the paradigms in educational research (e.g. Creswell, 2013; Kivunja & Kuyini, 2017; Ma, 2016; Mackenzie & Knipe, 2006). This study aimed to investigate teachers' PCK/PCK&S in their classroom, thus it included the interpretation of teachers' knowledge and skills in the classroom context. When I interpret the actions and knowledge of research participants in their classroom, I acted as an inquirer who also constructs meaning through reflection. As I interpreted the classroom practice and constructed meaning, put simply, the interpretation itself constructs. Schwandt (1998) professed this idea as "To prepare an interpretation is itself to construct a reading of these meanings; it is to offer the inquirer's constructions of the actors one studies" (p.222). Interpretivism deals with human actions in the real world, in this case the teachers' practice, so interpretivism made a good choice for the paradigmatic lens for this study. Interpretivism reflects the narrative of human actions as being tied to specific social, historical, and cultural contexts (Ma, 2016). The interpretive research paradigm is a form of a researchers' subjective point of view and pursues an explanation within the context of the participant rather than a simply objective observer (Ponelis, 2015). Thomas (2009) described interpretivism's pattern in research as:

> The main point about interpretivism is that we are interested in people and the way that they interrelate - what they think and how they form ideas about the world; how their worlds are

> constructed. Given that this is the case we have to look closely at what people are doing by using our own selves, our own knowledge of the world as people. We have to immerse ourselves in the research contexts in which we are interested - for example talking to people in depth, attending to every nuance of their behaviour, every clue to the meanings that they are investing in something…The key is understanding. What understandings do the people we are talking to have about the world, and how can we in turn understand these. (p.75)

This view discloses that interpretivists generally go with mostly qualitative methods by selecting methodological approaches such as case study, grounded theory, phenomenology, ethnography, action research, etc. and researchers mostly collect data through interviews, observations, document review, and audio and video data analysis.

A paradigm can be divided into four components to elaborate on the phenomena by raising questions associated with ontology, epistemology, methodology, and axiology. The position of my study in this paradigmatic division and how it helps to investigate the teachers' teaching are discussed in the following subsections.

3.3.2 *The ontological stance of this research*

I was interested to find evidence of teachers' use of PCK/PCK&S during their chemistry teaching practices in the classroom. The teachers' knowledge and actions also reflect their personal attributes [e.g. beliefs, prior knowledge, cultural meaning] that affect their practice. As an educational researcher, I needed to explore the ontological considerations of this research to understand what is actually happening in practice when teachers use PCK.

Generally, ontology discusses the questions about what is reality or being real (Creswell, 2013) and these same questions are also debated in the social research world (Thomas, 2009), but in a social phenomenon, a single situation might have multiple realities. So, "it is concerned with the assumptions we make to believe that something makes sense or is real, or the very nature of reality and what you believe can be known about reality" (Kivunja & Kuyini, 2017 p. 27). It reflects that an individual sees or creates reality by using the lens of their experience, beliefs, and knowledge.

A dichotomy is present in ontological stances about the existence of reality, especially when it deals with a social phenomenon; from an ontological objectivist point of view, the reality is independent of social actors, while in contrast, ontological constructivism views that a phenomenon and its meaning is given by the individual (Bryman, 2016). In my ontological point of view about a social process, I believe that the value-free social actor does not exist, and my experience with diverse teachers [different background, experience, context, schooling, teaching subjects] during my teaching and research career imbued in me that each teaching session and context can alter the teachers' thinking about students, their own teaching, planning, and even practice of particular teaching methods for particular concepts for particular students, which leads them to reshape their PCK. Guba & Lincoln (1994) elaborated that constructivism is more aligned with the educational context: reality is intangible, shaped by experiences of the world and it is dependent on the individual who experiences it, and can be developed with new knowledge. For this research, I endorse an ontological constructivism view, as outlined in these above views, so my standpoint is that teachers' skills and knowledge are determined by not only their individualities but also depend on interaction with students.

Ontology does not discuss *how* a teacher deals with students and *what* is the source of knowledge. To find the answers to these questions in this study, I need to adopt or discuss its epistemological aspect.

3.3.3 *Epistemological stance of this research*

In philosophy, epistemology underpins the questions associated with knowledge, such as it deals with *what* we know and *how* we know (Creswell, 2013). In detail, it is concerned with knowledge bases, nature, forms, how it is gained, and how it is communicated with other humans (Kivunja & Kuyini, 2017). Furthermore, Kivunja and Kuyini (2017) suggested to researchers to ask questions like, "what is the nature of knowledge and relationship between the researcher and the would-be known? What is the relationship between me as an inquirer, and what is known?" (p. 27). These recommended questions directly deal with an investigation of truth, to understand the knowledge, and what counts as knowledge.

Before deciding my epistemological position for this study, I explored more in the literature about sources of knowledge and their relation with this type of philosophy. Slavin (1984) described four sources of knowledge and they are intuitive knowledge, authoritative knowledge, rational/logical knowledge, and empirical knowledge. The epistemological base becomes intuitive if it relies on beliefs, faith, intuitions, etc. If data are gathered from books or leaders in the organizations then epistemology is grounded on authoritative knowledge. In rationalist/ logical epistemology, research data stress reasons or logic as the surest path to knowing the truth. If data emphasizes the understanding that knowledge is best derived from a sense of experience, is demonstratable, and has objective facts then the research approach is empirical epistemology (Kivunja & Kuyini, 2017).

In considering these four types, the epistemological position of this study leans towards empirical epistemology because the teachers in my research were delivering their teaching in the natural teaching style in the classroom according to their schedule. I observed their teaching practice, and located knowledge components in teaching by using the PCK consensus model of 2015, in order to understand their science teaching through my own teaching experience and knowledge of literature.

Specifically, in my study, the empirical epistemology deals with questions allied to knowledge components in teaching practice, and a researcher is required to adopt a methodological frame to conduct research and the next subsection discusses these issues in my work.

3.3.4 ***The methodology stance of this research***

In broad terms, in methodology, a researcher plans all phases of a study to conduct research step by step to meet the objectives. The researcher deals with questions in advance in this methodology such as: what instruments are appropriate for data collection, what are suitable criteria to select participants, how, who and when will I collect data, etc. According to Kivunja & Kuyini (2017), methodology articulates the logic and flow of the research process in conducting a research project. All data were collected for this project in a natural situation and so the process established for this methodology was naturalistic. The methodological process and logic to adopt that particular process, development of research instruments, and data analysis for this study are discussed in Sections 3.5 and 3.6 *Data collection* and *Research Tools* later in this chapter.

Methodology and ethical issues are linked to each other (Rozsahegyi, 2019a), thus it is important to understand the questions related to *values* in the study; the next subsection explains the values concerns of this project.

3.3.5 ***Axiology stance of this research***

This study collected data in New Zealand classrooms, whereas I have not grown up in this country and have little knowledge about this contextual background, so this study requires me to present a strong axiological consideration to conduct this project. Axiology refers to the research values in planning a research project and it involves defining, evaluating, and understanding ethical rights and wrongs in research (Kivunja & Kuyini, 2017). Moreover, these researchers quoted axiological questions for planning research with humans that are indicated by the Australian Research Council (2015). Those questions are:

> What values will you live by or be guided by as you conduct your research? What ought to be done to respect all participants' rights? What are the moral issues and characteristics that need to be considered? Which cultural, intercultural, and moral issues arise and how will I address them? How shall I secure the goodwill of participants? How shall I conduct the research in a socially just, respectful, and peaceful manner? How shall I avoid or minimise risk or harm, whether it be physical, psychological, legal, social, economic, or other? (p. 28)

These questions illustrate that this aspect of philosophy is concerned with the context of a study such as participant rights or culture; the participants' rights and culture vary from nation to nation, for instance, culture in Australia and the right of research participants may be different from other countries such as New Zealand. New Zealand classrooms are the context of this study, so the upcoming paragraphs discuss the values, conduct, rights of the participants and researcher in studies in New Zealand.

The National Ethics Advisory Committee (NEAC) of New Zealand (2012) discusses in detail the values related to human research in New Zealand under the categories: respect for people, Māori and ethical considerations, justice, beneficence and non-maleficence, integrity, diversity, and conflict of interest. Here, respect for people or participants refers to participants' rights during research. It incorporates two fundamental principles: autonomy and protection of people. Autonomy means in this document that people should be treated with respect for their capacity for self-determination. The second principle indicates that people who are dependent or vulnerable be afforded security against harm.

In the justice subsection of this document, a strong case is made for balanced axiology in the New Zealand context. Justice is a fair distribution of burdens and benefits of participation in research. This committee (NEAC) emphasized the following suggestions for a researcher: firstly, they must avoid imposing on specific people and group of participants an unfair burden and benefit of the research; secondly, the design of study must provide fair conditions of inclusion and exclusion in the study for each participant. Considering justice in research also emphasizes that a researcher does not discriminate on the grounds of ethnicity, age, sex, disability, religion, etc. in the selection of research participants. Balanced axiology was selected for data collection of this study to share the burden of research among participants: a complete chemistry topic was observed for each teacher participant and all data for this research was equally gathered from each participant within a set period.

To sum up, the elements of the interpretive paradigm for this study are empirical epistemology, constructivist/relativist ontology, naturalist methodology, and balanced axiology. I interpreted my observations of the science teachers' teaching practice and the teachers' views of their own practice by using a PCK model and my experience in the science teaching field. I adopted a constructivist/relativist ontology because this study investigated the teachers' unique knowledge and skills for teaching and their realities by exploring their reasoning behind their actions in the class. I selected naturalist methodology because all data were gathered in a natural setting, for example, the largest chunk of these data were gathered through observations, and video recordings in the natural classroom practice. Balanced axiology was adopted between participants to share the research burden, for example, a complete chemistry topic was observed from both participants' classes.

In this section, I discussed the philosophical questions raised in the research process. The next section elaborates the research approach and describes why it was selected, and what criteria were adopted to select the participants are elucidated in the following section.

3.4 Research Approach

From the last three decades, many researchers have contributed to developing the PCK notion, but there is still less agreement among researchers about what PCK *actually* is (Neumann et al., 2019), and it is not fully defined and developed (Gess-Newsome, 2015). Therefore, this study has aimed to contribute to understanding the nature of PCK, especially teachers' enacted PCK&S in their classroom practices. van Driel, Berry and Meirink (2014) suggested to researchers that PCK research needs to focus on classroom teaching components to investigate how teachers use their knowledge in interaction with students. To investigate teachers' PCK is quite a complex phenomenon, as PCK is a set of implicit knowledge. Thus, different ways have been proposed and evaluated to document and investigate the PCK of a teacher (Fernandez, 2014). Mostly, researchers have used qualitative studies for measuring and constructing the PCK concept, but few have used quantitative or mixed methods. The remaining portion of this subsection discusses the selection of the research approach to this study.

As discussed, the paradigm for this study is interpretivism and interpretivists mainly use qualitative methods in their research (Cohen et al., 2018). Moreover, interpretivists choose qualitative methods due to their epistemological stance of inquiry as human knowledge about the world is socially created, diverse, relative, provisional, and emerging (Ma, 2016). In educational research, qualitative research can focus on the teaching process to get detailed information and thick descriptions of what occurs in the classroom (Merriam, 2009). The nature of this research demanded a qualitative approach.

Specifically, this study used a case study approach to investigate the teachers' PCK/PCK&S in the classroom because it is a suitable method to note the combination of knowledge components by a science teacher during teaching practice. As researchers claim, a case study is considered a strong research method for a project, specifically when a holistic, in-depth investigation is required (Zaidah, 2007), and needs to explore the processes involved (Creswell, 2013). Creswell (2013) defined a case study as a single instance of a bounded system (single case) or multiple (cases) like a child, a school, or a class, whereas Yin (2009) has argued that the boundary between process and its context in the system are not clearly evident. In teaching practice, it is not easy to draw a line between teaching and the context of teaching, but this study focused on only teachers' use of knowledge components and their actions within a context, and the role of their amplifiers and filters when they utilized knowledge components to facilitate teaching. This study didn't account for the students' learning outcomes, beliefs, prior knowledge, etc., except when these elements became a part of the teaching process, for instance, when teachers used question-answer instruction techniques to diagnose students' prior knowledge. During practice, teaching and context are working together and become a single process to achieve the main goal (student learning) of the educational process.

This study explored the teachers' knowledge components and skills in a natural setting so it would explore the biotic and abiotic context of teaching practice when those become a part of teaching. The case study is convenient for investigating or interpreting the natural setting (process and context), and the actions and knowledge of an individual in-depth. The researcher can capture or interrogate the real situation (Atkins and Wallace, 2012), through detailed contextual analysis of events, and their relationships (Zaidah, 2007). The main purposes of the case study are: to portray, analyze and interpret the uniqueness of individuals, to catch the complexity of behavior, and to present and represent the reality to give a sense of being there (Cohen et al., 2018).

Yin (2009) categorizes four designs of case study: single-case, embedded single-case, multiple cases, and embedded multiple-case study. When a researcher studies two or more settings to gather data, then it implies a multiple case study (Bogdan & Biklen, 2003). Multiple case study is selected for this research to examine PCK/PCK&S of science teachers in their classrooms to provide in-depth descriptions. So, two experienced science teachers are the sample of the study, and data were collected when they taught a complete chemistry topic to Year 10 students (14 years old). I collected data from their chemistry teaching in the respective classrooms; these cases were different because their PCK/PCK&S were different due to the context and students were different, and the PCK consensus model indicates these factors can make a difference. The research participants of this study have different experiences, backgrounds, schooling, beliefs, etc., and these features may make a difference in their teaching.

Importantly, as the researcher of this study, I am an international research student: my background, schooling, beliefs are also different from the participants, but we all are from the education sector and have experience of secondary school chemistry teaching. The next subsection describes my background to give context to the study.

3.4.1 *The researcher's professional background*

In the interpretive paradigm, the researchers' point of view, background, and beliefs are important in the contrivance of data, events, the real world, and their accompanying processes. The researcher in this paradigm is free to color the observed situation by using his or her own colored brushes [e.g. background, schooling, and cultural context]. According to Denzin and Lincoln (2000), paradigms are human constructions and their value reflects where the researcher is coming from and, as such, how their ideas are constructed and planted in the data. The concept of PCK has not been adopted in Pakistani documents such as the curriculum, which is to say it is not considered as an essential element for teaching. Furthermore, there are very few contributions by Pakistani researchers in PCK studies, therefore, I could not satisfy my thirst to research PCK in my home country. So, I flew to New Zealand for this purpose. The following paragraphs portray my experience, schooling, and context, and detail some challenges in collecting data in the New Zealand context as an Asian researcher.

Growing up as I did in my Pakistani hometown, I got all my initial qualifications from local educational institutes. The education system and culture of my region are different from what I found in New Zealand, meaning my schooling and cultural background are different from that of my New Zealand research participants. Society, culture, educational context, and schooling play a focal role in the individual's creation of their beliefs, thinking style, and the development of their opinions in relation to the perception of events.

I earned a professional teaching degree level-7 in science education, after which I worked for more than ten years in the teaching profession as a science teacher at a well-reputed teacher training institute in Pakistan. During my professional career, I taught chemistry to high school students, along with other subjects such as the Teaching of Chemistry and the Teaching of Biology to graduate teacher education students. In addition to this work, I observed, evaluated, provided guidance and assessments of pre-service science teachers when on their practicum, twice-a-year over eight years. Furthermore, I have worked as a teacher trainer in different in-service teacher training programs run by the provincial government body. I have developed and designed science teaching training courses, manuals, and materials for teacher trainers.

While this work history involved my evaluation of pre-service teaching students on practicum, working with experienced science teachers in various professional development programs, and interacting with experienced science teachers during my dissertation research for my M.Phil, I didn't have any experience of science teaching and classroom observations in the educational systems of developed countries. This meant I faced new challenges, during the data collection process, such as language, interpreting teacher beliefs, thinking style, research questions, student attitudes towards teachers, classroom discipline, and teachers' classroom management strategies.

I gained an idea of the challenges I was facing during pre-study classroom observations and tried to reduce any difficulties through the use of accessible technologies and the help of New Zealand educators (supervisors and other New Zealand Ph.D. students). For instance, in relation to the fact that I am not a native English language speaker, I video-recorded all the lessons and interviews, which helped me to slow down and pause by listening or re-listening to the audio of participants during the data transcription phase of my research. I also spent some time in the New Zealand classrooms observing other science teachers' practices [of teachers who weren't research participants]. These teachers shared their teaching documents with me and in this way, I captured a real image of classroom teaching practice in New Zealand.

This study began with piloting my method and instruments with each class of participants. The principal aim was to develop, test, and refine the data collection procedure and strategies. This pilot comprised a visit to each class during which I was introduced briefly to the class and then sat silently and observed and videoed one lesson. The purpose of the piloting was also to cultivate a familiarization with the learning context [teachers and students] and to reduce the impact of the researcher's presence within the teaching-learning process. The third purpose of the piloting was to enhance my skills in management and the organization of materials for this project (e.g. camera locus and setting, recorded voice quality, handling observation notes, etc.). My chief supervisor went with me on the first visit to each participant's classroom and he shared his interpretation following the lesson observation. At that time, my understanding of teaching chemistry was different from his: although we observed the same event, his feedback added to my perception and world-view of the context. My chief supervisor grew up in New Zealand and has intensive experience in science teaching and the learning environment in New Zealand classrooms. He guided me through the thinking styles and teaching practices of science teachers in New Zealand classrooms. Overall, all techniques, the use of technologies, and colleagues' support helped during the data gathering process, but it remains a limitation of this research project as my background when it comes to interpreting the science teachers' teaching practice.

The selection of participants was also a challenge for me, and the upcoming subsection describes the procedure used to select participants and the sample size of this study.

3.4.2 *Selection of participants and the data collection phase*

My supervisors helped me to arrange a series of meetings with each participant, the head of the department, and the school principal. My chief supervisor went with me to initial meetings with participants, where we shared the research purpose, the research engagement duration, and the data collection procedures.

Educational researchers have established different techniques for selecting participants for qualitative research. I decided to use the convenience-sampling technique for this project. Using this technique, the researcher selects a sample by using their own resources and by evaluating the feasibility of participants for research participation according to their academic schedule. Sometimes this technique is also known as opportunity sampling and involves choosing the nearest available individuals who are willing to participate as respondents and who are available at the time the research is conducted (Cohen et al., 2018; Creswell, 2013). I prepared a list of possible target high schools that were conveniently located, with the most convenient school being prioritized over the least convenient school. Then, I selected and contacted the most convenient school because it had a manageable sample due to the intensity of the data and the frequency of visits for classroom observations. Next, I contacted the science teachers, the head of the science department, and the school principal.

To this purpose, the researcher and researcher's supervisor arranged an appointment with the head of the science department of the selected school. At this meeting, we shared a brief introduction of the research, its purpose, the data collection procedure, the long-time of data collection would involve, and the benefits of research. We also requested the head of the science department suggest a few science teachers who might be willing to participate in this study. We contacted these science teachers via e-mail. These science teachers indicated their willingness to participate in this study.

To set the criteria for selecting the most suitable participants we developed some selection standards. These standards were based on science teaching experience, whether these teachers already had experience in participating in a research project, teaching qualifications, experience background, and their availability during the period of the data collection process. An e-mail was sent to all teachers who indicated a willingness to participate to express gratitude for their voluntary readiness to collaborate in the project. A request was sent to selected participants for another meeting in order to proceed to the next phase of the study. On this occasion, my supervisor joined me in meeting with participants to discuss the details of this project, including the time frame, mode of data collecting, and interview times. We also decided with the collaboration of participants to set a time to conduct pre-study observations of their teaching practices in their routine classrooms before beginning formal classroom observations. We provided an information sheet and a consent form to each teacher. A summary of the sample is shown in Table 3.1.

Table 3.1

Participants selection process and their description

Population	Sample of study	Selection Criteria	
		George*	Philip*
All nominated science teachers by the Head of Department	Two Science Teachers	Bachelor in Education and Postgraduate Diploma in Science.	Bachelor of Teaching and Bachelor of Science.
		Non-subject specialist science teacher.	Subject specialist (chemistry) science teacher.
		More than 20 Years of science teaching experience with the same level of students.	More than 20 Years of science teaching experience with the same level of students.
		All professional experience in NZ.	The participant has experience in NZ and other countries.
		Experience as a research participant.	Experience as a research participant.
		Involved in non-teaching activities in the school.	Involved in non-teaching activities in the school.

* Pseudonyms

The size of the sample varies due to the research purpose or qualitative design (Creswell, 2013) and this could involve the adoption of one case or several cases. The sample size is informed by the need for the sample to be fit for purpose and, as such, there are no clear rules on the size of the sample in qualitative research (Cohen et al., 2018). Two experienced secondary school science teachers were chosen as the sample for this study. Most researchers involved in PCK studies (e.g. Hume & Berry, 2011; van Driel et al., 2014; van Driel, Verloop, & de Vos, 1998) state that experienced teachers will have strong PCK compared to their novice counterparts. Experienced teachers can identify the nature of practical knowledge in the classroom; something that they possess and affirm through the utilization of this knowledge in their interaction with students (Wei & Liu, 2018). For my study, the small number of cases facilitated me to collect intensive, rich data, observe each teacher in the naturalistic settings of their classrooms and provided the opportunity to enhance the validity of fine-grained triangulate data. From a reality standpoint, PCK use by teachers for particular students, for particular concepts, and for particular situations needed a close examination of each case. The two cases provided a chance to examine the use of PCK by two different teachers for their students, and a deep description of that could enhance the opportunity for transferability of the research.

The details of the research tools used to collect data are discussed next.

3.5 Research Tools

This study aimed to investigate two experienced science teachers' PCK and PCK&S in their respective classrooms during the teaching of a complete chemistry topic to year-10 students. Furthermore, the biotic and abiotic contexts of the classrooms were also considered as amplifiers and filters of teaching practice. For this purpose, a systematic data collection process was adopted to enhance the research quality and for the convenience of participants without disturbing their working routine. Research instruments were used to gather the data; how these instruments were developed and their appropriateness to this study are described in upcoming subsections.

Interpretivists employ qualitative data collection tools that reflect their ontological and epistemological stance on inquiry and, as such, they often use interviews, observations, and field notes (Ma, 2016). For the deeper investigation, researchers might analyze transcripts of conversations or study videotapes in extraordinary detail to learn more about the thoughts and behavior of individuals. In this analysis, they might be looking for understated nonverbal communication to understand the detail that characterizes interactions in their context (Neuman, 2014). Experts in this field suggest the use of such research tools for understanding the depth of human interactions with context [e.g. students, multimedia] in a teaching process. These tools have been used by many other PCK researchers to capture science teachers' PCK in their classrooms (e.g. Barendsen & Henze, 2019; Carpendale, 2018).

In light of expert recommendations, the demands of a qualitative case study, and the needs of this study, I gathered data using a pre-topic questionnaire, document analysis, classroom observations, video recordings, post-lesson interviews, and post-topic interviews. Each tool was used for the specific purpose of capturing the science teachers' knowledge and their actions during classroom practice. With the help of technology, first, I tried to minimize the possibility of data loss, for example, interviews were both recorded and documented using written notes; and second, video recordings helped me to discuss the teachers' actions in detail after physical observations. The data tools and their purpose are presented in Table 3.2.

Table 3.2

Data collection tools and their purpose

Data Collection Tools	Purpose
Pre-topic questionnaire	To note the teachers' beliefs about science teaching To know the teachers' background, e.g., teaching experience, time spent with recent class, school norms, etc.) To investigate personal PCK (pPCK)
Teacher documents	To interpret PCK in planning To explore the sequence of content in the topic To explore teachers' understanding of students' possible prior-knowledge related to the topic gained in previously chemistry topics To know the teachers' links of the topic with *The New Zealand Curriculum*
Interviews	To reflect on lesson teaching To explore the teachers' reasoning behind their actions when teaching To account for teachers' planning for the next lesson To reflect on the successes and challenges of the topic
Observations	To explore teachers' exhibited PCK To examine teacher skills during practice To explore live-class experience in the context
Video recordings of teaching practice	To examine teacher skills in depth as their enacted PCK

How and why I developed the pre-topic questionnaire for this project are questions that are discussed in the next subsection.

3.5.1 *The questionnaire*

Different types of questions can be used in educational research with respect to the need for participant responses, for instance, multiple-choice, rating scale, ratio data, dichotomous, and open-ended questions. Frequently, a questionnaire will engage large samples but it is also a valuable instrument for capturing the specific situation of small samples. Cohen et al. (2018) suggest that in site-specific case studies, questions that are less structured, word-based, and open-ended are a more appropriate tool as they are more likely to capture the specificity of that particular situation.

I used a questionnaire as my research instrument to explore teachers’ PCK, beliefs about science teaching, the teachers’ backgrounds, classroom contexts, and school contexts (see below). Most of the items in the questionnaire were open-ended and have the intention of capturing the teachers’ responses in detail. For example, question number 9: ‘If a student asks a question in your class, what approach do you take when responding’? On the other hand, the questions related to the teacher’s experience or their professional background appeared as close-ended questions in the questionnaire.

This questionnaire consisted of 17 items, with some questions having sub-questions that explore the interviewee’s answer to the previous question (Bartram, 2019), For instance, question 7 asked: ‘In general, how do you determine what to teach and what not to teach your students?’, which was followed by the sub-question 7 (b): ‘Why do you think it is important for students to learn the aspects you identified in the above question?’ Each question was focused on an element of PCK and derived and modified from data that has already been elicited in the literature. With respect to the limitations related to the project’s design and construction, I systematically took a novel approach to nurture engagement with each question, so that the derivation of each question’s source would be grounded in related research. A summary of these questions with their derivations is shown in Table 3.3.

Table 3.3

Questions and their derivations

Element	Question number as the pre-topic questionnaire	Derivation source
Teacher context	1: What tertiary qualifications do you have (including teacher qualifications) or any professional topics related to teaching? 2: How many years have you been teaching in secondary schools? 5: What work experience have you had other than teaching? 3: What subjects have you taught and at what levels have you taught in this school?	Chan (2014)
School context	4: How many class periods do you currently teach each week? 6 a: Do you currently have other responsibilities within the school? 6b: Do you currently have other responsibilities related to your work outside the school?	Chan (2014)
Belief	7a: In general, how do you determine what to teach and what not to teach? 7b: Why do you think it is important for students to learn these things? 8: How important do you believe it is for students to ask questions in your class? 9: If a student asks a question in your class, what approach would you take when responding?	(Huling, 2014); Mavhunga & Rollnick (2016)*; Luft & Roehrig, (2007); Campbell et al. (2017)*
Personal PCK	10: What is your philosophy of science teaching? 11: What do you believe effective Chemistry teaching at this level or especially for this topic looks like? 17: How important do you think it is that students make connections between their Chemistry learning and the real world? 13: As you begin this topic, what do you already know about the students in your class? 12a: How do you know about students' prior knowledge of this topic? 12b: Is it important for you to know this or not? Why? 14: Do you think this topic will be difficult or easy for your students? Why do you think this?	Moeed (2010); Campbell et al. (2017); Lankford (2010); Mavhunga and Rollnick (2016); (Luft & Roehrig, 2007) Luft & Roehrig (2007); Kaljo (2014); Chan (2014)

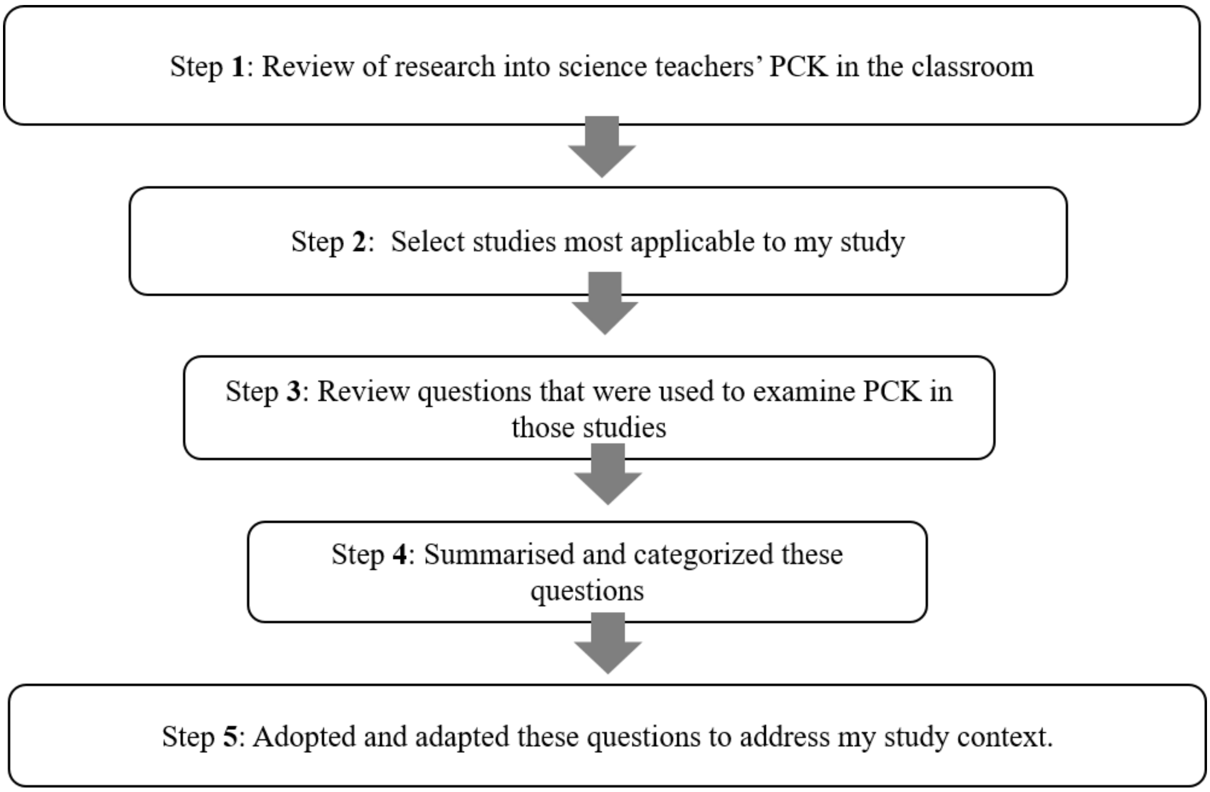
*Mavhunga and Rollnick (2016) adapted questions from Luft and Roehrig (2007).

Note: Questions number 15 and 16 are not displayed in this table because these questions are context-specific.

The table 3.3 shows the aspects of teachers' knowledge which are hinted in the CM. One connction in the CM shows that teachers bring their knowledge components into the classroom through interactions with their Amplifiers and Filters (e.g. belief, context). To examine this angle of the CM, I needed to capture these aspects of their PCK. Their responses of the questions related to Teacher Context helped me to consider teachers' teaching experience and expertise in the subject; School Context helped to see teachers' other responsibilities that may have impacted their classroom practice; Teachers' Belief helped me to know their ideas about teaching and learning in advance of observing their clasroom practice; Personal PCK helped me to explore their perception of science teaching as a constructive activity or just a transfer of content knowledge. These questions were derived from literature as shown. For this derivation from related research, a systematic five-step process was developed to reflect the original source of each question and maintain its validity to capture the science teachers' PCK in this research context. These steps are shown in Figure 3.1.

Figure 3.1

Questions derivation steps



In the above figure, in step 1 recent PCK research was found [mostly selected from the last 10 years] which focused on science teachers' PCK in their classroom, and in step 2 I filtered these studies to locate those which were more relevant to my study, for instance, research which was focussed to explore the teachers' PCK in teaching practice; in step 3, I selected and organized those questions which were used in the studies that are most appropriate for my study. I summarised similar questions from these questions and developed relevant questions without altering the essence of the original questions in steps 4 and 5 respectively. The full questionnaire of this study is shown in Appendix A.

The next subsection refers to another research method that was used to gather the teachers' PCK from teaching-related documents.

3.5.2 *Document analysis*

This study is designed with the purpose of better understanding science teachers' PCK in their classroom practices. To this end, I was interested to know what knowledge components were planned to be used by each teacher for teaching a concept, lesson, or topic. Some specific pedagogies and particular achievement objectives are suggested for a New Zealand science teacher in national and school documents. By looking at these documents, I could explore how a science teacher might convert the designated and planned topic content into teachable content for a specific lesson or lessons, and how a teacher practices in relation to this content. Furthermore, *The New Zealand Curriculum*, the school curriculum and teacher notes provide information regarding recommended teaching pedagogies, content under the unit, school objectives, teachers' lesson objectives, and recommended assessment approaches. These pieces of information helped me to cross verify teachers' particular claims, and establish the connection of their teaching with the curriculum. Therefore, these documents might help me to understand the teachers' PCK.

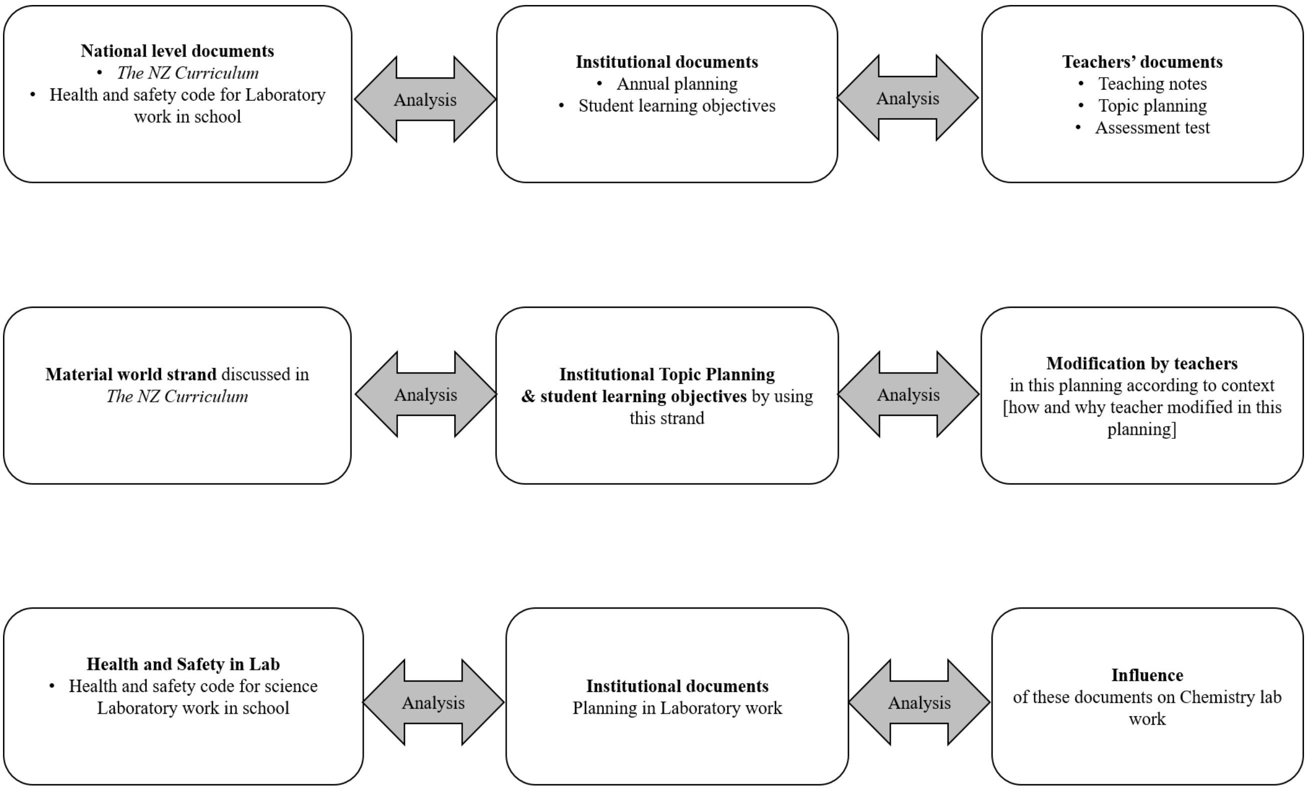
A document is written material compiled by an individual, institute, or nation. Written documents can consist of a rich range of content – words, images, plans, and ideas, and furthermore they help interpret or understand the past, present, and future events. Principally, national governments, local governments, and educational settings all have a propensity of documents that are generally accessible (Connolly, 2016).

The document analysis method comes under the broad umbrella of discourse analysis and has the main aim of investigating the social meaning of language, images, and text (O'Connor, 2019). In this research, teachers' documents [teaching notes, assessment tests], institutional documents [topic planning, students' learning objectives], and national documents [curriculum, general health documents, and safety codes for laboratory work in schools] helped me in understanding both teachers' personal PCK and enacted PCK. More precisely, they helped me to explore the linkage between teachers' knowledge components and their classroom practice.

I analyzed teachers' notes to capture the PCK in the planned teaching and its linkage to their classroom practice. Furthermore, teachers' notes also indicated different knowledge components teachers were using when planning their teaching. Institutional planning was analyzed to explore the contextually based PCK and its connection to the teaching of single lessons. The national-level document analysis helped me to understand the national science teaching goals for high school students, and how a school uses these goals in meeting its teaching objectives. There was no intention to criticize the content of these documents. Rather the purpose was to analyze the relevant portions of these documents with respect to how a science teacher would use these documents in their classroom. This document analysis was also used to identify the connection between these documents, their influence as amplifiers or filters of teaching practice, and what changes teachers bring in their PCK when achieving the desired objectives at the institutional and national levels. The process and purpose of this document analysis are illustrated in Figure 3.2.

Figure 3.1

Process set for document analysis



The above diagram shows the specification of documents from the country level to the classroom level from left to right. The second and third rows of the diagram indicate the specific aspects of the document analysis to see their stimuli to influence the science teachers' PCK for the planning of a particular topic.

It is understood that the teaching documents only inform the teachers' possible practice and this may not be what actually happens in the classroom. So, to document the actual teaching practices, it was important to do so through observation. The next subsection discusses the observations as a data-gathering tool.

3.5.3 *Observation*

Doing observations can provide a valuable source of data in qualitative research (Rozsahegyi, 2019b) and are, as such, a favored technique in social science research done in the educational context (Connolly, 2016). The reason for this is that this type of data reflects a holistic, thick description of an education system, its processes, and practices (Lin, 2016). Furthermore, the practice of doing observations also supports the researcher in understanding the social process and the actual situation in its natural setting. Doing observations, as a data collection technique that includes the researcher taking observational notes, sometimes involves collecting and constructing rubrics or specifically highlighted defined terms that are used when exploring the educational process and its context. In this study, I used the PCK elements, as suggested in the consensus model, to capture the teaching practice. While doing this I noted unusual activities that occurred during routine classes to identify the stimuli that precipitated this teaching process. During the last few decades, educational researchers have begun using video recordings to observe an educational process, aligned with researchers' physical observations. I also video-recorded all the observed lessons.

Doing observations is not just about looking at the event, thing, or process: it is more than this in that it also includes the systematic noting of people, events, behaviors, settings, artifacts, routines, etc (Cohen et al., 2018). Doing observations also encompasses noting the physical features of the context in which the observations are made along with the making of notes relating to the activities of an individual or individuals. On this aspect of doing observations, Rozsahegyi (2019b) noted:

> Observations include the physical features of the setting and how these change with different educational activities: human organization of the classroom; allocation of teaching assistants in lesson time; the frequency and nature of interactions between educators [teacher] and

> learners or between learners themselves; and pedagogical features, such as employment of teaching strategies or use of resources. (p.26)

In this research project, both perspectives of the classroom context: the research participants' context, and the physical [or abiotic] context were observed along with other biotic contexts, including the students' context in these classes and the context of the teacher aide.

There are two main types of observation based on the researcher's participation in the targeted process: participant or non-participant observation. If the researcher acts as a research participant or is involved in the process which is responsible for influencing the outcomes of the event, then this observer would be considered to be a participant-observer. On the other hand, if a researcher does not take part in the process and only observes the event, as a fly on the wall, then the observer would be considered to be a non-participant observer.

I felt that my professional teaching background and my chemistry teaching experience of students of the same level would help me to analyze the science teaching practice during observations. My participation as a research participant could influence the natural teaching routines, teaching activities, and also the behavior of research participants, hence I considered this to be undesirable that this aspect of my research project should disturb the teachers' pedagogies and natural setting of the research context. A non-participant position was therefore adopted with the aim of not interfering in teachers' routine activities and with the classroom context. Rozsahegyi (2019b) provides an account of some advantages of the researcher acting as a non-participant in their collection of data. The researcher can in this way be more focused on the set aims of the study and remain neutral while observing the real picture of the event. However, the subjectivity that characterizes this type of observation may make the collection of data more tricky, as it depends on how the observer understands, records, and interprets that event. In this study, this problem was partially off-set by using post-lesson interviews (see below).

Before beginning my formal classroom observations, I did some pre-study observations in the same context with the same participants in order to familiarize myself with the process and the classroom context, including the students. This enabled me to clarify my understanding of the physical and teaching-learning process, and to do my research "homework" (Basit, 2010, p. 125) by doing observations in a natural setting. I had already collected the details of participants' professional backgrounds through speaking with them and through examining school documents that provided such information as to their timetable for school activities. Moreover, I discussed with participants the role of any teacher aide and the ability levels of the respective students in their classroom. I also collected the topic planning documents that had a connection with *The New Zealand Curriculum* in order to assist me in making my observations.

The next question in the researcher's mind has to do with understanding the best way to collect data with respect to the technique to be used i.e., whether it be structured observations, non-structured observations, and/or semi-structured observations. Basit (2010) explains that structured observations are mostly adopted by quantitative researchers when collecting numerical data which can be analyzed statistically. In the case of qualitative researchers, they often use unstructured observations that involve the taking of field notes and making narrative or thematic recordings, which may consist of non-verbal action data. Researchers who use the mixed-method approach mostly use semi-structured observations.

The elements of the PCK Consensus Model of 2015 were used for observing the classroom teaching to investigate in-depth detail of science teachers' PCK and skills, so, I went with the semi-structured observational protocol (Appendix B). Making observations involved taking notes and making audio-video recordings of all teaching-related activities in the classroom. In my semi-structured observational notes, the suggested PCK elements were arranged in one column, leaving the second column blank in order to note the teacher's use of that element in their practice. In addition to this, a blank page was added to provide space to note any unusual events that occurred during the class. This space was also used to construct questions for the post-lesson interview. There was another page (headed Abiotic Factors) added to the observational notes for noting the abiotic factors in the classroom. These observations were done in the teaching-learning setting and involved noting down the natural routine of each science teacher's teaching – observations that can be referred to as *naturalistic* observations (Rozsahegyi, 2019b).

Meaningful observation requires an effective methodology (Rozsahegyi, 2019b), in order that the observations be meaningful for the research and, as such, I recorded all observed lessons using a video camera. Why video recordings, as an observational tool, were added and their importance to this study is elaborated on in the next subsection.

3.5.3.1 Video recording.

Observations induce psycho-dynamic (e.g. emotional, intellectual) reactions in the researchers themselves during data collection, for example, they induce memories, professional experiences, uncomfortable feelings, and these phenomena "may color our perceptions and interpretations” (Papatheodorou, 2013, p. 69). Cohen et al. (2018) point out some of these psycho-dynamic risks that occur during observations, such as selective attention, being judgmental, attention deficit, and discriminating data recordings. In order to avoid these hazards, I chose to video record all lessons and teaching activities, because a camera does not have its own emotions, feelings, attention deficit, cerebral memory [which is used to analyze], or rational judgment toward teaching. It is possible for a researcher to focus video recording on one part of the class acitivity and ignore other activities in the classroom which may result in reflecting researchers’ bias. In my study, I used one fixed camera that focused on the teacher only, capturing what they did throughout the class. Also, the research did not involve students, so I had no purpose to capture their activities in the class except in relation to what the teacher did. Analysis of the video data was interpretive, as described below.

According to Tiberghien and Sensevy (2012), video recordings have been used as a data-gathering tool in science education since the 1970s. Fischer and Neumann (2012) discuss numerous examples of video recordings used as research evidence, summarizing that “[i]t can be concluded that video analysis has proven to be a valuable tool to investigate instruction in the large scale as well as on the level of individual teacher” (p. 131). It is tough for the researcher to capture all activities in the classroom in a single moment, e.g., what the teacher writes on the whiteboard while asking questions of students and what is the teacher’s actions all in the same movement. Data from video recordings enable the researcher to study all the teacher’s actions after the observations that have been made. Being able to watch a video again and again, makes this tool valuable (Fischer & Neumann, 2012).

This instrument has helped me, as an international research student from a non-English country, to understand the science teachers' use of language after the observations, because the repetitive watching enhances the researcher's possibilities of understanding the data. The video recording, as a relatively new instrument, has modified researcher practice at the level of how much information is now available to researchers, in part because of the different nature of the data, the literal recording of observations, and even audio recordings (Fischer & Neumann, 2012). Powel, Francisco, and Maher (2003) noted that, unlike the nature of data gathered from live observations, which can be transient, researchers are now able to study recorded events as frequently as needed and in flexible ways; which is to say, in real-time, slow motion, frame by frame, and through utilizing the technologies and various technical features. I used a single camera in the classroom, in which I focused on the teacher’s actions. It was set up in a corner of the room or in a suitable place where its presence would not unduly influence teaching practice. In George's case, the recorded chemistry topic consisted of 10 lesson videos with each recording lasting between 40 and 50 minutes (teaching lessons were 40 minutes while laboratory activities lasted 50 minutes). In Philip's case, all recordings of lessons and laboratory activities were the same, except the chemistry topic consisted of 12 lessons.

While I noted what happened in the classroom by observations and video recordings, what was the rationale behind the act of teaching was explored in the follow-up interviews, so, the next subsection discusses the purpose and procedure of interviews.

3.5.4 ***Interviews***

This study also aimed to better understand the implicit nature of PCK through engaging with the knowledge and thinking behind the teachers' actions in classroom practice or topic teaching. To explore this approach to better understand PCK, I conducted lesson follow-up interviews after each lesson and arranged a full-length post-topic interview.

Interviews are a research tool used to collect verbal data from participants for specific purposes. For example, in this study, interviews were used to capture a teacher's thoughts after each lesson. Interviews empower research participants to elaborate on their experiences and interpretations of the situations that they find themselves dealing with in a class (Winwood, 2019). They are also an effective tool for accessing participants' beliefs, interpretations, and feelings when wanting to understand how participants construct their realities (Connolly, 2016). During this project, the interview enabled me to explore participants' beliefs, their reflections on lessons, their reasoning behind their actions, and planning for the next lesson. Interviews are, as Cohen et al. (2018) argue, an effective tool for validating and exploring data in greater depth in relation to issues already studied using other techniques. Interviews also add additional thoughts and enrich the study through the generation of new qualitative data. In this project, lesson follow-up interviews were used to explore the teachers' actions that had been observed during the lessons. In a face-to-face interview, the researcher's physical presence should allow the possibility of examining subtle nuances with regard to both verbal and body language expressed by the participant (Connolly, 2016). To this effect, I conducted all interviews in order to experience these things for myself.

Several types of interviews could be used to investigate, depending on the nature of the study. This study used a semi-structured interview to probe for the elements of the consensus model at a deeper level and in order to better understand the teaching skills used by the teacher in their teaching practice (Appendix C). The semi-structured interview consists of predetermined questions while providing the freedom to explore the new areas of inquiry as the interview progresses (Connolly, 2016), and a semi-structured interview aims to engage with the theoretical perspectives that govern real-life (Cohen et al., 2018). Sometimes, I added my insights to the interview questions with the intention of exploring the participant's rationale behind their actions and any unusual teaching strategies used in the classroom.

Each follow-up lesson interview was 10-20 minutes in duration and the post-topic interview was 40-60 minutes long. Post-lesson interviews were conducted as soon as possible after each observed class in order to catch the teacher’s impressions on what had occurred during the class. If teachers were not available at that time, I asked them to suggest another time for the interview. The overview of their topic teaching was recorded at the end of the completion of the topic in the topic follow-up interview. Topic follow-up interviews were semi-structured interviews (Appendix D) and the questions were developed after watching all respective lesson video recordings. Questions in this interview were focused on exploring the teacher’s reasoning for their decisions in the lessons, the knowledge components they used, and their beliefs underpinning the teaching of their topic.

With the help of these tools, I collected the data of the study, so the following section subscribes data collection process of the study.

3.6 Data collection process

The data collection process involves all those activities related to collecting data from participants through the use of research tools. For this research, I collected a range of data from both participants during the second and third school terms of 2018. Some data were collected before the start of the chemistry topic, some were captured during teaching practices and some of the data were gathered after the completion of the topic.

A pre-topic questionnaire was administered to the participants in March 2018; that is, before the beginning of the chemistry topic. There were two main reasons for handing out the questionnaire in advance of the teaching: firstly, participants would have plenty of time to complete it; secondly, they would be able to use their teaching knowledge or knowledge related to this particular chemistry course and to respond to all other questions in detail. The questionnaire helped me to understand the participants’ teaching beliefs and the nature of their personal PCK (pPCK).

Before beginning formal observations I observed each teacher in their classroom practice during piloting my method and instruments. These observations included trialing video recording, post-lesson discussions, and trialing observation notes in the classroom. The aims of the pre-study data collection were: familiarization with the context, improving the data collection procedure, interacting with each participant's classroom environment, camera adjustment in the classroom, checking the quality of the recorded voice and the quality of the video, my position during the class or lab work, and observing the abiotic classroom environment (science charts, science models, etc.). The data from these observations were critically viewed during the analysis process and the code generation. It also helped me to begin to know the individual participant's teaching style, their instructional strategies, teaching methods, and the types of knowledge that they use in their classroom.

Teaching-related documents prepared by the school (e.g. science departmental topic planning, calendar [annual schedule], teacher timetable, etc.) were collected one month before formal observations to gain an understanding of the topic content. This also helped me prepare myself for what the teachers would be teaching. The teachers' self-developed documents for teaching practice, such as help notes, were collected after each lesson or were provided by the teacher before the start of class; depending on the participant's practice.

In this study, classroom observations were a significant part of the data collection process. This collection of data was realized in two ways: live observations as a result of my presence and through video recordings of all chemistry topic lessons. During live observations, my role in the class was as a non-participant, which involved my taking notes during these observations. Video recordings were done using one camera, which focussed on the teacher. A total of 10 lessons (complete topic: ionic chemistry) were observed in George's (pseudonym of participant) class in Term 2, while Philip's (pseudonym of participant) chemistry topic focused on 'acids and bases' and consisted of 12 lessons in Term 3.

Post-lesson interviews were conducted as soon as was possible after each respective lesson or at a later time when the participant was available. During the data collection process, all post-lesson interviews were conducted immediately after each lesson, except in the case of one lesson when the participant had an appointment with someone after a lesson on 29-08-18. In that instance, the participant agreed to be interviewed after their meeting. The post-lesson interview consisted of a very limited and predetermined set of one or two questions about how teaching went in their lesson; a conversation that consumed no more than 5 to 10 minutes of the participant's time. During the interviews, I wrote down bullets of information and audio-recorded all interviews to decrease the level of data loss. A full-length post-topic interview was conducted with each teacher at the end of the topic in order to explore their overall thoughts and reflections on their topic teaching. A suitable time for the post-topic interview was decided by the teachers such that it would be convenient to their schedule. The post-topic interviews lasted about 40-60 minutes each. I also needed some time to show participants some relevant documents in order to refresh their memory about particular lessons or events. The complete audio recordings of the interviews were transcribed and sent back to each interviewee for their verification, which was essential to enhance the credibility of the data. The timing of the data collection is presented in Table 3.4 on next page.

Table 3.4

Case, date, and what data were collected

Case	Date	Topic	Data Collection
Meeting with both participants	March 2018		A questionnaire was handed over to the participants providing them with plenty of time to complete it before the formal class observations in the following terms.
George	May 2018	Ionic Chemistry	Video recordings and observation notes of all lessons to complete the topic. Audio recordings of each post-lesson interview. Topic interview after completion of the topic.
Philip	Aug-Sep 2018	Acids and Bases	Observation notes and video recordings of each lesson in the topic and audio recordings of the post-lesson interview. A full-length topic interview after finishing the topic.

Brief introductions of George and Philip's background, classroom context, content of taught topics in the school curriculum, and the number of students in their classes are presented in Chapters 4 and 5.

The school planning allowed the teachers to teach particular topics at different times in different classes. It was not possible for me to personally observe two classes with same topics at the same time. I observed teachers at different times when they taught different topics. as the research focused on the use of teachers' combined knowledges in response to specific teaching situations, the topic is taken into account when examining their PCK in practice. The data were gathered by using these research tools. These data were analyzed by using the analytical framework of this study. The following section discusses the conceptual framework of this study.

3.7 Analytical Framework

The conceptual framework (Figure 2.12) for this study was developed by using the Consensus Model-2015 (Gess-Newsome, 2015). For the analytical framework, most of the components of the conceptual framework were defined by using the description given in Consensus Model-2015 discussed by Gess-Newsome (2015), and others are defined by using literature (references given in the analytical framework). The components of this framework were defined to analyse the generated data, therefore an analytical framework was proposed. The following tables 3.5, 3.6, and 3.7 represent the analytical framework of this study.

Table 3.5

Analytical framework of Teacher Professional Knowledge Base (TPKB)

TPKB components	Description
Assessment Knowledge	Knowledge of: • designing assessment (e.g. MCQs, short questions) • Implementing formative and summative assessment in teaching
Content Knowledge	Knowledge of: • the academic content of the subject • the relationship among concepts within and cross-subject
Knowledge of Students	Knowledge of students' interests, abilities, prior academic success, personality traits (e.g. introverts or extroverts, etc.), family background (e.g. parental/siblings involvement in academic learning), and peer relationship (Mayer & Marland, 1997)
Curricular Knowledge	Knowledge of: • curriculum structure (e.g. key competencies, recommended pedagogy) • curriculum goals and objectives • relationships between the school curriculum and the national curriculum
Contextual Knowledge	Knowledge of: • school context (e.g. colleagues, classroom setting) • context beyond the school (e.g. community, country)
Pedagogical Knowledge	Knowledge of: • designing a lesson • ways that students learn (e.g. social interaction) • using assessment results in planning and teaching (e.g. when assessment results show poor learning in the class then a teacher would modify teaching) • using Knowledge of Students in designing lesson plans (e.g. select appropriate learning activities according to students' ability) • personalize their responses to students (Marland, 1986) • strategies for classroom management (e.g. organize students for an experiment), and strategies for student engagement (e.g. questioning techniques)

Table 3.6

Analytical framework Topic Specific Professional Knowledge (TSPK)

TSPK Components	Description
Science Practices (SP)	Knowledge of: • exploring scientific concepts through activities • Recording, analyzing and interpreting data obtained in activities (e.g. record information, represent this information in a table, interpret and analyze the data for results)
Knowledge of Content Representation (CR)	Knowledge of: • particular representations (e.g. diagram, demonstration) and affordances of a particular representation (e.g. diagram afford to summarize the content) • representing a chemical concept at a macroscopic level (e.g, observation of flam color in a flame test), sub-microscopic level (e.g. atoms/molecules involvement in a reaction), and symbolic level (e.g. balanced chemical equation)
Knowledge of Student Understanding (KSU)	Knowledge of : • students' prior knowledge for learning particular concepts • students' areas of learning difficulty (e.g. why students find it difficult to learn a particular concept) (Magnusson et al., 1999)
Knowledge of Instructional Strategies (KIS)	Knowledge of: • strategies specific to a subject (e.g. how to use the periodic table as a teaching aid in chemistry) • effectiveness of specific strategies for particular students

Table 3.7

Analytical framework for Amplifiers and Filters

Amplifiers and Filters	Description
Teachers' Belief	• beliefs about the purposes and goals of science teaching for the particular grade (Magnusson et al., 1999) • beliefs about student engagement with peers and classroom management for learning
Teachers' Prior Knowledge	• the knowledge that originates from experience (e.g. teaching experience, daily life experience) • the knowledge that develops from "tinkering and experimenting with classroom strategies, trying out new ideas, refining old ideas, problem setting, and problem-solving" (Wallace, 2003, p. 8)
Teachers' Context	subject-relevant experience (e.g. work experience in the chemical industry), schooling (e.g. professional development training at pre-service or in-service levels), and life experience (e.g. worked as a pastor in church)

By using this analytical framework, I examined each of the teachers in their classrooms as a case. This research has quality aspects which are discussed in the next section.

3.8 Research Quality

Qualitative research needs to embrace manifold quality standards which are variously recognized as validity, credibility, and rigor or trustworthiness (Morrow, 2005). Cohen et al. (2018) argue that case studies may not have the external checks like other forms of research. However, case studies do have to abide by the canonical standards of validity and reliability. Credibility in qualitative research is used parallel to quantitative techniques of internal validity, transferability is parallel to external validity, dependability corresponds to the reliability, and confirmability to objectivity (Bryman, 2012). In this qualitative research, I use the terms credibility, transferability, dependability, and confirmability to describe the measures taken to enhance quality; all of which are elaborated upon in the remainder of this section.

In a qualitative research project, researchers are more interested in achieving authenticity than being able to identify with a single version of truth (Neuman, 2014). Credibility (internal validity) can be achieved through persistent observation, researcher reflexivity, and participant checks (Morrow, 2005). For these purposes and to increase the credibility of this project, I prolonged my engagement with participants in both interviews and observations, as well as the time I spent doing video recordings of classroom practices in order to capture the complexity of PCK and to understand the teacher's skills based on their PCK. I intended to be reflexive in this research about my own experiences as a chemistry teacher in a different context in Pakistan that enabled me to interpret the chemistry teaching. All transcribed interview data was sent back to participants for cross-checking; actions that elevate the credibility of this research project.

This study investigated two science teachers' PCK in different contexts; settings that can enhance the opportunity for transferability of the research (Wiersma & Jurs, 2009). However, Merriam (2009) claims that multiple case studies increase the variation in the study, which assists with establishing its external validity. Furthermore, Carcary (2009) indicates that external validity can improve through triangulation and respondent validation. With this possibility in mind, I sent all transcribed data to the respective respondent for validation before putting these data through analysis.

Traditionally, it was perceived that case study findings could not be generalized or transferred to another context, but Flyvbjerg (2006) discusses this misunderstanding along with many other misunderstandings about case studies, stating:

> Carefully chosen experiments, cases, and experience were also critical to the development of the physics of Newton, Einstein, and Bohr, just as the case study occupied a central place in the works of Darwin, Marx, and Freud. In social science, too, the strategic choice of a case may greatly add to the generalizability of a case study. (p. 9)

Supporting Flyvbjerg's (2006) thoughts, Carcary (2009) suggests researchers need to provide detailed descriptions of the study context, data gathering, and analysis of phenomena so as to assess the findings' transferability. A complete systematic process of data generation and analysis of phenomena was generated to present research findings to enhance the transferability of this research. Additionally, I selected each case study for the generation of data as the consequence of adopting a strategy to increase the findings' transferability. Furthermore, I discussed or interpreted every single case separately using a thick description of this study, which can elevate its transferability. For transferring the findings, a reader would need to consider their own context t because each school in the world has its own values, objectives and abilities of students. When I would think of transferring the findings of this study into

Pakistani context, I would reconsider them according to the context. For instance, Pakistani school science teachers prefer a lecture method to teach science that reflects their behaviourist approach toward science teaching (Tufail & Mahmood, 2020). On the other hand, New Zealand school science teachers (the context of the study) use constructive approaches to teach science as researchers have noted in their studies (e.g. Garbett, 2011; Moeed & Anderson, 2018). As a former chemistry teacher of Pakistan, I am familiar that Pakistani schools have not as much teaching resources (Abiotic context) as New Zealand schools. These resources can influence science teachers' teaching or use of knowledge repertoire as indicated in the conceptual framework of the study, therefore, I would consider all aspects of the framework accordingly. Likewise, any researcher can consider whether it is valid to transfer the findings as per their context.

The data gathered as a consequence of each case came from different research instruments. Creswell and Miller (2000) believe this practice validates the procedure where the researchers aim to search for convergence among multiple sources of information to form categories in research data. Rozsahegyi (2019a) explains:

> The whole process captured different outlooks on the same phenomenon and enabled triangulation, the cross-verification of data from a range of sources, to be carried out, an important tool for achieving a sense of trustworthiness in the data and its research outcomes. (p. 128)

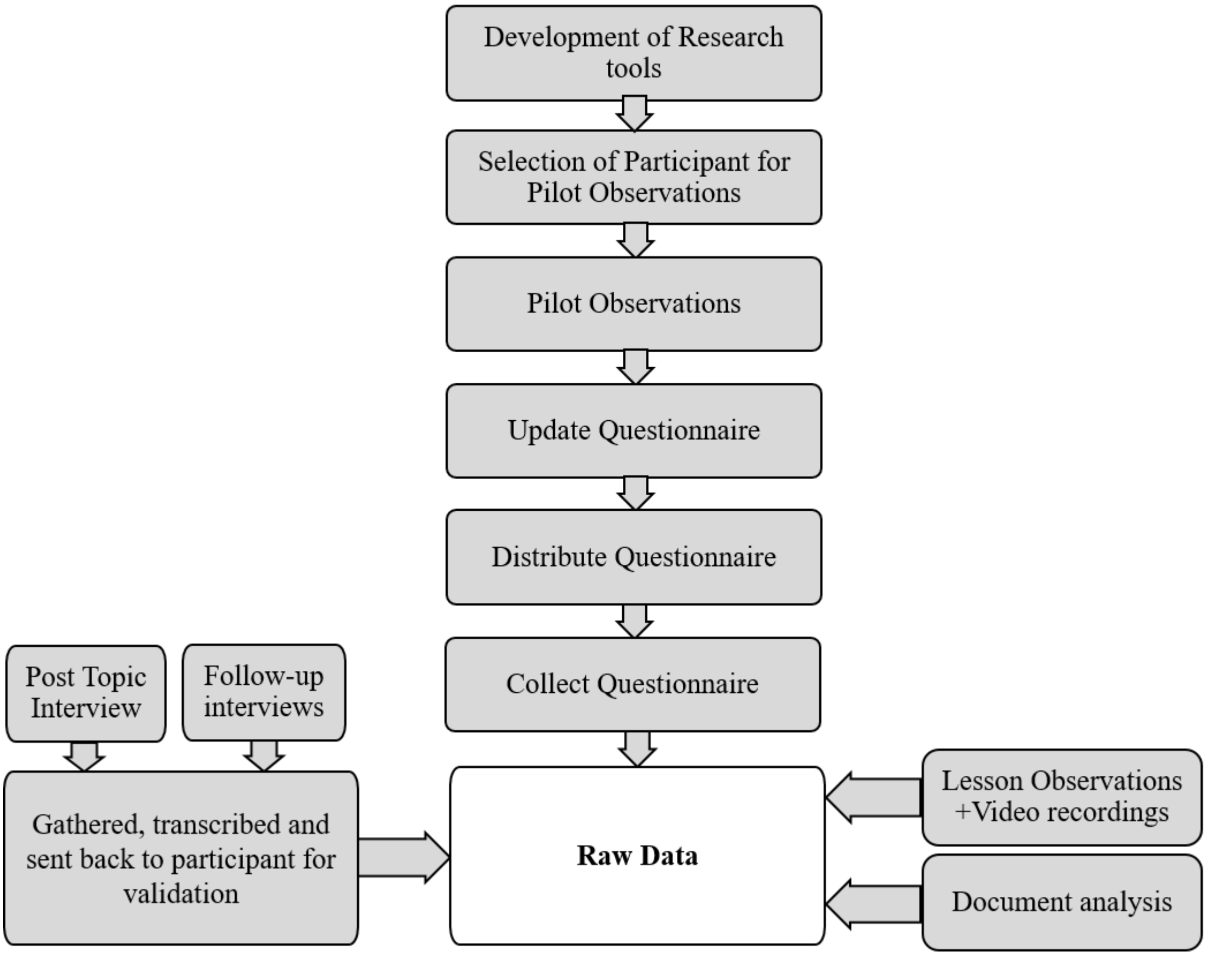
To create trustworthiness, the data from this study included lesson follow-up interviews with each teacher after their classroom observations. The purpose of this was to gain clarity about what had been observed in their teaching. In addition to this, a follow-up interview focused on the overall outcomes of the teaching topic was conducted. In summary, I attempted to thoroughly explore a single event by using different means of creating clarification through cross-checking sources of data and in this way improved the trustworthiness of my study. I gathered data using audio recordings, video recordings, observations, and using interview notes to enhance the confirmability aspect of the research quality. Barendsen and Henze (2019) captured teachers' PCK in the science classes by using Magnusson's PCK model and noted that having anonymized data gathered from recordings and note sheets contributed to the confirmability of the research, which was the approach taken here.

The confirmability and dependability of a study should be established through the audit process or audit trail. Carcary (2009) suggests that the researcher should provide an account of all research decisions and activities carried out during the research process and suggests that this practice helps other researchers to determine the reliability of a study’s findings and, as such, their value as a platform for further research. Lincoln and Guba (1985) describe six categories of information that need to be collected to inform the audit process: raw data, data reduction, and analysis notes, data reconstruction and synthesis products, process notes, materials related to intentions and dispositions, and preliminary development information. All these categories are considered at the time of data generation, construction or reconstruction of data, and during the analysis process; a practice that can increase its dependability and confirmability in this research project. These categories are elaborated upon in the following section.

3.9 Data Analysis

The data analysis process includes data organization, an account of the explanation of the data, and identifying patterns, themes, categories, and regularities (Cohen et al., 2018). As discussed above, all gathered data in this research is qualitative in nature and, as such, during the raw data generation process, it was important to try to maintain its confirmability and dependability of this data. The process responsible for raw data generation from each case is outlined in Figure 3.3.

Figure 3.2 *Raw data generation*



The raw data were recorded and organized according to each case study; data gathered from the case study involving George were organized first, in that there was almost three months gap between data gathering from George and Philip. Once data were collected it was organized immediately, for example, I received the school planning document from Philip, and I retrieved and arranged relevant data from it. In both case studies, I analyzed the data using the same management strategies. The remaining portion of this section provides some examples of the data organization, the coding system used, and a snapshot of the data analysis.

I received the completed questionnaire and any relevant teaching documents at the beginning of the topic from each participant. The participant's responses to the questionnaire were categorized according to a set system (see Tables 3.5,3.6 and 3.7) using teacher knowledge and amplifiers or filters under one umbrella. For instance, in George's case, all related responses were put in one column as shown in Table 3.8. This table is a sample and indicates how data from the questionnaire were prepared for analysis.

Table 3.8

Preparation of questionnaire data for analysis

Response of questions	Comments
Q7: In general, how do you determine what to teach and what not to teach?	
Response (R): This is determined by the Science Department at school and is based on the national curriculum.	Knowledge of Curriculum
Q7b: Why do you think it is important for students to learn these things?	
R: Our Junior Science program leads directly to level 1 NCEA science.	Knowledge of curriculum
Q8: How important do you believe it is for students to ask questions in your class?	
R: Boys who are asking questions are thinking about the issue. If they cannot get answers to their questions they can't learn those aspects and get frustrated which inhibits other learning.	The teacher can explore what is going on in a boy's head as a consequence of what students ask. (developing knowledge of student understanding)

In this organization of questionnaire data, the responses from the questionnaire are connected to teaching practice and other sources of data, such as lesson observations and video recordings. Relevant data from documents were retrieved and used to match or understand, and to clarify and cross-check the data obtained from other sources.

Data from observation notes and lesson videos were brought together for checking. The data were organized in a sequence: the follow-up lesson interview was always followed by the respective lesson and lessons, and a lesson summary according to their dates. This sequence helped me to understand what happened in classroom practice and to understand the responses of the participant about his particular experience of teaching practice. The arrangement of lessons according to their dates shows the connection of previous lessons with the present lesson. Furthermore, the follow-up topic interview was transcribed at the end of all topic lessons, which helped me understand from the participants' responses what happened across the whole topic.

The audio recordings of the interviews were transcribed, including pauses in the dialogue, while the video recordings of the lessons were also transcribed episode-by-episode. Each lesson was divided into different numbers of episodes, with each episode depicting a moment in teaching practice. For instance, the teacher explained the formulae of three different acids during a lesson, meaning all the teacher's moments, knowledge, and skills incorporated in an explanation of one formula of acid are included into one teaching episode. The number and duration of episodes varied in a lesson for the reason that it is the teacher who determines how long it should need to take to teach about a new concept or make a point. These data were placed into tables, and the duration of the episode was noted in the first column, to make it easy to revisit the particular episode. In this way, video data were processed, reduced, and organized for analysis – an example of which is provided in Table 3.9 on next page.

Table 3.9

An example of transcribed teaching episode

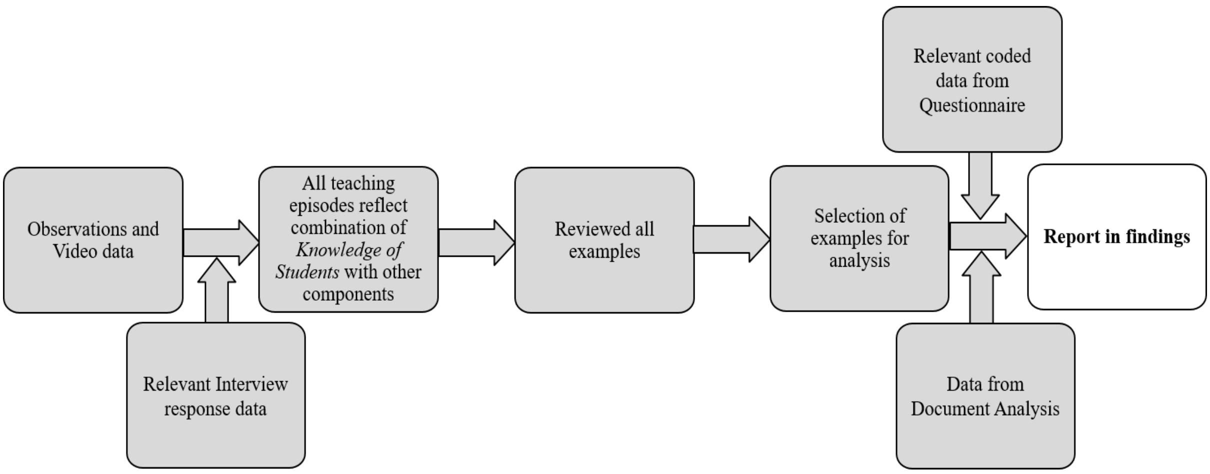
Time	Summary Lesson 1	TPKB	TSPK	Amplifier and Filter
30:40 to 36:00	He begins the answers to these questions. He draws the atom structure and explains; the location of sub-atomic particles, which are responsible for atomic mass and the atomic number, the number of the shell, and the number of electrons in the shell. Student: Electrons are moving. Teacher: Yes, that is a good point; "Good point, the electrons are moving Ok. We draw in one place (indicates towards board) but it is not still in one place OK. It is convenient for us; we draw in one place, we account for it and whatever, but that's not right. But, actually, they are not still in one place and you are not able to take a photo to account for them because they will always be moving. Ok, and all we can say; shells are a concern, we can say it is right, could be, but that's as much or as little as you can say. They are moving all the time, they move very fast and you can't ever predict exactly where they will be. But for our purposes, the Bohr's diagram with two electrons here and eight electrons here and another eight here and the whatever (he moved his hand on diagram)". Student: What is the shell made of? *OK, the shells are not [pause]. Shells are construction in your brain other than on the whiteboard. Ok it is just easier to figure out roughly what it could be. The shell doesn't actually exist. It's just…. (another student asks another question, and even though the teacher wanted to elaborate on his answer more, he stopped to hear the second question).*	Pedagogical Knowledge	Knowledge of Instructional Strategies and Content Representation is used to make effective teaching by drawing a diagram and the verbal explanation, describing the shell in air through the use of hands (Skill).	Amplifier and Filter: Student (context) question acts as an influencer (Amplifier) on the subject matter knowledge of the teacher. Students' curiosity to understand science acts as an influencer (elaborator)

The above table shows a fragment of the transcription of the video data from case study 1. The left-hand column presents the starting and finishing time of a teaching episode; this episode of lesson 1 began at 30:40 and ended at 36:00. The second column from the left provides a summary of the teaching practice and includes student questions when they became part of the teaching practice. The other columns present coding of the major teacher knowledge components according to the Consensus Model: Teacher Professional Knowledge Base (TPKB), Topic Specific Professional Knowledge (TSPK), and Amplifiers and Filters. Each episode in the first round of analysis was coded deductively and in color to help me to easily find both the same code, when completing the topic, and to find its location in the summary of teaching practice. For example, purple indicates the locus of amplifier in the summary and its relevant interpretive connection with the PCK element in the consensus model. In the second round of analysis, the same data were inductively analyzed to identify the teacher's skills, the different sorts of knowledge they had, and the connection of these phenomena to the teaching documents.

All coded data were reviewed before presenting the findings and examples of teaching episodes that clearly illustrated the use of knowledge components and other elements of PCK were reported in the findings. For example, in chapters 4 and 5 all teaching episodes and interview responses that had been coded in the Knowledge of Students category were reviewed with some examples being chosen to be discussed to explore the combinations of knowledge components that appeared to represent that teacher's practice. The flow of data from all sources and how it led to the findings is shown in Figure 3.4.

Figure 3.3

The flow of data in the findings



Audio and video recordings were transcribed, and organized for analysis, while field notes were used to portray the observed teaching scenario at that time. The transcribed data were sent to each participant for validation. After feedback from participants, these data were uploaded into NVivo for coding. All information from the questionnaire responses was categorized according to the teachers' backgrounds, teaching beliefs, content knowledge, knowledge of context, and teaching orientation. Collectively, these categories were used to investigate the teachers' PCK in their teaching practice. Relevant data from teaching document analysis were captured and entered into NVivo for coding.

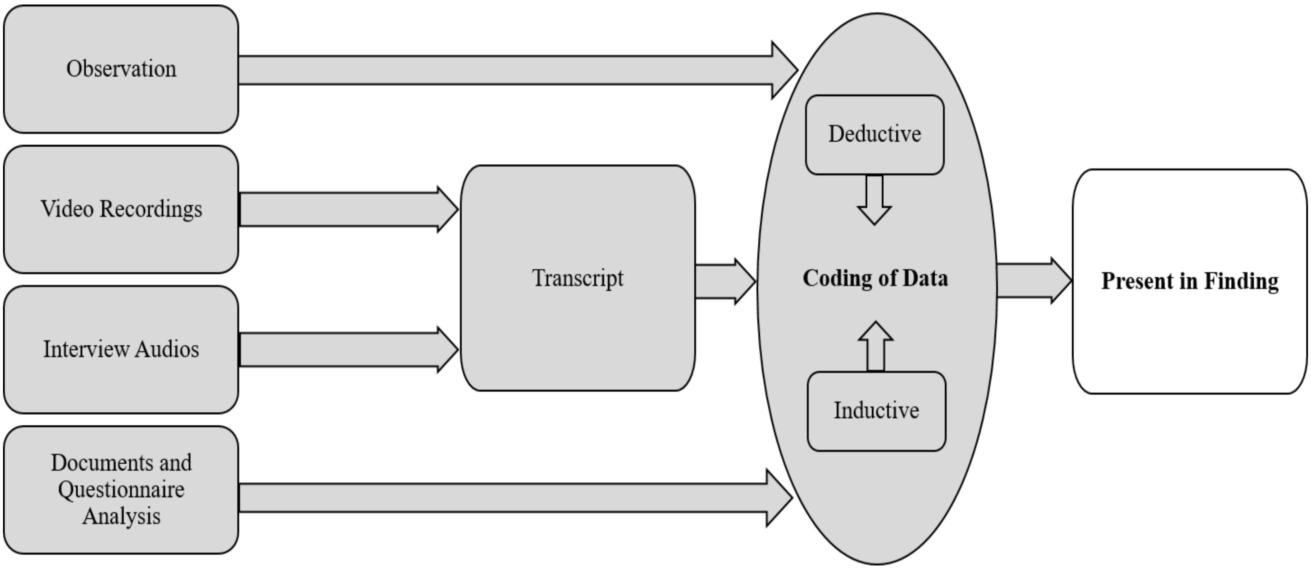
The obtained codings were used in presenting findings. By using these codings, teaching episodes were selected where one knowledge component was identified as a prominent knowledge in participants' particular teaching. The other knowledge components were also noted along with the prominent knowledge in particular teaching then all these components were presented in the form of combinations of knowledge components. All episodes regarding prominent knowledge components (e.g. Knowledge of Students) in teaching are discussed under a section and the given name of that section is based on that prominent knowledge (e.g. Knowledge of Students). So, each case study is organized into six sections (Assessment Knowledge, Pedagogical Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, and Contextual Knowledge).

The selected teaching episodes are discussed under the relevant section for their prominent knowledge. The teacher's PCK is represented in the form of combinations of knowledge components that were identified in the particular teaching moments. The number of knowledge combinations varies in each section when they were clearly identified in the teaching. At the end of each section, I use a quantification of knowledge components by using their appearance, coded according to the analytical framework, in the discussed knowledge combinations in that section to understand the relativity of identified components within the combinations. The quantities are not absolute, only relative to that teaching epsiode, and serve to provide indications of how combinations occur. For instance, one section has four different combinations. The number of appearances of Knowledges/Amplifiers and Filters in the combinations were represented by showing more prominence. This simple and relative method cannot represent the complex nature of knowledge combinations completely, but it has value to visualize and portray the implicit nature of teachers' PCK in the classroom. This simple method helps to evaluate use of knowledge components in particular teaching for particular students. Importantly, it illuminates the dynamic nature of knowledge components within PCK in the classroom.

To sum up, data were organized systematically: first, recorded data from observations and interviews were transcribed and where appropriate, were validated by the participants. Responses to the open questions in the questionnaire were also typed up, and data from document analysis captured as typed text. Second, all data were imported into NVivo for analysis. An analytical framework was used to understand the data in a deductive way according to the PCK consensus model, and also interpret the same data by selecting the inductive approach to search for new features of PCK/PCK&S. Codes gained through NVivo nodes were grouped into themes and considered for presenting in the findings. Teaching episodes were selected based on identified prominent knowledge components in the knowledge combinations. Episodes are discussed under the relevant knowledge section in the findings chapters to understand knowledge combinations. A summary of the overall analysis process is shown in Figure 3.5.

Figure 3.4

Data analysis process



It is very important in social research to account for potential ethical issues in advance before the start of research in the field and to address these issues throughout the study. The next section discusses the ethical issues in this project.

3.10 Ethical Issues

The ethical issues vary from research context to research context and from culture to culture, and these issues impact in distinctive ways depending on the nature of the research project. For example, the ethical issues related to conducting research in pure science are different from the ethical issues related to conducting research in the educational sciences. Put frankly, research participant rights in New Zealand are different from research participant rights in the research context in Pakistan. The upcoming paragraphs discuss how these issues are addressed in the New Zealand educational research context.

It is the responsibility of the investigator, as recommended by the New Zealand National Ethics Advisory Committee (2012), to protect the integrity of research participants. This is to say, "[a]n investigator's commitment to the advancement of knowledge implies a duty to conduct honest and thoughtful inquiry and rigorous analysis and to be accountable for her or his activities" (p. 10). On the other hand, 'diversity' in research means in the New Zealand research context that the researcher should understand the values of a culture. That is, every participant has the right to provide information or not, be willing to give services for data, and can stop providing data at any stage, and in ways that take into account the participant's values, religious, social, beliefs, ethnic group, etc. The School of Education, University of Waikato, New Zealand deals with such concerns at the research proposal stage. I received ethical approval for this study from the Human Research Ethics Committee, the School of Education, and provided answers to all questions that were of any concern. I collected data following the ethics guidelines when addressing issues of privacy, accessibility, research outputs, the storage of data, and the impact of findings on the professional career of the participants.

An information sheet was provided to participants and the school principal to communicate the ethical aspects of the research project, with a comprehensive introduction of this research. As Rozsahegyi (2019b) suggests to researchers, it is their responsibility to provide this form to participants. The information sheet was a complete pack of information about the study: the study's aim, the participants' roles, voluntary involvement, and details on the benefit to the teachers [e.g. it is hoped the outcomes will help them to improve their teaching], and the potential risks. Informed consent refers to the right of participants to weigh up the risks and benefits involved in participating in a research project (Cohen et al., 2018). This consent form also mentioned the approach that participants need to follow when addressing a conflict; a process that needs to involve the chief supervisor. The National Ethics Advisory Committee (2012) emphasizes this point [conflict of interest], that the investigator should nominate a responsible person or organizations (e.g. co-investigator, research supervisor, university, employers) who are involved with the study because any conflict of interest should be resolved.

Before the data collection process began, the consent was granted from participants as well as from the head of the school. I met the respective teachers with my chief research supervisor before data collection began and we informed the students about the study and the fact that the researcher would be present and using a camera in their class (during the data collection period) and clearly described for them that they will not be a part of the study, and their learning outcomes would not be discussed in the report. We also asked if they had any questions.

During the classroom observations, I was present as a non-participant and avoided creating any disturbance in the teaching-learning process. Because my presence could potentially have influenced classroom practice I tried to reduce my influence by spending some time in the classroom before the formal observation began, as some experts have recommended. I performed as a good listener when I conducted the interviews with the participants and I worked hard to ensure that there was no negative effect on the participants through either my words or my body language; always respecting the teachers' decisions to answer questions or not. I also ensured that the follow-up interview period did not consume too much time for the teachers. With this intention in mind, I asked each participant before beginning each lesson follow-up interview about their free time and if they agreed, then I conducted an interview, otherwise, I arranged it at any time according to their suggested time; it was totally their choice. The complete data gathering process was conducted in a very professional way and not a single issue was raised throughout the process.

In the data collection process, the ethical matters relating to this study were followed as a priority. For instance, no single action [e.g. video recording] was taken without permission of the participants as this could influence their careers. All ethical issues are important at the thesis-writing stage, for example, all teachers were given pseudonyms in the report and the personal information of participants was kept confidential. The school's name was also not used in any documentation of the study because such information should be no part of the data. For confidentiality, I kept their records secure through the use of password protected files in the computer. Hardcopies of all concerned documents have been put in locked drawers that no one could access without an authorisation. In my case, only my supervisors have the authority to check the data for verification. Earlier in the analysis of the data, such information was filtered and removed because sometimes the data and information were intermixed, as has been described:

> The terms ‘data’ and ‘information’ are often used interchangeably. Data can refer to raw data, cleaned data, transformed data, summary data, and metadata (data about data). It can also refer to research outputs and outcomes. Likewise, information takes on many different forms. Where information is in a form that can identify individuals, protecting their privacy becomes a consideration. (Australian Research Council, 2018)

I used this filter at the data cleaning stage to get a surety that I was keeping the information confidential at all stages of writing my thesis and in that way such information does not appear in the findings.

3.11 Summary

This investigation was done to investigate science teachers’ PCK and skills in their New Zealand classrooms. A theoretical framework was established that was based on the 2015 PCK Consensus Model. For this purpose, a qualitative multiple case studies research method was administered to capture the complexity of PCK in the classroom. This involved use of an interpretive paradigm. More specifically, the elements of this paradigm that are applicable to this research project are empirical epistemology, relativist/constructivist ontology, naturalist methodology, and balanced participant-researcher axiology. A convenient sampling procedure was adopted to select the participants. The participants used in this study were two experienced science teachers: both participants have more than 20 years of teaching experience. Each teacher was observed teaching 10-12 lessons (a complete topic) during their chemistry topic in their year-10 science class. A brief description of my background was presented to clarify my research strengths and to highlight the challenges I faced in this unfamiliar context. I did the data collection; data being collected using a pre-topic questionnaire for each of the teachers to probe aspects of their teaching beliefs, the teachers’ and school’s planning documents used for document analysis, through classroom observation including video recordings to explore the enacted PCK, lesson follow-up interviews were shaped to capture teachers’ reflections about their teaching, and topic follow-up interview with each teacher to know overall their thoughts about the topic teaching and learning. All data were arranged and analyzed systematically: recorded data were transcribed, data from the questionnaire and document analysis were typed, all data were coded using NVivo. The gained codes and samples of evidence from data were presented in findings. Using a multiple case study approach, rich descriptions, data triangulation and cross-verification of data helped enhance the trustworthiness and credibility, and confirmability of the study.

The next two chapters present the findings of the study, case by case.

Chapter 4
George's Case Study

4.1 Overview

This chapter presents a case study of George (participant's pseudonym) with data gathered through a pre-topic questionnaire, document analysis, classroom observations and associated video recordings, follow-up interviews after each classroom practice, and a final interview after the topic. These data are reported in this chapter as question-question number e.g., (Q-8), (Q-11), and follow-up interview responses as an interview- interview number e.g., (I-4), (I-7), with final interview data denoted as interview-final (I-F), and observations/video recordings from specific lessons as a lesson-lesson number e.g., (L-1). Firstly, this chapter reports the context of the study that provides the details of the classroom setting and George's background. The second portion is the major body of this chapter that deals with components of his PCK in his teaching practice; it includes evidence of George's Assessment Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge. Finally, it presents a summary of this chapter.

4.2 Context of this Study

The case study involved an experienced science teacher in a public boys' high school in an urban area of New Zealand. Research data were generated when George taught a chemistry topic 'Ionic Chemistry' to Year 10 students (junior secondary science class, age 14-15). The topic content included theoretical ideas and practical activities. The school administration allocated a timeframe to George to teach the content and to achieve students' learning objectives (SLOs). The teacher decided the sequence of topic content and was assisted by a science book recommended by the school as a science textbook. This section discusses the classroom context and research participant's background.

4.2.1 *Classroom context*

The observed classroom consisted of 28 students from multicultural backgrounds: most of them appeared to be Pākehā (a Māori term to describe European-origin New Zealanders), less than 5 were Māori (indigenous Polynesian people of New Zealand), and 3-5 appeared to be Asian or from other cultural backgrounds. This Year 10 class was a precursor year for students studying Level 1 in the National Certificate of Educational Achievement (NCEA). At this level, a science teacher needs to start a particular topic from its basic concepts because students at junior science level have little foundational level knowledge of specific chemistry concepts, so, George admitted that there was ‘new stuff’ (L-1) for students in this topic. In this situation, the science teacher may put their effort more into pre-concept teaching (if students have no prior knowledge about a specific concept or ‘new stuff’ in the content, then a teacher may work to develop foundations) to build a concept. Further, a teacher’s teaching style, actions, skills, and knowledge might make chemistry easy or difficult for them and encourage or discourage students to develop an interest in chemistry as a subject in their future academic journey. Therefore, it could be considered a rich scenario to observe a science teacher’s use of pedagogical content knowledge (PCK) during their teaching practices in a secondary chemistry classroom.

The school science department provided the school curriculum to George, which consisted of SLOs, topic content, and a list of practical activities. Most of the SLOs were derived from *The New Zealand Curriculum* (NZC) (Ministry of Education, 2007). Key concepts of ionic chemistry recommended by the NZC were also included in the school curriculum. These key concepts were: all matter is made of particles, the properties of materials derive from identity and arrangement of particles, energy plays a key role in determining the changes that matter undergoes, and chemistry is everywhere. A derivation linkage between the school curriculum and NZC can be noticed.

According to the school curriculum, the topic content included: draw and label the structure of an atom, define atomic mass and atomic number, calculate the number of subatomic particles in an atom, explore how elements are arranged in the periodic table, describe names and formulae of common ions, draw electron arrangement diagram using Bohr’s model of an atom for the first 20 elements, write electron configurations using 2,8,8 notation for the first 20 elements of the periodic table, name and write balanced formulae for ionic compounds, explain why ionic compounds are neutral and how formulae relate to this, recognize the colors of common precipitates formed from the reaction of metals and sodium hydroxide, write ionic equations for common precipitates, identify various metal ions from the flame test, and conduct simple practical application of metals and ion color. The practical activities included flame tests and precipitation reactions involving sodium hydroxide.

The chemistry class was taught three days a week: one 40-minute lesson in an ordinary classroom, and two 50-minute lessons in the science laboratory classroom. The science laboratory classroom was specially designed for science teaching. A big teaching table, a whiteboard, a multimedia projector, and student benches in rows in the classroom, and there were water taps and sinks and natural gas connections on benches around the walls, and safety gear for every student. All of these facilities indicated a science laboratory classroom for conducting science experiments under safety measures. The science classroom wall was well decorated with science diagrams (e.g. labelled diagram of muscles in the human body, scientist mixing chemicals in a conical flask, etc.), a big periodic table, color printed A4 size symbols of nitrogen (N), oxygen (O), titanium (Ti) and cerium (Ce) with their atomic number and atomic mass. There were health and safety sign charts for fire, corrosion, and danger that were printed on yellow paper. There were also many small informative science charts and photos on the wall. It would provide an excellent opportunity for George to help students to apply science content in his teaching practice by effectively using this physical context.

4.2.2 *Research participant*

George has science and professional teaching qualifications. He completed his Bachelor in Science in parallel with a Bachelor in Education degree 30 years ago and recently, he earned a Postgraduate Diploma in Science. Alongside these, he had also achieved a Diploma in Nursery Management and a Level-4 National Certificate in Beef production. He had completed all his schooling and professional qualifications in New Zealand institutes.

He had more than 20 years of science teaching experience at the secondary level in New Zealand schools. He had been teaching the ionic chemistry topic regularly in each academic year during his teaching career. A science teacher's interaction with the same level of students [e.g. junior secondary science] in a particular science topic [e.g. ionic chemistry] may indicate their sound experience and well-developed set of knowledge for this topic, but even under the same circumstances like teaching the similar topic, the resulting PCK may differ between teachers and between their classes (Park & Chen, 2012). At the start of his teaching career, George taught Biology to Year 11, 12 & 13 students in another high school in the same city, but he had spent most of his professional career in this current school. He was currently teaching Mathematics to the students of Year 10, General science to Year 9, 10 & 11, and Horticulture to Year 9, 10, 11, 12, & 13. In the academic term of the study, he was teaching 16-20 lessons a week and he was also involved in non-teaching activities within the school. The number of lessons of teaching that are assigned, time availability for teaching planning, and duties outside the classroom can all influence the instructional planning of a teacher for any given class (Gess-Newsome, 2015). In addition to this, George has a small beef and crop business selling products from his farm.

Teachers' knowledge or sets of knowledge are frequently utilized in classroom practice for teaching, and some of these are tacit, and some of them are explicit in their teaching. The Consensus Model of PCK (CM) suggests much of the knowledge components contribute to a teacher's PCK for teaching and learning relationships in the teaching process for teaching a particular content to particular students. Therefore, the following sections present and analyze data gathered in George's topic teaching. The presented data in each section were selected when that knowledge appeared prominent in his teaching. The name of each section represents the knowledge in the Teacher Professional Knowledge Base TPKB in the CM of 2015 (e.g. Assessment Knowledge). The order of sections (from 4.3 to 4.9) is arranged according to knowledges in TPKB (from left to right) of the conceptual framework of the study. The following section then discusses George's Assessment Knowledge in his teaching.

4.3 Assessment Knowledge

A teacher's Assessment Knowledge is shown as a knowledge component of the Teacher Professional Knowledge Base (TPKB) in the consensus model (CM). This knowledge includes teachers' knowledge toward assessment designs and implementation of formative and summative assessment in teaching (See section 3.8). Teachers also require some skills to apply these assessment methods in their classroom practice. This section describes how George's Assessment Knowledge combined with knowledge components of TPKB and components of TSPK in his classroom practices. This section also discusses his Amplifiers and Filters when they appeared to amplify or filter his teaching.

4.3.1 *Diagnosing students' prior knowledge*

George triggered his students' prior knowledge in the classroom that reflected his use of Assessment Knowledge. He claimed through his pre-topic questionnaire responses that he can assess his students' understanding in the classroom through their interest in the class activities or the nature of questions they ask, noting "The type of questions they [students] ask. The answers they give to questions and problems. The involvement in practicals and responses in the assessment [exam]" (Q-15). Similarly, he said, "Hopefully, with questioning, on a daily basis. But then [pause] when they do the test, they'll do the exam, then I'll have a good idea" (I-7). These statements show his ways of assessment: he assessed his students through questioning in the class (i.e. diagnostic assessment) and responses in the exam (i.e. summative) which indicate his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of implementing formative and summative assessment in teaching.

I was able to associate his claims in the questionnaire with his classroom practice. I observed that George came with some written questions to the first lesson of this topic, which he wrote on the whiteboard at the start of the lesson (L-1). These questions appeared to focus on the topic of 'Ionic Chemistry'. These questions were:

- Draw an atom and label [its] four parts.
- What is an Atomic Number?
- How many electrons in a Helium atom?
- What is an ion?
- How does oxygen become an ion?
- How are electrons arranged in a Lithium atom?
- What does NaCl tell us about common salt?
- What could happen if we mix a solution of NaCl and $CuSO_4$?
- What does precipitation mean?
- What is a metal cation?
- What would you see if you burned a copper compound?
- How could we use this effect? (L-1)

He prepared and wrote all the questions on a paper before the start of the class, he then printed these questions on the whiteboard during the class. He gave some time for students to discuss these questions with each other. He asked each question one by one to the students and explained them. He drew the structure of an atom and explained its four parts: protons, neutrons, electrons, and atomic shell (L-1). The preparation of these questions indicates his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of designing short questions. He engaged the students by asking these questions which indicate his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his strategy to engage the students in learning through questioning. His explanation of atomic particles and atomic shells indicates his Content Knowledge. It is Content Knowledge because it reflects his understanding of atomic structure which is specific to chemistry content. In this teaching slot, Assessment Knowledge was identified in designing the assessment task, Content Knowledge combined with Assessment Knowledge to explain the questions, and Pedagogical Knowledge combined with Assessment Knowledge and Content Knowledge to engage the students by asking these questions.

These questions were selected from the topic and the previous year's chemistry content as George discussed. This aspect of questions was explored in the follow-up interview when he responded to the question [How did you prepare these questions?]:

> Ok, Mostly, I prepared from (the school) learning outcomes. I made up questions based on these [he showed topic content]. Some of them I left out, some of them I simplified a lot but it is interesting that they don't think they remember very much from last year because they would have done it last year. We talked about atom structure and they would have learned the first twenty elements [last year]. They would have done some basic reactions but they didn't write what was happening in the reaction and why it happened. (I-1)

This response illustrates that he used the school curriculum and their previous academic learning for the preparation of these questions. He used learning outcomes from the school curriculum in assessment indicates his Curricular Knowledge. It is Curricular Knowledge because it reflects his understanding of the school curriculum structure. He knew that 'They would have done some basic reactions' last year, which indicates his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge of these students' prior academic work. This identified that George used his Curricular Knowledge and Knowledge of Students combined with Assessment Knowledge for designing the formative assessment. He described the purpose of these questions to the class:

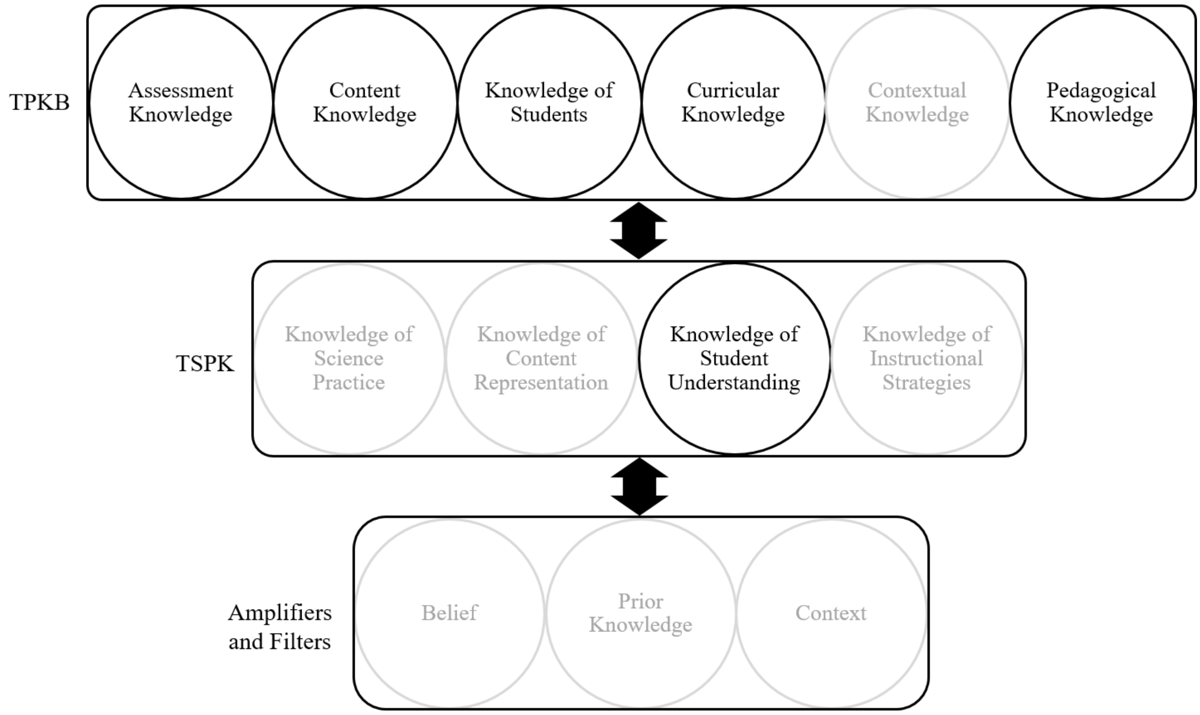
> We'll talk through the results [of these questions], so I'm not going to record your results. But we will go get through them, and I'm interested to see what you guys know from last year or what you have picked up elsewhere. Because with a bit of luck that will make it easier for us, Ok ... We are finding that a little bit, there might be some questions that you guys don't know, some of you just skipped over them quite quickly, and there might be some that are obviously difficult concepts, and so we need to spend quite a bit more time on that. (L-1)

George appeared to use these questions to assess the students' prior knowledge by diagnostic assessment. The outcomes of this diagnostic assessment activity were identified as helpful to develop his topic planning. This part of the statement 'there might be some questions that you guys don't know' indicates his Knowledge of Students Understanding. It is Knowledge of Students Understanding because it reflects his knowledge of students' prior knowledge for this particular topic. The combined knowledge also combines with his Knowledge of Students Understanding in this teaching episode. There is a combination between TPKB and TSPK components because his knowledges combined (Assessment Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge) for designing the assessment task, explaining the questions, using the school curriculum, and engaging the students in these questions that might inform his Knowledge of Students Understanding [there might be some questions that you guys don't know], while his Knowledge of Students Understanding combine with his Pedagogical Knowledge and Content Knowledge to shape 'there might be some that are obviously difficult concepts (i.e. content), and so we need to spend quite a bit more time on that (i.e. planning)'.

In these data, his Assessment Knowledge was identified in designing and implementing assessment, his Content Knowledge combined with Assessment Knowledge to explain the chemistry concepts like atomic shells, his Knowledge of Students combined with Assessment Knowledge to use his students' prior academic work in constructing short questions, his Curricular Knowledge combined with Assessment Knowledge to use the school curriculum in designing assessment, and his Pedagogical Knowledge combined with Assessment Knowledge to engage the students in responding to these questions. His Knowledge of Students Understanding also combines with these combined knowledges to use students' prior knowledge about relevant ideas. The combination of these knowledge components is framed in Figure 4.1, where black circles indicate evidence of that knowledge component and grey circles represent no evidence.

Figure 4.1

Combination of knowledge components for diagnosing the students' prior knowledge



Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge). This combination of knowledge components also combined with his Knowledge of Students Understanding in diagnosing students' prior knowledge.

4.3.2 *Implementing formative assessment*

George's Assessment Knowledge appeared to be used to inform his ongoing teaching practice. For instance, he arranged an activity in Lesson 3 where he drew a table of electron configurations on the whiteboard. This table consisted of 10 rows and 8 columns. He explained to the class how to fill this table by using the periodic table on the wall. He filled one of its rows by using the periodic table as examples (Figure 4.5). He asked the students to fill the rest of the table by using the periodic table (L-3). He started moving around the class to help the students and check students' work. He clapped his hands and said, "remember, in the case of carbon; four electrons in its outermost shell are not going to lose and gain electrons, that's why it doesn't make an ion, So, leave it" (L-3). Through this, he indicated that he observed the students' difficulty in applying the concept to fill electrons [electron configuration] into the carbon shell. Therefore, he decided to ask students to leave it. After this in Lesson 3, he introduced the concept of the covalent bond to clarify the nature of carbon bonding for students.

In this teaching episode, he checked his students' work in class during a task which indicates his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of implementing formative assessment in teaching. He explained that carbon atoms do not make ions because they have four electrons in the outermost shell, which indicates his use of Content Knowledge. It is Content Knowledge because it reflects his understanding of electron configurations, which are specific to chemistry. He engaged the students in filling the table which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of a strategy to engage the students and to allow him to formatively assess their developing understanding.

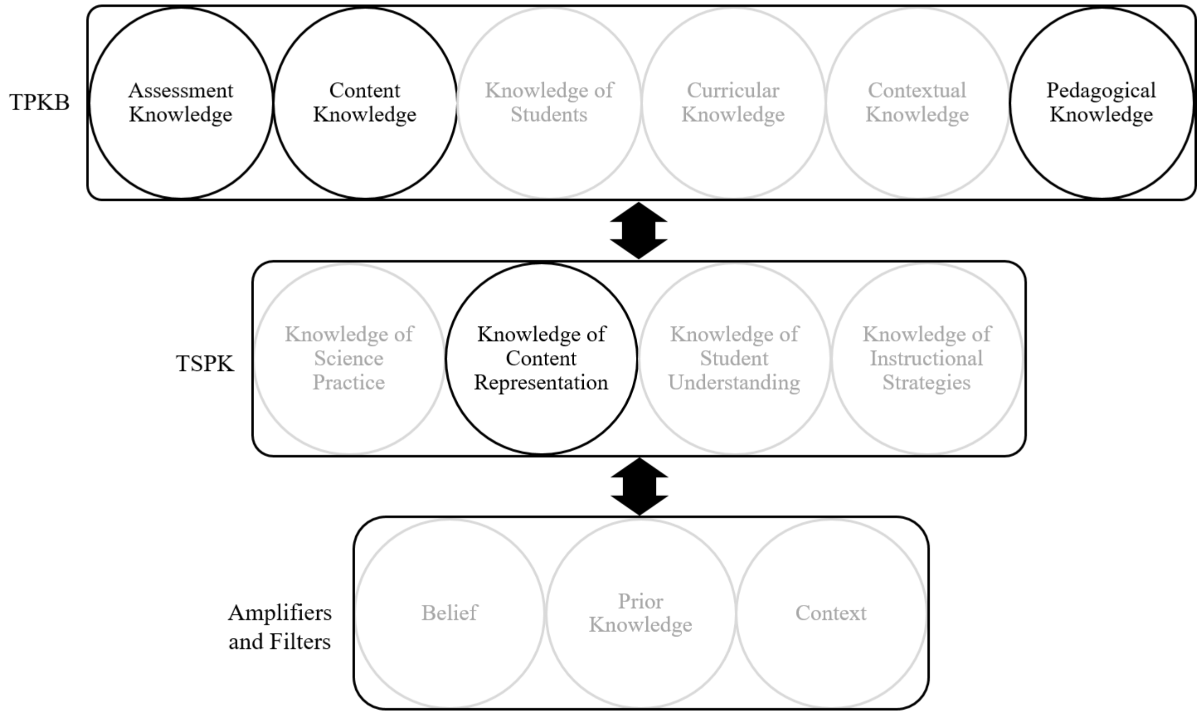
In this teaching episode, George's Assessment Knowledge was used to implement formative assessment in his teaching, his Content Knowledge combined with this Assessment Knowledge to clarify electron configurations in carbon atoms, while his Pedagogical Knowledge combined with these knowledges to engage the students in filling the electron configuration table. He accessed this content by asking the students to draw and fill the electron configuration table, which indicates his Knowledge of Content Representation. It is Knowledge of Content Representation because it reflects his understanding of the affordances of this particular representation to access and develop a better understanding of electron configuration in students. The TPKB knowledges (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) combined with his (TSPK) Knowledge of Content Representation in this teaching episode to address the particular concept of electron configurations.

George used the same approach in Lesson 8 when he identified the students' difficulty with a concept in class and then started to explain the concept again. At the start of this lesson, he wrote the rules of writing chemical formulae on the whiteboard and explained these with some examples. Then he wrote the names of some compounds on the board and asked the students to write the remaining formulae. He started to move around the classroom to check the students' work. After checking some students' work he went to the whiteboard. He wrote the formulae of the remaining compounds and explained the reasons why elements balance each other in a chemical formula (L-8). In this activity, he formatively assessed the students' work and he used the outcomes of this strategy in deciding to write the remaining formulae with explanation, therefore changing his strategy by using assessment to one of guided support to more transmissive teaching. George's use of Assessment Knowledge again reflects his knowledge of implementing formative assessment in the class. He explained the rules of writing chemical formulae with examples that indicate his Content Knowledge. It is Content Knowledge because it reflects his knowledge of writing chemical formulae that are specific to chemistry. He engaged the students in writing the chemical formulae which indicate his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflected his knowledge of how to engage his students in learning.

In these data, his Assessment Knowledge encouraged him to implement formative assessment in his teaching, his Content Knowledge combined with Assessment Knowledge to explain the chemistry concepts, and his Pedagogical Knowledge combined with these knowledges to engage the students in learning. His Knowledge of Content Representation also combined to adopt the most appropriate content representation method for electron configuration and writing chemical formulae. This combination of knowledge components is framed in Figure 4.2.

Figure 4.2

Combination of knowledge components in formative assessment



Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge). This combination of knowledge components also combined with his Knowledge of Content Representation in implementing formative assessment.

4.3.3 *Summary of Assessment Knowledge focus*

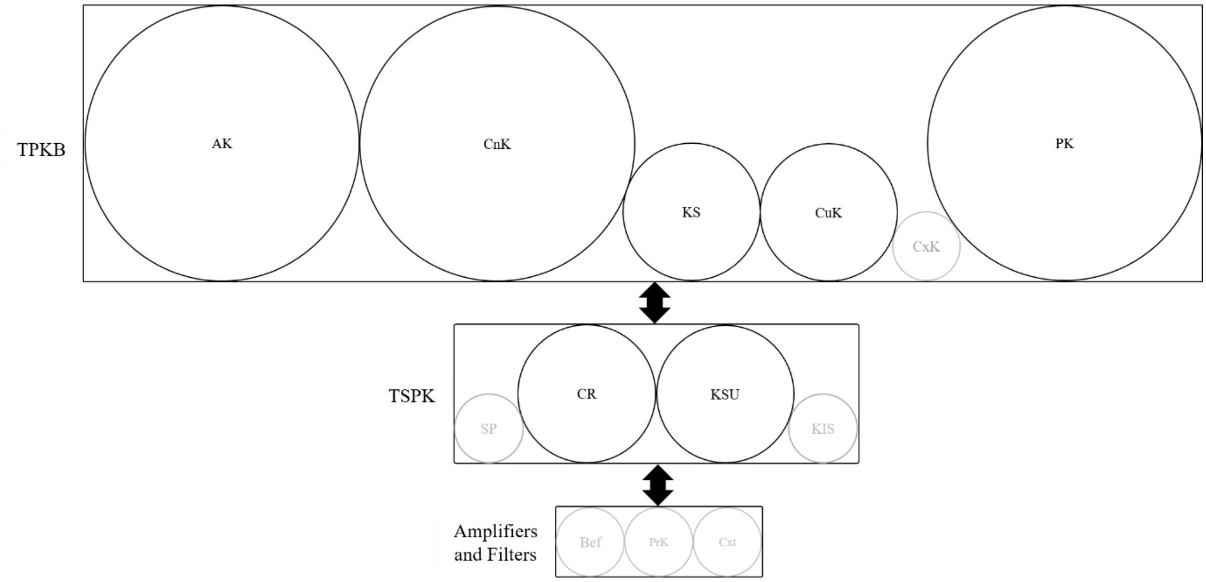
The previous sections have illustrated George's use of Assessment Knowledge in designing and implementing diagnostic and formative assessments in teaching. In these classroom examples, his Assessment Knowledge was used to diagnose students' prior knowledge, his Pedagogical Knowledge combined with this Assessment Knowledge to engage students in learning, his Content Knowledge combined with this Assessment Knowledge to explain content, his Knowledge of Students combined with this Assessment Knowledge to discuss his students' previous years' content learning and Curricular Knowledge combined with this Assessment Knowledge to make coherence with the school curriculum. The combined TPKB knowledge components also combined with his Knowledge of Content Representation and Knowledge of Students' Understanding in different situations to teach particular concepts. The combined knowledge components in his teaching can be seen to indicate his PCK and the practice of this combination in teaching indicates his skills.

The two figures above (4.1 and 4.2) represent George's PCK in the selected pieces of evidence when his Assessment Knowledge was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Assessment Knowledge in this evidence. In these figures, Assessment Knowledge naturally appeared two times in this data (2/2), with Content Knowledge and Pedagogical Knowledge also present both times (2/2). Knowledge of Students and Curricular Knowledge both appeared once in combination with Assessment Knowledge (1/2), while Contextual Knowledge did not appear in these combinations (0/2), so its circle is presented in a grey color. Of the TSPK components: Knowledge of Content Representation appeared once each (1/2), Knowledge of Students Understanding (1/2), while Knowledge of Science Practice and Knowledge of Instructional Strategies (0/2) were not evident. In Amplifiers and Filters, no single component has appeared in this selected data.

The relative appearances of the knowledge components and their percentages are presented in the form of the size of the circles in Figure 4.3. I am aware that this Figure cannot represent an exact quantitative relationship among George's knowledge combinations for his teaching, but it can be seen to represent the relative combinations among them, as observed. The size of the circle shows the strength of the combination with Assessment Knowledge e.g., the combination of Assessment Knowledge with Content Knowledge is stronger than with Knowledge of Students according to Figure 4.3. Furthermore, the size of circles in TSPK are not representing the combinations with each other, but it shows the relative combining strength with TPKB combination and vice versa. Likewise, the size of circles in Amplifiers and Filters are not representing the combinations with each other, it presents their relative combinations with components of TPKB and TSPK.

Figure 4.3

Combination of Knowledge components, when Assessment Knowledge is prominent in George's classroom practice



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

This figure shows his Content Knowledge and Pedagogical Knowledge combined more often with Assessment Knowledge as compared to Knowledge of Students and Curricular Knowledge while Contextual Knowledge did not appear to be used in any combination when Assessment Knowledge was prominent. His Knowledge of Content Representation and Knowledge of Students Understanding also combined with his combined knowledge while his Knowledge of Science Practice and KIS did not combine in these selected data. His Amplifiers and Filters did not amplify and filter his teaching.

The following section discusses examples when George's Content Knowledge was identified as prominent knowledge in his classroom practice.

4.4 Content Knowledge

A teacher's Content Knowledge in this study refers to knowledge of academic content of the subject and understanding of the relationship among concepts within and across subjects. George's background shows through his questionnaire data that he completed his Bachelor of Science (B.Sc) 30 years ago and recently earned his Postgraduate Diploma in Science, which shows that he has been trying to maintain up-to-date knowledge about science content. Moreover, he did a Diploma in Nursery Management and got a national certificate of level-4 in Beef Production, and is putting these studies into practice on his farm, as he noted that he "raises beef and grows plants for sale" (Q-6b).

His academic science background, along with his interests in beef and plant nursery appeared to influence his perception of chemistry and helped him to generate examples for science teaching. For instance, he perceived chemistry in a general sense as, "The nature and interactions of materials and the study of these things" (Q-16). His descriptions of chemistry applications in society echoed these interests, as he wrote: "The use of fertilizers to enhance production in primary sectors" and "The manipulation of growing processes and techniques to improve characteristics of products such as beef and apples" (Q-17), which are related to his private business, context and recent study background. Through this understanding, I was able to associate his pre-topic questionnaire data and classroom teaching.

4.4.1 *Responding to students' questions*

George's Content Knowledge appeared to be reflected in his responses to his students' questions in the classroom. In Lesson 1, he drew Bohr's atomic model to explain the structure of an atom. By using the diagram, he explained the location of electrons, protons, neutrons, and atomic shells in an atom. A student asked him about the movement of electrons in the atomic shells (L-1). Then he explained:

> Good point, the electrons are moving Ok. We draw in one place (indicated toward board) but it is not still in one place. It is convenient for us; we draw in one place, we count it and whatever, but that's not right. Actually, they are not still in one place and you are not able to take a photo to count them, because they always are moving. Ok, and all we can say; shells are the concern, they are moving all the time, they move very fast and you can't ever predict exactly where they can be. But for our purposes the Bohr's diagram with two

> electrons here [in the first shell] and eight electrons here [in the second shell] and another eight here [he was moving his hand on the diagram to indicate the location of electrons in shells] and the whatever. (L-1)

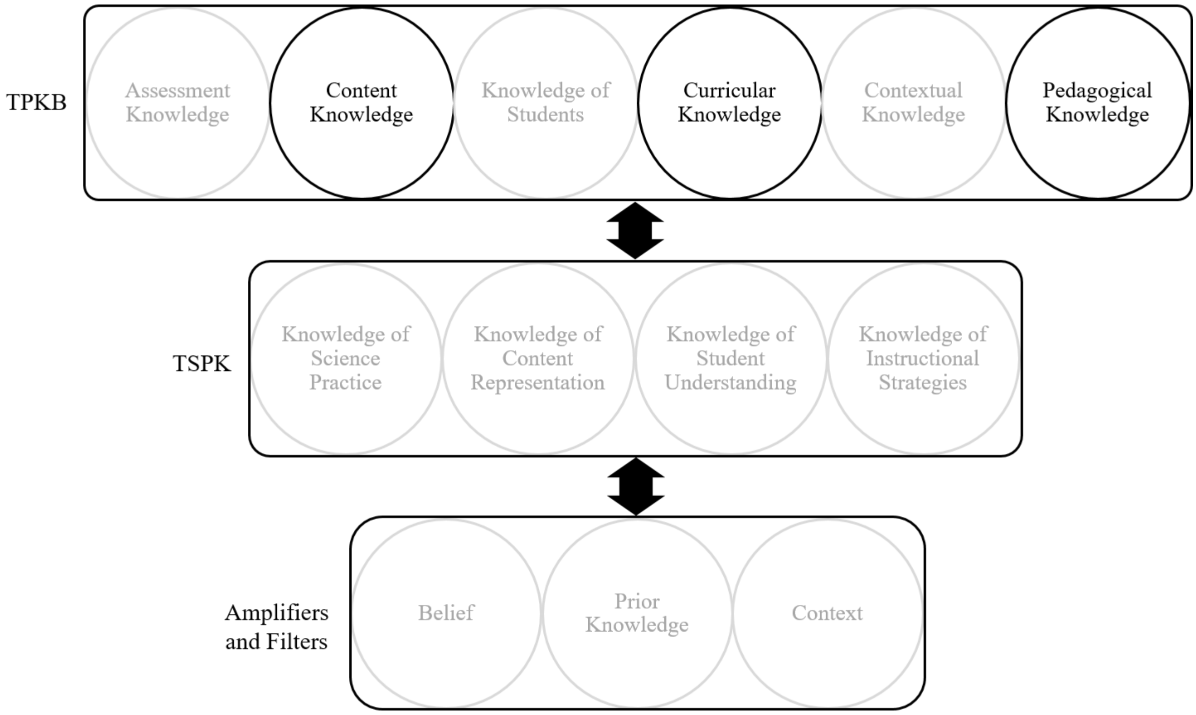
This example shows that in response to the student's question, George employed his Content Knowledge to help him to explain the concept. His explanation of the arrangement of electrons in an atom by using Bohr's atomic model indicates his Content Knowledge. It is Content Knowledge because it reflects his understanding of atomic structure. At the start of this response, he started with the encouraging word 'Good point' which indicates his Curricular Knowledge. I have coded this as Curricular Knowledge because it reflects coherence with *The New Zealand Curriculum's specifically* recommended pedagogy 'Encouraging reflective thought and Action' (Ministry of Education, 2015, p. 34), although it could also have been coded as pedagogical knowledge.

In the same discussion, another student put another question [what is the shell made of?] in the class (L-1). He responded that "the shells are not [he took a pause]. The shells are constructions in your brain. The shell doesn't actually exist" (L-1). This time he did not go with a deep explanation of the answer to the student's question as compared to the previously asked question [which he explained in case of movement of an electron]. In a close look at both responses, in my view, it shows that the teacher simplified his use of content knowledge according to the context [academic level and need of the students] to not elaborate on the concept. This simplification of content to respond to a question indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his using of Knowledge of Students to personalize his response to students by considering the students' academic level.

In this teaching episode, his Content Knowledge was identified in his response to students' questions, his Curricular Knowledge combined with this Content Knowledge to bring *The New Zealand Curriculum* recommended pedagogy to encourage the student's reflective thought. Pedagogical Knowledge combined with Content Knowledge to personalize his response according to students. The combined knowledge identified in response to students' questions is framed in Figure 4.4.

Figure 4.4

Combination of knowledge components to respond to students' questions



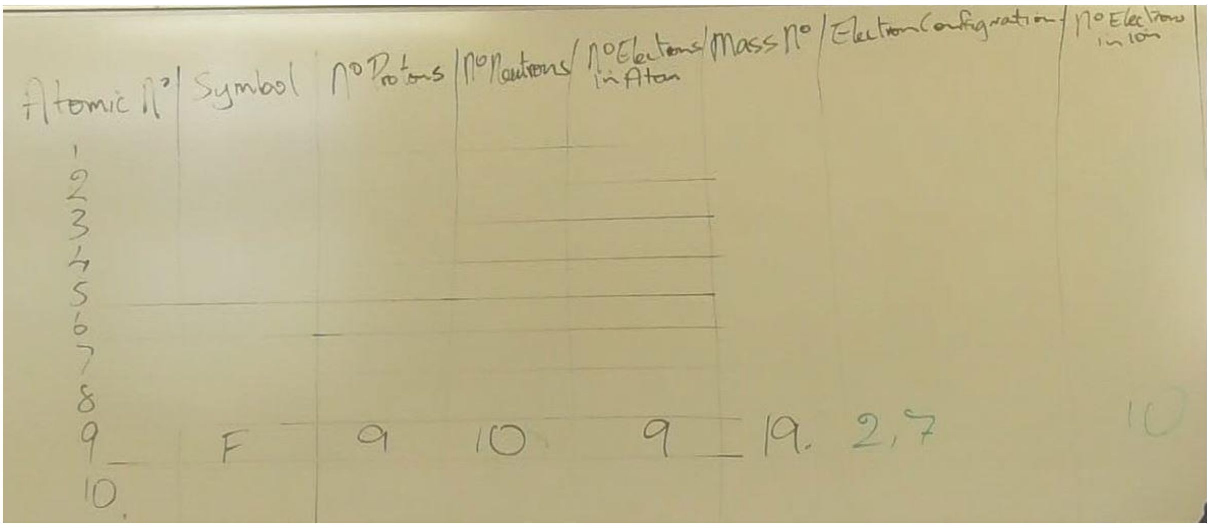
Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in responding to his students.

4.4.2 *Explaining electron configurations*

George's Content Knowledge appeared to be used to explain the electron configurations of the first ten elements in the periodic table. In Lesson 3, he taught the filling of electrons [electron configurations] in atomic shells through a table-completion activity, as described earlier. He drew the table which consisted of 8 columns and 10 rows. The rows represent the atomic number of the atoms. In columns, he wrote: atomic number, symbol, and number of protons, number of neutrons, number of electrons, mass number, electron configurations, and number of electrons in ion (see Figure 4.5). He filled a row using the periodic table on the wall to show how to fill the table (L-3).

Figure 4.5

George's table to explain the electron configuration of atoms



Note: This screenshot was taken from the video of George's Lesson 3 to show an image of his table-filling activity on the whiteboard.

Before the start of this activity, he explained the periodic table divisions according to the number of electrons in the outer shell (L-3). I observed in this lesson that he often used the periodic table on the wall of the classroom to develop his students' understanding of the position of elements in the periodic table. It seemed that he did that because this explanation could help the students to find the symbol of elements by using their atomic numbers. It could also help to calculate the number of protons, number of neutrons, and number of electrons. He explained:

> The number of things we talk about, first, hydrogen; according to the rule I gave you, it gains an electron and its outermost shell will have two electrons, but it's funny, hydrogen does not fit the rule. I am not expert in it. You will touch on it [position of hydrogen] in the coming years.
>
> If we go down here in the drawn table on the whiteboard, [Then he moved to periodic table on the classroom wall and started to explain the right side of the periodic table.] They have a complete outermost shell [noble gases] so they do not gain or lose an electron and are non-reactive, called inert gases.
>
> [He discussed the properties of carbon] They [carbon, silicon, etc.] also do not gain or lose electrons; they have a different system of sharing electrons.

> [He was moving his finger on group seventeen and explained] fluorine, chlorine, etc., they need to [gain] one electron to complete one extra electron, so it tends to be very reactive likewise first group [he said 'forget the hydrogen at this moment'], those need to lose one electron, again they are very reactive. (L-3)

In this teaching episode, when he did not explain the reason behind 'why hydrogen does not fit the rule' indicates that he filtered the content according to the students' academic level, so he said, 'you will touch on it in coming years'. The abiotic classroom context [periodic table] plays an important role to explain the concept. The explanation of the periodic table in detail indicates his use of Content Knowledge. It is Content Knowledge because it reflects his understanding of the positions and divisions of elements in the periodic table. He filtered the content according to the students' needs at this level indicates his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge about students' learning ability at this academic year, in saying that 'you will touch on it in coming years'. He used the classroom abiotic context as a teaching aid to explain the content which indicates his use of Contextual Knowledge. It is Contextual Knowledge because it reflects his awareness of what is available in the classroom setting. In using the periodic table in his teaching to provide an example for students to follow, this reflects his use of Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his understanding of using teaching aids like the periodic table in his teaching.

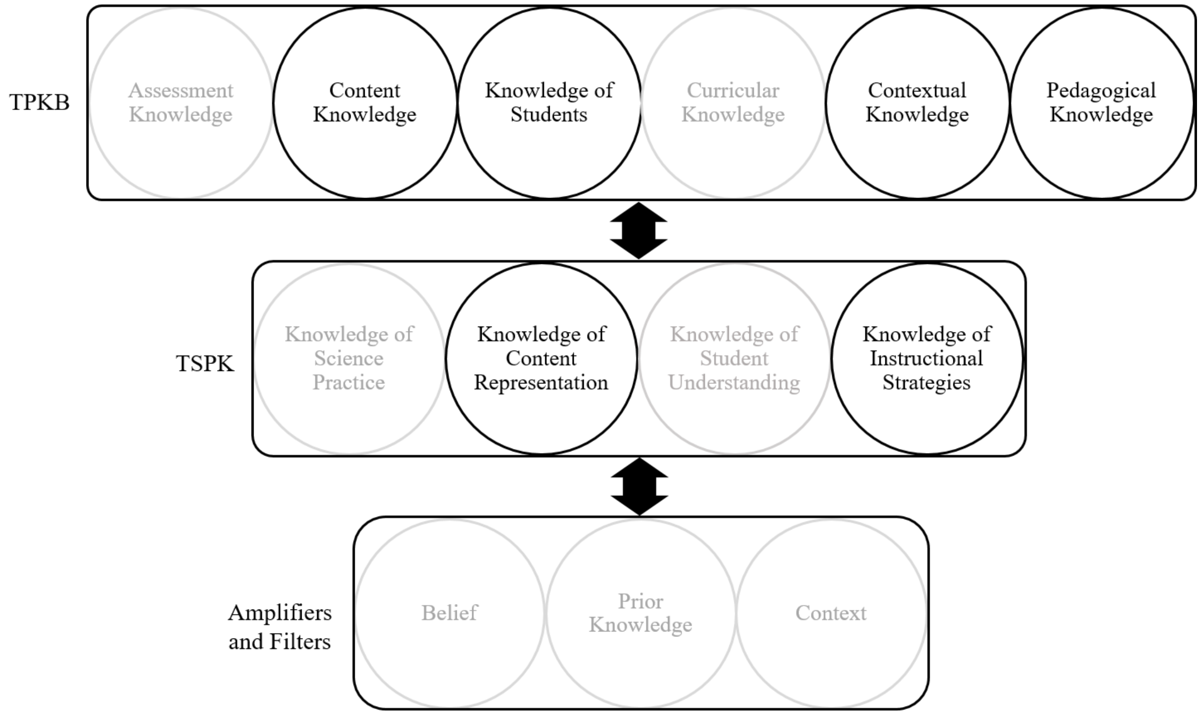
Herein, his Content Knowledge was used to explain the content, Contextual Knowledge combined with this Content Knowledge to elaborate the content by using classroom context, and Pedagogical Knowledge combined with Content Knowledge to use context in teaching. He presented the content through a table-completion activity which indicates his Knowledge of Content Representation. It is Knowledge of Content Representation because it reflects his awareness of a particular representation for a particular concept. The combined knowledge (Content Knowledge, Contextual Knowledge, and Pedagogical Knowledge) also combines with Knowledge of Content Representation to conduct the table-completion activity in the class. The combined knowledge might have informed this teacher to adopt the most suitable representation [table-completion] for understanding electrons in an atom from his repertoire of representations, and Knowledge of Content Representation afforded the teacher to use the classroom context in teaching and engage the students in table filling by using the periodic table. His use of the periodic table with students filling the electron configurations table as a teaching aid also indicates his Knowledge of Instructional Strategies. It is Knowledge of

Instructional Strategies because it reflects his knowledge of strategies that can help students learn chemistry.

This teaching episode shows his use of Content Knowledge to explain electron configurations, positions of elements, and division of elements in the periodic table, his Knowledge of Students combined with Content Knowledge to simplify the content to the students' level, his Contextual Knowledge combined with Content Knowledge to use the periodic table (i.e. classroom context) as a teaching aid, and his Pedagogical Knowledge combined with Content Knowledge to demonstrate how the students could participate in the table filling activity. His Knowledge of Content Representation combined with knowledge components of TPKB to adopt the most appropriate content representation for electron configurations. His Knowledge of Instructional Strategies was used to enable students to learn the electron configurations by the filling table. His combined knowledge in this teaching episode is framed in Figure 4.6.

Figure 4.6

George's knowledge combined in explaining electron configurations



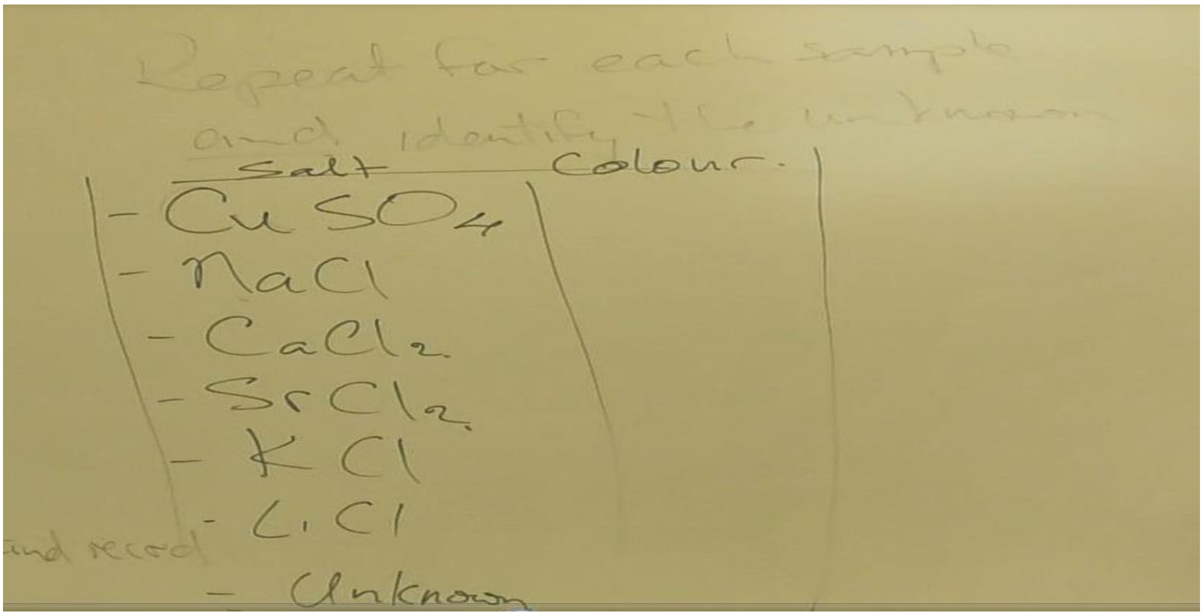
Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Content Representation and Knowledge of Instructional strategy of TSPK in the teaching of electron configurations.

4.4.3 *Organizing and conducting the flame test*

George appeared to use Content Knowledge when organizing and conducting a flame test in the class for identification of the color of cations. In Lesson 7, he said to the class, "please get your book out and read about a flame test for a cation. We are going to be testing the color of cations". He wrote the practical instructions, method, and precautions on the whiteboard. He drew a table with two columns: one column he filled with formulae of provided salts [$CuSO_4$, NaCl, $CaCl_2$, SrCl, KCl, LiCl, and Unknown], and the other he left blank for writing the students' observations during the flame test (see Figure 4.7). He demonstrated a flame test by using one salt: he used solid salt on the wire loop and burnt it in the flame provided by a bunsen burner. An orange-red color flame appeared. He did not explain why this color appeared. He said, "students, please take the apparatus, and start the experiment". All the students took the apparatus and performed this experiment with given salts. He moved around the class and guided the students in the experiment (L-7).

Figure 4.7

George's table to record the colour in the flame test



Note: This screenshot was taken from the video of George's Lesson 7 to show the table drawn for the recording of the color of salts in the Flame test.

When the students completed the experiment with the solid salts. He performed the same experiment using another method to fill this table. He used salt solution [salt in water] in spray bottles and a Bunsen burner. He sprayed the salt solution one by one on the flame of the Bunsen burner, verified the colors, and asked the students to note the color in their notebook (L-7). At the end of this experiment he asked the students:

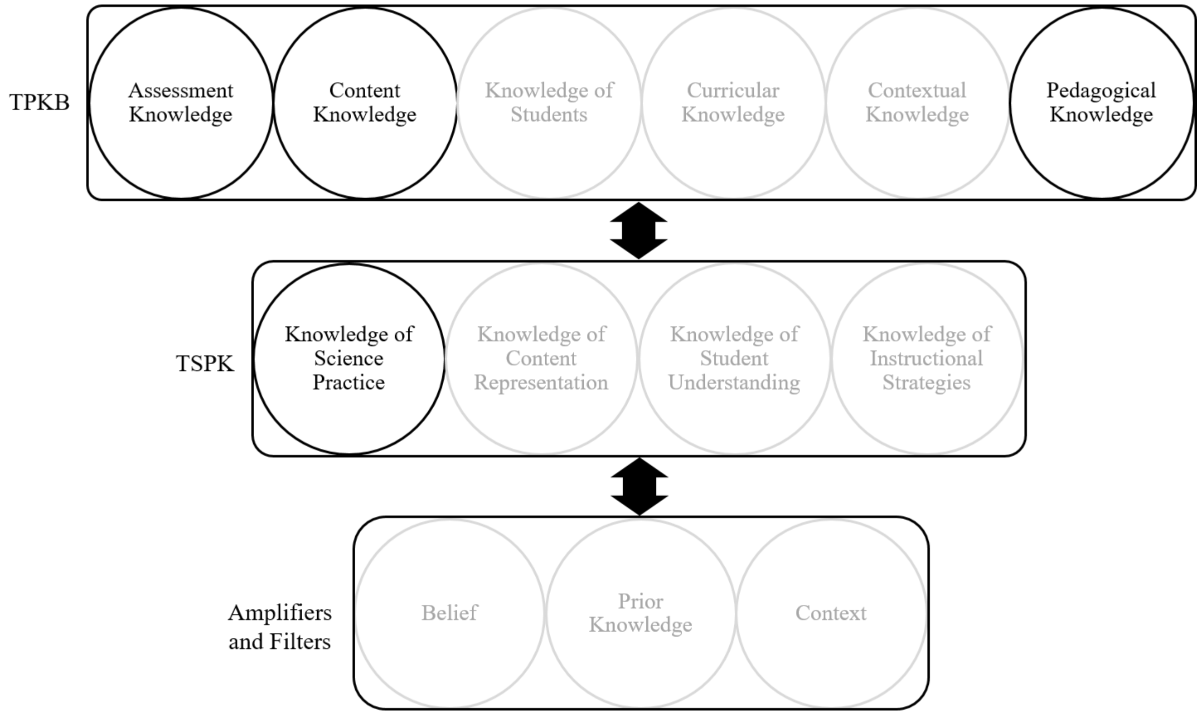
> Teacher (T): These are the distinctive color of cations. So what is happening to those solid ions in the flame?
>
> Student 1 (S1): Melting
>
> T: Right (Note: the teacher gave this response to encourage student engagement, and not to comment on the accuracy of the student's response)
>
> T: What happens when things burn?
>
> S2: Gases
>
> T: What chemical reaction occurs in burning?
>
> T: What happens in burning?
>
> [Silence in the class]
>
> T: Generate heating, burning of oxygen
>
> T: Where do we use these colors?
>
> S3: In fireworks
>
> T: Yup, we use them in a range of fireworks
>
> T: The other places where we use these colors?
>
> S3: Signal flare
>
> T: Yes, signal flares, easy to see from distance. Fireworks and signal flare where we use these colors most, and other applications but these two are common. (L-7)

In this teaching episode, George appeared to use his Content Knowledge to explain the flame test and work with the students' feedback. He explained what happens in the burning of cation solids and solutions, and our use of the cation colors produced, which indicates his Content Knowledge. It is Content Knowledge because it reflects his chemical understanding of what happens when certain cations are heated, which is particular to chemistry content. He engaged the students in the experiment to develop an understanding of the flame test through their own personal experiences, which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of strategies for students' engagement in learning. He assessed the students' understanding of this experiment by asking questions at end of the experiment which indicates his Assessment Knowledge. It is Assessment Knowledge because it reflects his understanding of implementing formative assessment in teaching to check student understanding. This teaching event shows that he used formative assessment through question-answer at the end of the experiment but the questions were more focused on just burning instead of the burning of salt or the flame test. The first question in the feedback is useful to the activity but the student's response is not the right chemistry behind the reaction. However, the teacher generated more questions to get more accurate responses from students.

In this teaching episode, his Content Knowledge identified to explain the flame test to test the color of cations, his Pedagogical Knowledge combined with Content Knowledge to engage the students in the experiment, and Assessment Knowledge combined with Content Knowledge to gather feedback from students. He used the flame test to examine the color of a heated cation through an experiment, which indicates his Knowledge of Scientific Practice. It is Knowledge of Scientific Practice because it reflects his understanding of exploring the scientific concept through experiments and that experiments are an important part of the finding of the world around us. The combined TPKB (Content Knowledge, Pedagogical Knowledge, and Assessment Knowledge) also combined with Knowledge of Scientific Practice to conduct the flame test. There is a combination because George used his combined knowledges to organize an experiment in which students will examine the actual color of heated cations (i.e. scientific practice) and Knowledge of Scientific Practice afforded the teacher to engage the students in exploring 'the distinctive colors of cations' and note their color in the drawn table (i.e. pedagogy). His combined knowledge components are framed in Figure 4.8.

Figure 4.8

Combination of knowledge components in teaching of flame test



Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Science Practice in the examination of cation colors.

4.4.4 *Explaining the experiment instruction*

George explained the reason how colors of cation changed with NaOH during explaining the experiment instruction, which reflected his Content Knowledge. In Lesson 6, he wrote that day's lesson 'identifying common cations' on the whiteboard. He said these reactions called precipitation reactions could be used to help identify them. He brought out bottles of solutions containing cations. He demonstrated a reaction between one of the cation solutions and sodium hydroxide (NaOH). He poured 1ml of cation solution into the test tube and added 2-3 drops of NaOH with a little shake. After shaking, a black color appeared in the test tube that indicated the presence of Ag^+ cation in the solution. He did not explain why the color had changed in that reaction. He wrote the practical steps on the whiteboard for students. He gave instructions: you will use these chemicals, and apparatus carefully, write down observations, clean up, and return the equipment. The students took the apparatus and chemicals to perform this practical activity. He went to each group and guided them in the experiment. When students completed the practical he started to write the cations [Na^{+}, Mg^{2+}, Ag^{+}, Fe^{2+}, Fe^{3+}, Cu^{+2}, Zn^{+2}] that were present in those solutions (L-6). He explained the results:

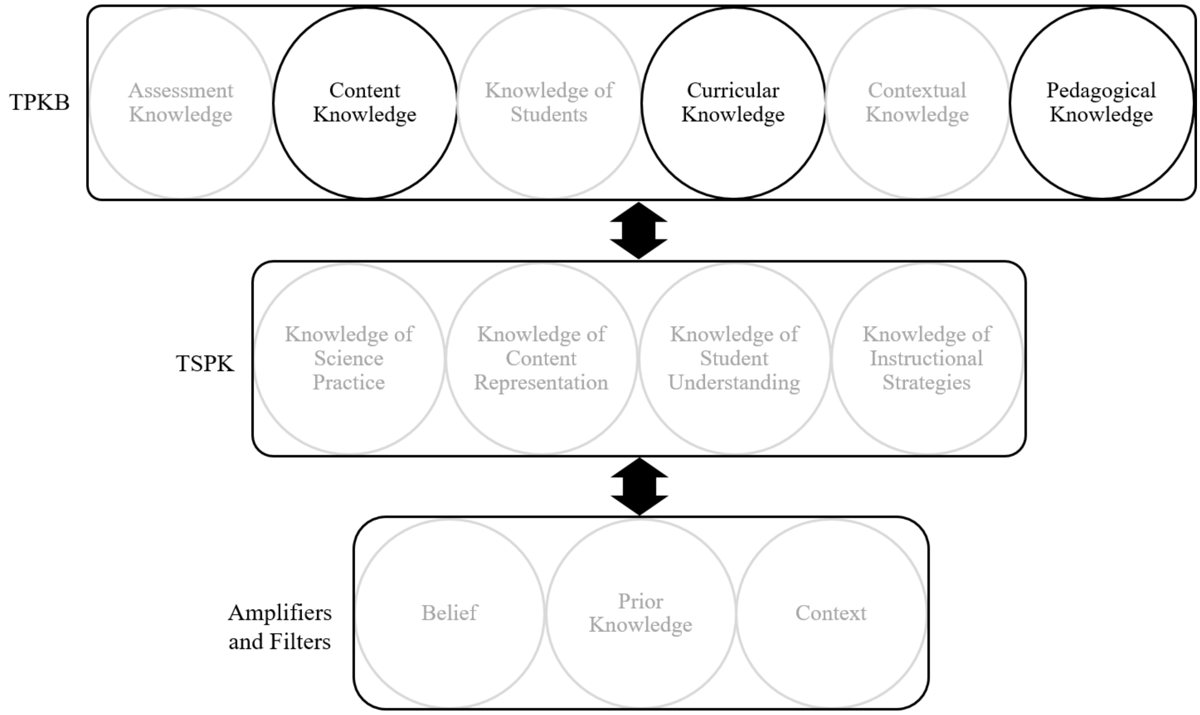
> Most of the reactions make a precipitate. As new compounds form in the state of solids. [He repeats the instruction.] I said last week, what happens when they swap partners [then he started to write the chemical equation on the board.] In these equations [of reactions], the copper hydroxide is a darker blue than copper sulfate. [Then he gave another example of such a result. He picked up the bottle of iron sulfate and showed it to the students]. It is a clear liquid but when it converts into iron hydroxide, it becomes green. (L-6)

In this teaching episode, he linked the previously taught content with the present activity results, and he emphasized the outcomes by repeating the colors of cations. The comparison of observed colors and showing the chemical in a bottle along with an explanation [what will happen in a test tube?] after a reaction is also the reinforcement of content. He explained the colors of cations that appeared in a reaction which indicates his Content Knowledge. It is Content Knowledge because it reflects his knowledge of the colour of cation solutions when they react with NaOH. He made a connection between students' prior learning and current lesson content, which indicated his use of Curricular Knowledge. It is Curricular Knowledge because it reflects his awareness of recommended pedagogy by *The New Zealand Curriculum* "Making connections to prior learning and experience" (Ministry of Education, 2007, p. 34). He engaged the students in the practical activity which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of students' engagement in learning.

Herein, his Content Knowledge was identified to explain the colour change of cation and their results in the experiment, his Curricular Knowledge combined with Content Knowledge to implement recommended pedagogy by *The New Zealand Curriculum*, and Pedagogical Knowledge combined with Content Knowledge to engage the students in the activity. The combined knowledge components identified in this teaching is framed in Figure 4.9.

Figure 4.9

Combination of knowledge components in explaining the experiment instructions



Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in explaining the experiment.

This section finds that George's use of Content Knowledge with Knowledge of Students, Assessment Knowledge, Pedagogical Knowledge, abiotic classroom context, and skills according to the nature of the content is a contribution of his PCK and it looks necessary to develop the particular conceptual understanding among the students. Secondly, it finds that Content Knowledge did not work individually during practice; it always worked with other pieces of knowledge, especially Pedagogical Knowledge and Curricular Knowledge.

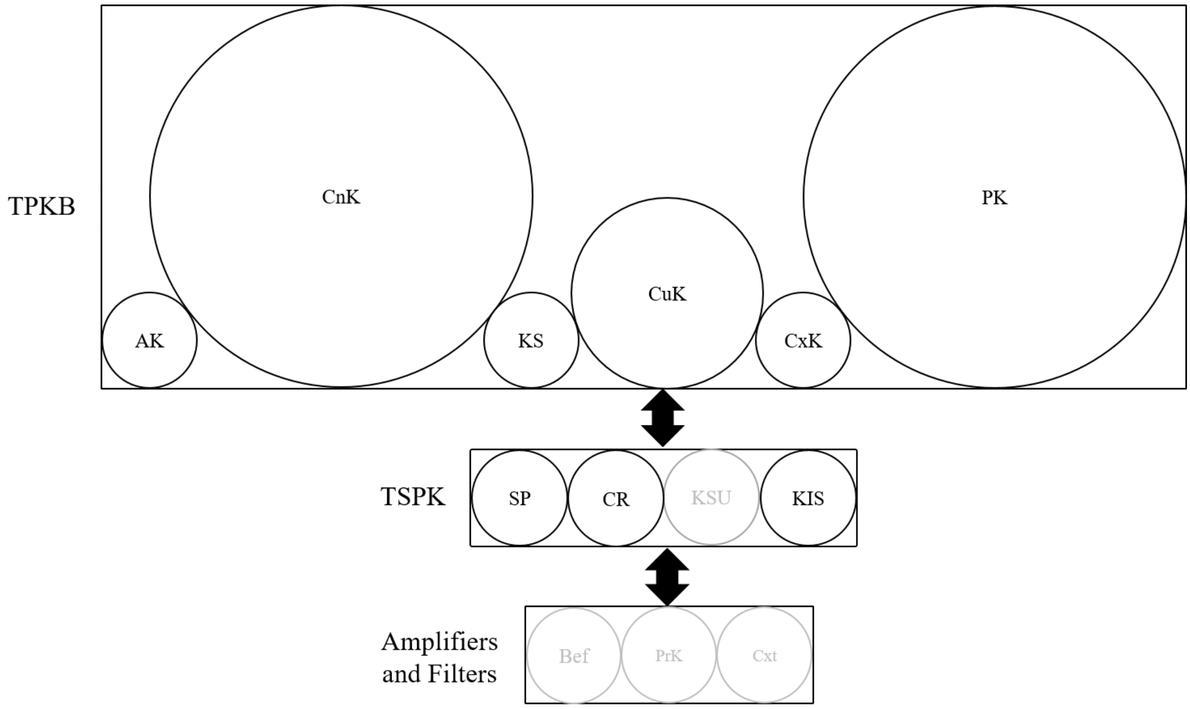
4.4.5 *Summary of Content Knowledge focus*

The four figures above (4.4, 4.6, 4.8, and 4.9) represent George's PCK in the selected pieces of evidence when his Content Knowledge was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Content Knowledge. In these figures, Content Knowledge naturally appeared four times in this data (4/4), with Pedagogical Knowledge also present four times (4/4). His Curricular Knowledge appeared two times (2/4) while Assessment Knowledge, Knowledge of Students, and Contextual Knowledge appeared once (1/4).

Of the TSPK components: Knowledge of Science Practice, Knowledge of Content Representation and Knowledge of Instructional Strategies appeared once each (1/2), while Knowledge of Students Understanding was not evident (0/2). In Amplifiers and Filters, no single component has appeared in this selected data. These appearances are represented in Figure 4.10.

Figure 4.10

George's combination of knowledge when his Content Knowledge as prominent knowledge



Note: In this figure the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

This figure shows his Pedagogical Knowledge always combined with Content Knowledge in these observed examples of classroom practice. Curricular Knowledge combined with Content Knowledge more often as compared to Assessment Knowledge, Knowledge of Students, and Contextual Knowledge when Content Knowledge identified prominently in his teaching. His Knowledge of Science Practice, Knowledge of Content Representation, and Knowledge of Instructional Strategies also combine with his combined knowledge of TPKB while his

Knowledge of Students Understanding did not identify in these selected data. His Amplifiers and Filters did not amplify and filter his knowledge.

4.5 Knowledge of Students

A teacher's Knowledge of Students includes knowledge of students' interests, abilities, prior academic success, personality traits, family background, and peer relationships. George had taught these students in the previous academic year which might contribute to him developing this knowledge. This section discusses examples of when his Knowledge of Students appeared as a prominent knowledge in his classroom practice.

4.5.1 *Describing students' interest in learning*

George's engagement of the students in learning in the classroom according to their ability or interest reflected his use of Knowledge of Students. He already felt familiar with his students' backgrounds and learning interests, as he described in the response to the pre-topic question [As you begin this topic, what do you already know about the students in your class?] "Interested in learning, trust in me as a teacher, ability to learn new concepts with little trouble, work together well" (Q-13). He was able to discuss specific students in detail because he had already taught them science in the previous academic year. This statement illustrates that he knew these students' interests in learning, positive relationship with him as a teacher, their abilities to learn a new concept, and peer relationships.

I was able to associate his described Knowledge of Students in the questionnaire with his classroom practice. He discussed students' general learning problems and learning trends at the country level, in a specific age group, and topic level in his interviews. For example, he explained his thinking about the learning trends in the secondary school students of New Zealand:

> Boys of this age are not very good at sorting out what is important [in the topic] and what is not… We do have in New Zealand a big problem with students who do not care [about learning]. And it is getting worse. (I-9)

This quote shows that his Knowledge of Students includes a specific 'age' group, gender 'boys' and students of a country 'New Zealand' because he has experience in boys' high schools at the secondary level in New Zealand. It is Knowledge of Students because it reflects his knowledge of students' interest in learning, and these elements during his professional career are the source of his Knowledge of Students that indicated his Contextual Knowledge. It is Contextual Knowledge because it reflects his teaching experience with the same age group of students in New Zealand schools. His belief amplifies this knowledge. There is amplification because he claimed this knowledge about a large context [New Zealand] without providing any further evidence.

George's experience as a teacher appeared to give him insights that fed his Knowledge of Students. For example, in the above statement he reflects one side of his thinking about why students are 'not very good', while in the below argument he expounds on why some students come to class with 'good knowledge':

> Sometimes boys already have good knowledge, sometimes it is because they have got an older brother or parent who has a good understanding, and so they have already talked about it at home and that sort of thing, in some cases. (I-F)

In this response, he highlights the students come with good knowledge in class due to the input of their siblings and parents. His discussion of this aspect of students' knowledge indicates his Knowledge of Students. It is Knowledge of Students because it reflects his understanding of parental and sibling involvement in students' learning (i.e. students' family background). It is not limited to the students themselves, as he discussed the factors 'older brother or parent related to students' academic learning that indicated his Contextual Knowledge. It is Contextual Knowledge because it reflects his knowledge of community members' contribution to students' learning beyond the school.

In Lesson 2, he wrote questions [same questions he used in Lesson 1] on the whiteboard. He said to the class these questions are the summary of this topic. He started to ask these questions one by one to the students and explained responses where needed (L-2). I observed he tried to involve all the students in the class. An example of this classroom practice is presented below:

> T: How many protons in oxygen
>
> S1: six
>
> T: six! Is it?
>
> S2: Eight
>
> T: Right! Six is interesting in this atom. What is six in oxygen number; it is a significant number in oxygen?
>
> S3: Number of neutrons

T: No, No, [he indicates toward another student]

S4: The number of electrons in the outer shell. (L-2)

He asked the questions to students from all sides of the class. He pointed toward the specific students (S4) to know their understanding of electrons in outer shell electrons. He asked the question to a student who was busy talking with his classmate (L-2). He explained why he tried to involve all students:

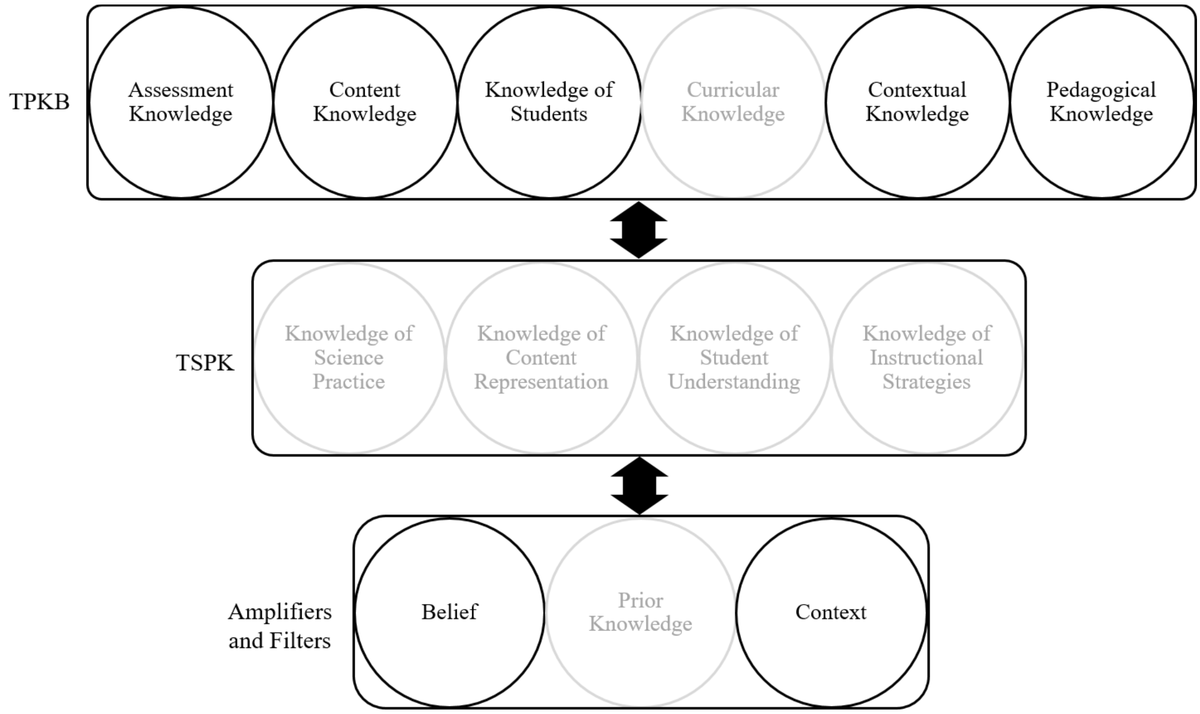
> These guys find it hard to concentrate for the whole period so when they start to get chatty or when they start to lose concentration, at that point I do not give them something to do when they are not going to learn anyway. So, when they start to lose concentration, then it's better to stop and say, Okay! We will do something different. (I-2)

This teaching episode and the following interview statement indicate his knowledge of students in teaching. He described his students as 'hard to concentrate', 'chatty', or when they 'lose concentration' in the class which indicates his Knowledge of Students. It is Knowledge of Students because it reflects his awareness of students' interest in learning. He assessed his students' understanding of the numbers of electrons in the oxygen atom by asking questions that indicate his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of implementing diagnostic assessment in teaching. He asked a question to those students who appeared to lose concentration, which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because he attempted to engage the student in learning by asking a question. In this teaching episode, he emphasized to make the distinction between eight and six electrons in an oxygen atom, which indicates his Content Knowledge. It is Content Knowledge because it reflects his understanding of electron arrangement in atomic shells. He aimed to better support student learning; this illustrates a combination of Knowledge of Students, Assessment Knowledge, Pedagogical Knowledge, and Content Knowledge.

In this piece of evidence, George's Knowledge of Students appeared to help him gauge students' interest and abilities to engage the students in better learning, his Assessment Knowledge combined with Knowledge of Students to assess students' prior understanding, his Content Knowledge combined with Knowledge of Students to clarify the arrangement of electrons in shells, his Contextual Knowledge combined to understand the influences on the students' learning, and his Pedagogical Knowledge combined with these knowledges to engage the students in the classroom. His teaching experience and associated beliefs amplified his argument about students' learning interest in New Zealand. His combination of knowledges and amplifiers and filters in this teaching is framed in Figure 4.11.

Figure 4.11

Knowledge combined to engage the students in learning



Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Knowledge of Students, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. His Context and associated Belief amplified his argumentation.

4.5.2 *Addressing students' behaviour in the class*

George used his Knowledge of Students when he classified his students based on their behavior in the class. In Lesson 1, I observed that he interacted with some students often as compared to the other students. I asked [Some groups of students are more involved in the class than the other students. Why?] in the follow-up interview. Then he said:

> Yes, different boys, just personality things, [silence] they are all pretty good at learning and pretty well behaved, but some of them are a lot more focused, some are a lot more interested. Yeah, some of them have different motivations. Some of them just want to pass, they don't really care about what they have learned, some of them don't worry about that, others just want to learn, just, it's what excites them. (I-1)

This statement illustrates that he has developed his knowledge of these particular students by interactions with them as he discussed ‘they are all pretty good at learning’, ‘some of them are a lot more focused’, and ‘some are a lot more interested’. His categorization of students at the group level is an indication of how he used his Knowledge of Students to classify his class’ attitudes towards learning with some being ‘more focused’, others ‘just want to pass’, or ‘don’t worry’. It is Knowledge of Students because it reflects his understanding of students’ personality traits and interest in learning. His experience with these students led him to classify them based on their learning attitude and behavior in the class which indicates his Prior Knowledge of these types of students. His Prior Knowledge amplifies his point of view about students because this categorization is based on his experience rather than any systematic evaluation criteria. Some of his pedagogical decisions were influenced by his understanding of students in the class:

> They are all so different but I think it is really important that I try to engage as different boys as possible, so I try to look around the room and I usually ask a question to the boy who has lost focus but also I try to shift around so they are thinking about the question. (I-1)

This statement shows a relationship between Knowledge of Students ‘they are all so different’, and pedagogy ‘I tried to engage’ and ‘I try to shift around so they are thinking about the question’. Herein, he pinpointed the situation when he shifted his question ‘I usually ask a question to the boy who has lost focus’, which indicates his use of Pedagogical Knowledge because it reflects his knowledge of how to engage students in learning. From my perspective, an experienced teacher employs tactics such as, ‘I try to look around the room’ and questioning skills ‘they are thinking about the question’ because he constructed questions in the way that stimulates students’ ‘thinking’ after identifying the boys who lose his concentration. This classification of students also helped him to teach them:

> This group here, they are pretty good. They catch on quickly. These ones are keen. They work well but they find it a little bit harder. But the guys in that corner muck around a little bit, so I need to chase them up sometimes, but they are all right. (I-4)

Moreover, he discussed his students in the same follow-up interview:

> I said to you a couple of lessons back, if you just gloss over it, they don’t pick it up. You need to catch the things that are going to be a problem and you need to specifically deal with them, otherwise, they don’t understand, they don’t catch up. They tell you they know what’s happening, but they don’t. (I-4)

In these two statements, he discussed his students' characteristics and strategies to engage them in learning. He describes his students' attributes as being able to 'catch on quickly', 'pretty good', 'keen', 'find it a little bit harder' and, 'guys in that corner muck around a little bit'. This indicates how his Knowledge of Students helped to design a teaching strategy to 'chase them up'. It is Knowledge of Students because it reflects his knowledge of students' learning abilities and personality traits. He discussed the results 'if you just gloss over it, they don't pick it up' if he would ignore the management problems. He shared his strategy 'to catch the things that are going to be a problem' which indicates his Pedagogical Knowledge because it reflects his strategies for classroom management.

In the final topic interview, he discussed his experience of teaching a low ability class in his professional career:

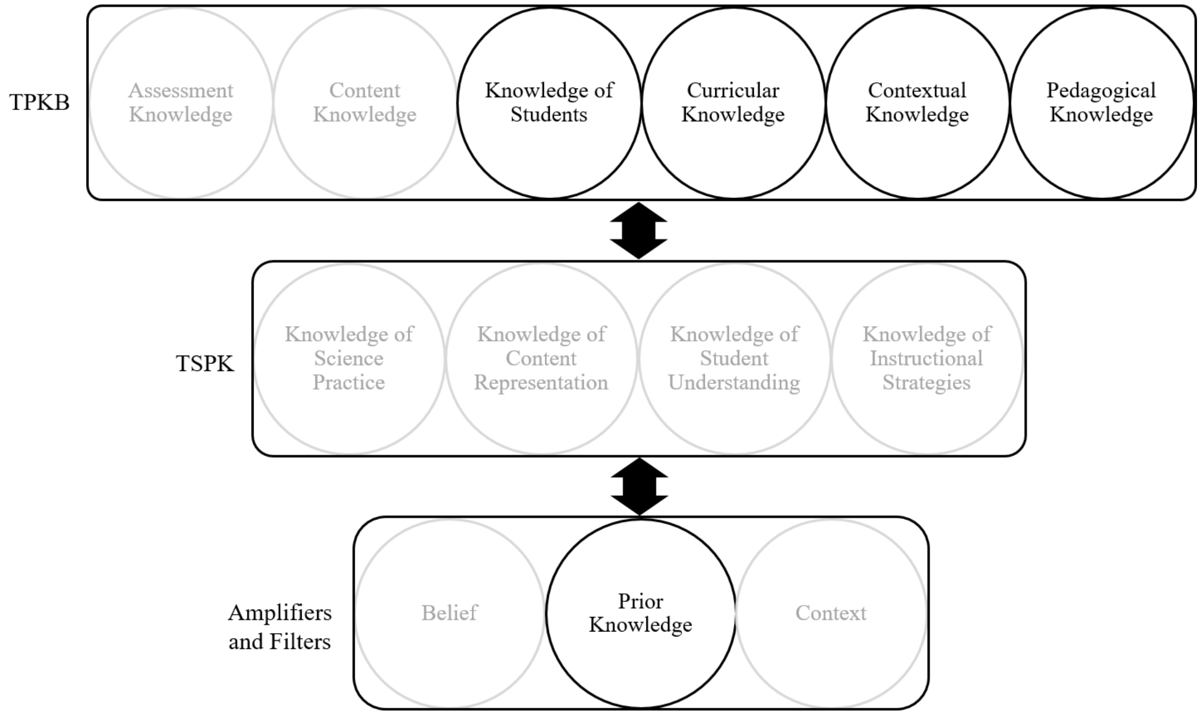
> One of the things that I find a lot, particularly with the lower ability classes, is they come along to school, the only reason for doing science is because the science teachers say [they must]. And the school says they have to do science and the parents say they have to do it. They don't have any internal reasons, they are all external reasons, and it's very easy for the boys to get frustrated with that. But if you can help them to develop internal reasons for knowing how this works or knowing why it's important, or whatever, then their understanding is likely to be better, they put more effort in. If they've got a reason for learning, they put more effort into learning. (I-F)

This reflective point of view discussed the factors in low ability classes studying science subjects, their behavior in the science class, and teaching strategies for these low ability classes. George discussed the students' learning ability and external factors that frustrated them in learning science, which indicates his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge of students' abilities to learn science. He also discussed external factors that influence the students' academic decisions, which indicate his Contextual Knowledge. It is Contextual Knowledge because it reflects his knowledge of context beyond the school. He suggested a pedagogy to teach such students 'if you can help them to develop internal reasons for knowing how this works or knowing why it's important, or whatever, then their understanding is likely to be better, they put more effort in', which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of strategies for student engagement to develop their scientific understanding. This pedagogy has coherence with The New Zealand Curriculum recommended pedagogy "Encouraging reflective thought and action" (Ministry of Education, 2007, p. 34), which indicates his Curricular Knowledge.

In these pieces of data, George used his Knowledge of Students understand his students' behavior in the class, his Curricular Knowledge combined with Knowledge of Students to discuss the most suitable recommended pedagogy for a low ability class in the curriculum, his Contextual Knowledge combined with Knowledge of Students to discuss the influence of external factors on their science learning, and his Pedagogical Knowledge combined with Knowledge of Students to discuss strategies for students engagement for these students. His Prior Knowledge of teaching such students helped to amplify his point of view about his students. His combined knowledge components and Amplifiers and Filters are framed in Figure 4.12.

Figure 4.12

George's combined knowledge components to address students' behaviour in the class



Note: This figure represents George's combination of TPKB knowledge components (Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. His Prior Knowledge amplified his point of view about students.

4.5.3 *Managing class activities*

George appeared to use his Knowledge of Students to manage classroom activities. In Lesson 3, he explained the calculation of the atomic mass of fluorine (F) by using the periodic table. He drew the table and involved his students in filling this table with the first twenty elements by using their cellphones to calculate the atomic masses and the periodic table to see their atomic masses (L-3). The students had the freedom to talk and share their ideas with their peers. He guided the students' groups in that activity to find the atomic mass by using the periodic table (L-3). His objective of this activity was identified in the follow-up interview:

> They talk to their mates but they are learning things, and they are clarifying ideas. Hopefully, you picked up that five boys said, 'Oh, I understand'. And that's what I want, that's what I need to do because those boys haven't told me that they didn't understand but now they've figured it out. (I-3)

When I associate his classroom teaching in Lesson 3 and his response in its follow-up interview, this reveals his expectations from students through this activity to develop an understanding of the calculation of atomic masses through discussion with their peers. He evaluated the activity 'talk to their mates' in the classroom as a learning process, which indicates his Knowledge of Students because it reflects his knowledge of students' peer relationships. His teaching of the calculation of atomic masses by using the periodic table indicates his Content Knowledge because it reflects his understanding of atomic particles in the calculation. He used the periodic table and allowed students to use their cell phones in the classroom which indicates his Contextual Knowledge. It is Contextual Knowledge because it reflects his knowledge of the classroom setting. He appreciated his students sharing their ideas with their peers, which reflected his Curricular Knowledge because it has coherence with *The New Zealand Curriculum* recommended pedagogy 'Facilitating shared learning' (Ministry of Education, 2007, p. 34). He engaged the students with their mates to achieve his objective 'I want to develop understanding among students'. His engaging of students with their mates indicated his Pedagogical Knowledge, because it shows his approach to develop the concept of calculation of atomic mass by students by engaging them with each other. This part of the statement 'They talk to their mates but they are learning things' indicates his Prior Knowledge that amplifies his claim. It is Prior Knowledge because it reflects that this knowledge seemed to originate with his interaction with this class in another activity before. There is amplification because he claimed 'they are learning things' without any assessment after this activity. George said that he would apply the same strategy with his other class then he would bring some changes:

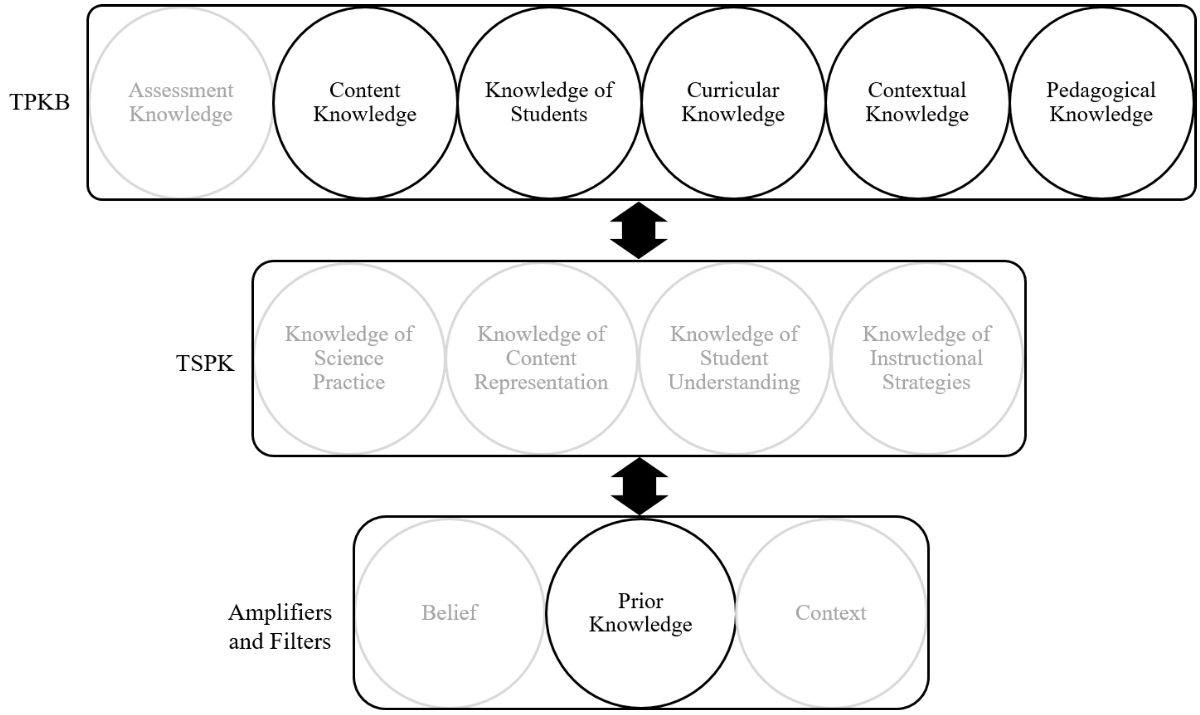
> I will do a similar activity with my other class but I probably have to keep it more controlled because the other class is not as motivated. The other class is more likely to take the opportunity to not work, so with the other class, it will have to be tighter. But the activity is too good [not to do] but I have to control it more tightly. Here, you can leave them. Because three [students] are talking here and four talking there, they are actually explaining to each other and that's good, that's effective. (I-3)

He was able to judge that a specific group of students would need some changes by his knowledge of the students. It is Knowledge of Students because he knows his students' interest in learning. His response 'I probably have to keep it more controlled because the other class is not as motivated' indicates his Pedagogical Knowledge because it reflects his knowledge of using different pedagogy for different groups of students. He made the comparison between the two classes that, based on his Knowledge of Students, he would also modify his content according to their abilities, as he described, "I started with the hard questions, for these guys, but with my other class I'll start with the very easy question" (I-8). It indicates that Knowledge of Students, Content Knowledge, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge work together to make effective delivery of content to achieve learning among students during classroom practice.

In these pieces of evidence, George used his Knowledge of Students to discuss students' participation in the activity, his Content Knowledge combined with his Knowledge of Students to develop an understanding of calculating atomic mass, his Curricular Knowledge combined with his Knowledge of Students to bring recommended pedagogy, his Contextual Knowledge combined with his Knowledge of Students to allow students to use cell phones for calculations, and his Pedagogical Knowledge for how to engage the students in learning. His Prior Knowledge was identified in these discussed data as amplifiers of his argumentation. The combined knowledges (Knowledge of Students, Content Knowledge, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) and Prior Knowledge in this selected data are framed in Figure 4.13

Figure 4.13

George's combined knowledge in managing class activities



Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Content Representation in the teaching of word equations. His Prior Knowledge was identified as an amplifier.

4.5.4 *Evaluating the class*

George seemed to use his Knowledge of Students to help him evaluate his students' learning capacity. In considering the level of understanding of his students, he pointed out that he was going to teach this topic to what he thought was an average class, a judgment informed by the school and his interaction with the students in the previous year. He described the school process as:

> The class as a whole is chosen on their test results from last year, so it's streamed to some extent. They looked, and they mark all their subjects and they work out the average across all the subjects and then put all these boys altogether. (I-3)

In this response, he discussed the school's decision on their replacement in the class according to their achievements in previous test results. This indicates his Knowledge of Students because it reflects his knowledge of students' prior academic success. His description of the school decision-making process indicates his Contextual Knowledge as it reflects his awareness of the school context. The label 'average class' is allocated by the school, and it seemed to influence George's expectations:

> This class has an average of about 60% to 65% on the two previous tests. I would like to think they could do at least that in this test… Traditionally, this is a hard test, Year 9 and Year 10 boys find it hard, so in that way, if we get more than 55% average for the class, I'll be ok with that. (I-8)

This statement shows, he set an average achievement objective of 'more than 55%' for his 'average class' because he had already set an image of this class from school streaming and evaluation of the previous tests' scores. He discussed the students' academic scores in the previous test, which indicates his Knowledge of Students and it reflects his knowledge of students' prior academic success. This kind of class labeling of 'average class' could place limits on teaching to set the achievement objectives for students.

In another example, George evaluated his students by their interest and by anticipating their learning. In Lesson 2, he taught the concept of loss and gain of an electron in an atom for completing their outermost shell (L-2). In the follow-up interview, he said he felt this idea was easy for them:

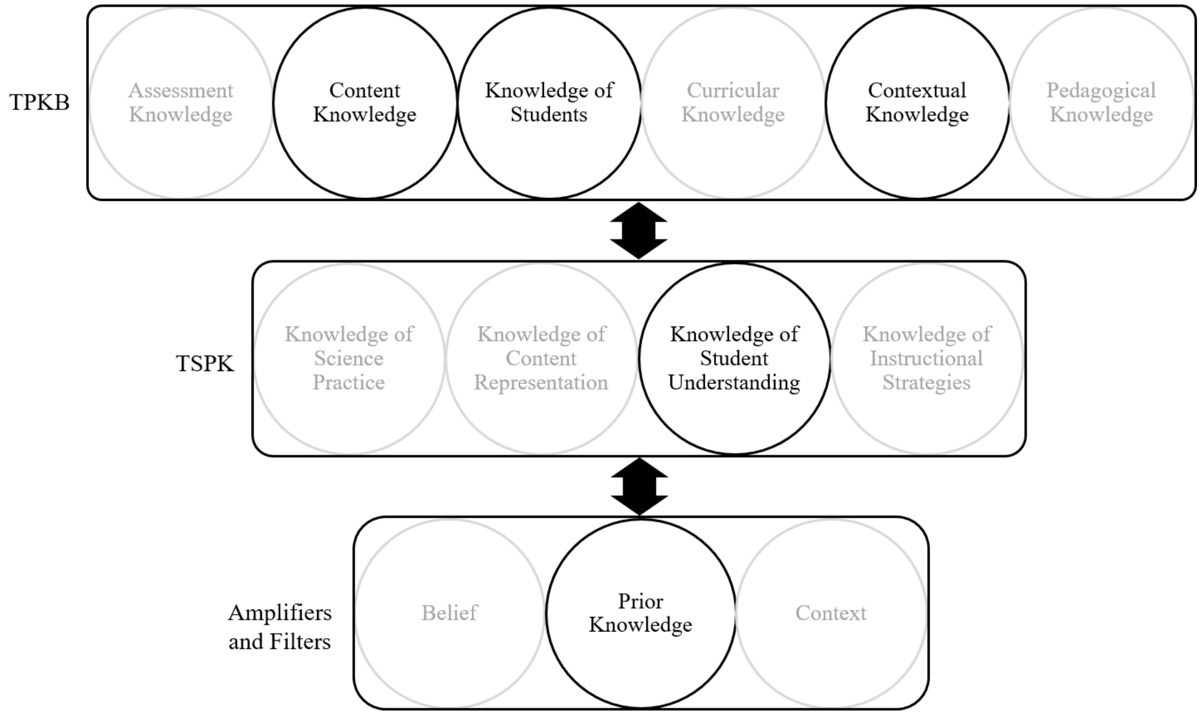
> This class is reasonably able and reasonably well-motivated. So, they are not top class but they are motivated to learn and I think they can understand, they all have a picture of the periodic table, they know roughly how it fits together. So, the idea of 1 electron [in an atom], needs to lose one electron and needs to gain one electron [to complete the outermost shell]. I think they find it reasonably sensible. (I-2)

According to this statement, he evaluates his students based on their motivation in learning with the idea 'they are motivated to learn and I think they can understand'. This indicates his Knowledge of Students because it reflects his knowledge of students' interest in the concept. He discussed 'the idea of 1 electron [in an atom], needs to lose one electron, and needs to gain one electron [to complete outermost shell]', which indicates his Content Knowledge as it reflects his understanding of atoms completing of the outermost shell. He claimed that 'they all have a picture of the periodic table, they know roughly how it fits together' which indicates his Knowledge of Students' Understanding because it reflects his knowledge of students' pre-requisite knowledge for learning this particular idea. The combined knowledge (i.e. Knowledge of Students and Content Knowledge) also combines with his Knowledge of Students' Understanding. Overall his perception of the class as being 'motivated', thinking they can 'understand', and they 'find it reasonably sensible' also shows his knowledge of students that seemed to originate from his experience with this class, which indicates his Prior Knowledge. This Prior Knowledge amplifies his point of view. There is an amplification because he made this claim 'I think they find it reasonably sensible' without offering any specific evidence for this response. In the same interview, he emphasized "the idea of shells for electrons is quite important in this topic but it's quite an easy idea for these guys" (I-2). It is his Prior Knowledge because it reflects his experience with this class.

In these pieces of evidence, George used his Knowledge of Students to discuss students' interests and abilities in learning, his Content Knowledge combined with this Knowledge of Students to explain the idea of loss and gain of electrons in atomic shells, and his Contextual Knowledge combined with this Knowledge of Students to discuss the process of the school for placement of students in the classes. His Knowledge of Students' Understanding combined with Knowledge of Students to inform him of the students' prior knowledge about the gaining and losing of electrons by an atom. His Prior Knowledge may have amplified his point of view. These combined knowledge components are framed in Figure 4.14.

Figure 4.14

George's combined knowledge used in evaluating the class



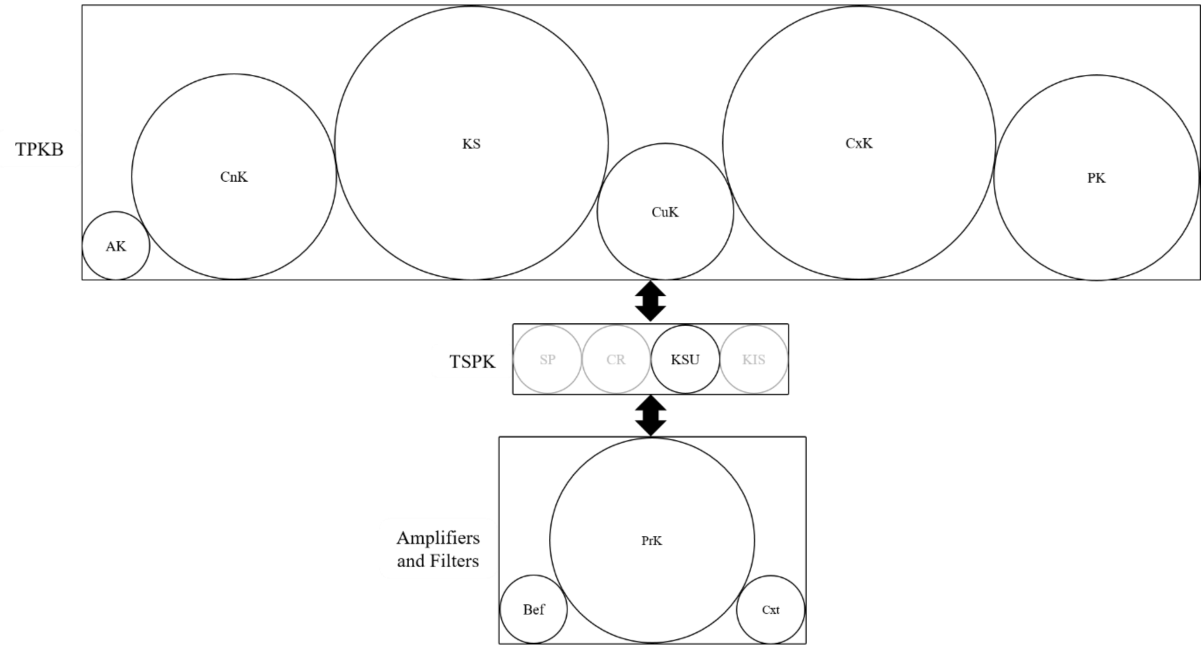
Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, and Contextual Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Student Understanding in the evaluating of the class. His Prior Knowledge amplified his point of view about the class.

4.5.5 *Summary of Knowledge of Students focus*

The four figures (4.11, 4.12, 4.13, and 4.14) represent George's PCK in the selected pieces of evidence when his Knowledge of Students was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Knowledge of Students. In these figures, Knowledge of Students naturally appeared four times in this data (4/4), with Contextual Knowledge (4/4). His Content Knowledge and Pedagogical Knowledge both appeared three times (3/4). His Curricular Knowledge and Knowledge of Students were both identified two times (2/4) while his Assessment Knowledge appeared once (1/4). Of the TSPK components: His Knowledge of Student Understanding appeared once (1/4) while other components were not evident. In Amplifiers and Filters: his Prior Knowledge appeared three times (3/4) while his Belief, and Context both appeared once (1/4). The appearance of knowledge components is shown in Figure 4.15.

Figure 4.15

George's knowledge combinations when his Knowledge of Students was prominent



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

This figure shows his Contextual Knowledge, and to a slightly lesser extent Pedagogical and Content Knowledge, combined more often with Knowledge of Students as compared to Assessment Knowledge and Curricular Knowledge. His Assessment Knowledge was identified least in these combinations. His Knowledge of Students Understanding did appear in one example, whereas his Knowledge of Science Practice, Knowledge of Content Representation, and Knowledge of Instructional Strategies did not combine with his TPKB in these cases. His Prior Knowledge, Belief, and Context amplified his particular teaching.

In my experience to examine his Knowledge of Students in this topic teaching, it is not easy to capture a teacher's Knowledge of Students only through classroom observation as Knowledge of Students mostly works in the mind of a teacher as a tacit agent during classroom practice, but by combining observations with interview data, Knowledge of Students became more explicit. Knowledge of Students seems linked to the uniqueness of the experience that a teacher brings into the classroom which can be seen as part of their personal PCK. Secondly, it seems that Knowledge of Students helps to influence pedagogical instruction, especially when the same activity transfers to another context. Importantly, a teacher's knowledge to interpret the classroom circumstance and bring modifications in pedagogy during classroom teaching is identified to be a contributor to PCK.

The next subsection explores how George's Curricular Knowledge appeared in his teaching practices as the primary focus.

4.6 Curricular Knowledge

Curricular knowledge might include a teacher's knowledge of the curriculum structure, the curriculum goals and objectives, and knowledge of the relationship between the school curriculum and the national curriculum. This knowledge (i.e. Curricular Knowledge) of TPKB is less likely to be openly observed in a classroom practice but it may be found in teaching planning. The school curriculum for this chemistry topic shows a clear coherence between topic planning and *The New Zealand Curriculum*. The school curriculum indicates the derivation of key concept ideas from *The New Zealand Curriculum* for this topic; moreover, it also shows a linkage between curriculum goals, key concept ideas, and topic learning objectives. These NZC key concepts are for the level of George's class: all matter is made of particles, the properties of materials derive from the identity and arrangement of particles, energy plays a key role in determining the changes that matter can undergo, and chemistry is everywhere. These key concepts are linked to two learning areas of Level 5: *Nature of Science* and *Material World*. The school curriculum showed the inclusion of the nature of science strand in this topic was to achieve, first, Investigation in Science [ask questions, find evidence and carry out appropriate investigations to develop simple explanation], second, Communicating in Science [use a wider range of science vocabulary, symbols, and conventions]. The Material world strand in this document focused on Properties of Materials [investigating the physical and chemical properties of substances and relate these to their appropriate and safe use, both in their personal and the wider environment] and Chemical Reactions [explore and investigate chemical reactions of a range of substances and identify these occurring in everyday situations]. This document described some specific learning objectives to achieve through the teaching of given topic content as described in the above subsection 4.2.1. To achieve these student-learning goals and objectives, science teachers need to use their knowledge and skills in teaching to achieve key concepts. George did not find it necessary to write down lesson plans, as he believed those [lesson plans] were saved in his mind, so there were no written teaching plans available as research data but some traces of his Curricular Knowledge can be found in the classroom observations data, which is discussed below.

4.6.1 *The teaching of chemical reactions*

George's appeared to use his Curricular Knowledge in his teaching when he discussed the significance of the topic for the students' different academic years. In Lesson 1, he taught the concept of losing and gaining electrons for completion of the outer shell. He eliminated the carbon atom from this concept because he said that that carbon atom has cannot gain or lose electrons so it has a different system [hybridization of shells] of share electron. For this, he said you would learn some of those in Year 10 (L-1). He gave a clue to students about the gaining of two electrons by oxygen by asking a question, "why does oxygen have a two negative charge?" (L-1). The students came up with different possible answers, then he elaborated:

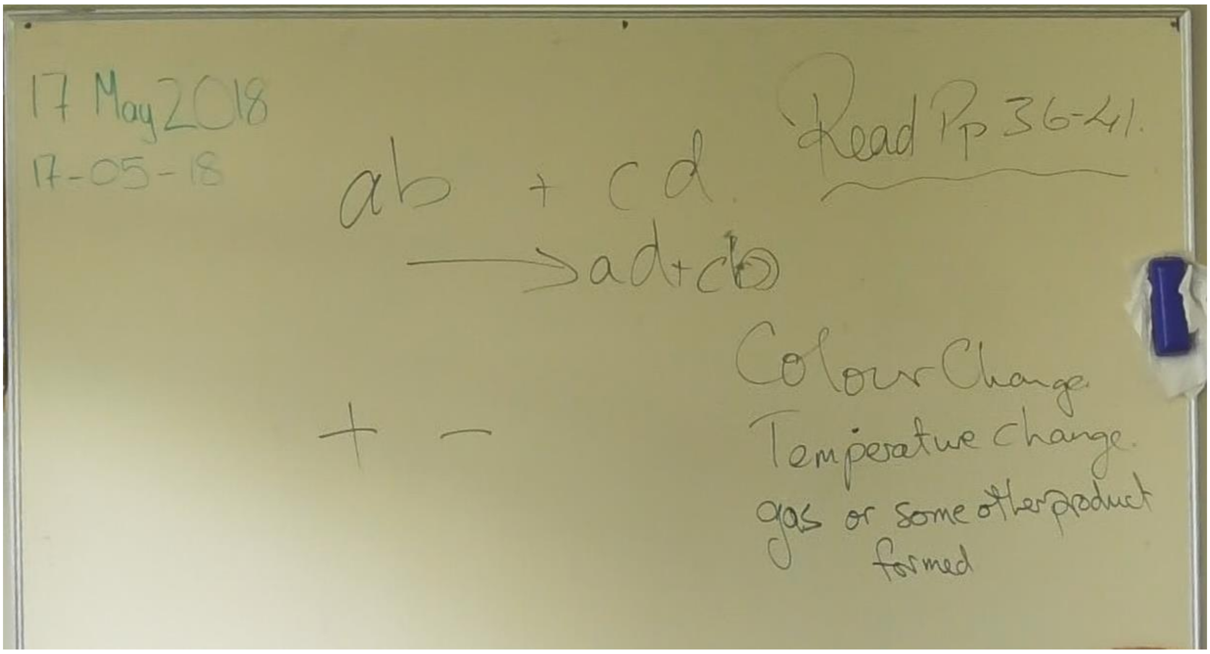
> That's really important guys! Some of those [atoms complete their outer shell by gaining and losing electrons] in Year 9 and some of those in Year 10 ok. So, you need to remember. When gaining electrons it is gaining negative charges. So, it's gaining two extra negative charges, it gains an overall negative. So, things that like jump [out] electrons and have a positive charge on it because they now have two extra protons. (L-1)

This part of the lesson shows that he indicated his Curricular Knowledge, because it reflects his awareness of the school curriculum structure: the coherence of this part of the topic with previous years' content with ionic chemistry. He explained that oxygen gains negative charges by gaining two extra electrons, which indicates his Content Knowledge as this reflects his knowledge of electron affinity, which is specific to chemistry content.

In Lesson 8, he revised the signs of chemical reactions. The students gave some signs of reactions like color changes, temperature changes, and gas formation. He wrote these signs on the whiteboard, then he turned to write the equation to elaborate on what happened in the chemical reaction. He wrote a general equation (Figure 4.16) to show this reaction [ab+cd→ ad + cb]. He explained that in a chemical reaction the chemical reactants swap their partners (L-8).

Figure 4.16

George's general equation to explain chemical reactions



Note: This screenshot is taken from the video of George's Lesson 8.

After writing this equation he said, I know you are a little confused (L-8). When I asked [When you completed the first equation, you said to the students were confused, how did you [know] that?] in the follow-up interview, he explained:

> Because most of them were watching and trying to figure it out, but a lot of them looked like they didn't know what was happening. It's just the look on their faces. I'm not surprised at that because it's quite a big leap, there is a lot of new stuff, and it's hard, it's a big change from last year. We've gone a lot further. What we try to do every year is built on what they already know. So, we try to get rid of the concepts and ideas which don't work and we try to build on some of those [other] concepts and we slowly get there. I hope that next year they will come and think, I have understood that, and then it will be easier next year. And if they carry on to do chemistry in Year 12 and Year 13 then this stuff should be reasonably easy. (I-8)

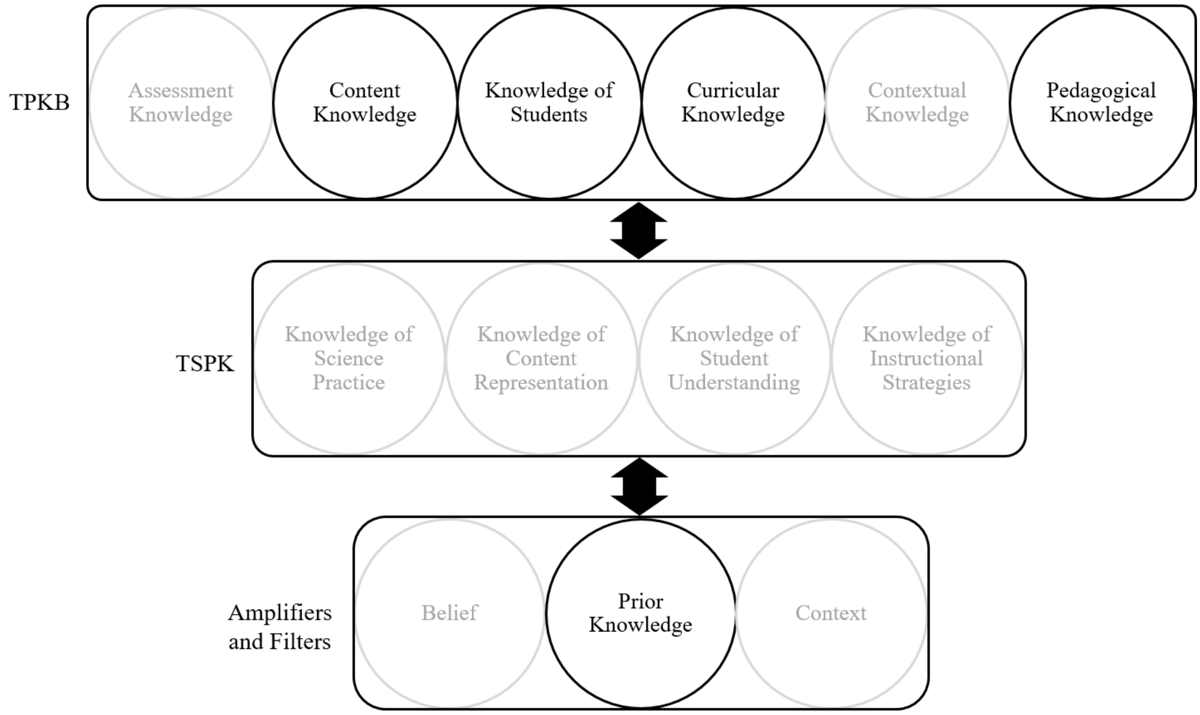
This quote indicates that his Curricular Knowledge helped him to give weight to the current learning and its scope or significance in the future. He discussed the importance of the topic which could make the concept easy in their Year 12 and Year 13 chemistry which indicates his Curricular Knowledge, because it reflects his knowledge of the national curriculum structure.

He explained the outcome of an ionic chemical reaction by using the general equation, which indicates his Content Knowledge, showing his understanding of chemical reactions. He engaged the students in discussing chemical reactions, which indicates his use of Pedagogical Knowledge to engage students in learning. He identified the students' interests of the equation as shown by his statement that a 'lot of them looked like they didn't know what was happening'. He judged his students by seeing their faces that indicated his Knowledge of Students because it reflects his knowledge of students' interest in learning. He discussed his routine to teach this content 'every year' which indicates his Prior Knowledge from tinkering and experimenting with classroom strategy, as he said 'we try to get rid of the concepts and ideas which don't work and we try to build on some of those [other] concepts and we slowly get there'. There is amplification because he explained his perception of students in the future 'I hope that next year they will come and think, I have understood that, and then it will be easier next year'.

In these pieces of evidence, he seemed to use his Curricular Knowledge to describe the significance of the topic content in the students' different academic years, his Content Knowledge combined with this Curricular Knowledge to explain the topic content, his Knowledge of Students combined with Curricular Knowledge to judge the students' interest in the learning of equations, his Pedagogical Knowledge combined with Curricular Knowledge to engage the students in learning. His Prior Knowledge amplified his thinking to describe the perception of students in the future about this topic. His combined knowledge (Curricular Knowledge, Content Knowledge, Knowledge of Students, and Pedagogical Knowledge) and his Amplifiers and Filters in this data are framed in Figure 4.17.

Figure 4.17

George's combined knowledge components for learning about chemical reactions



Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in the teaching of chemical reactions. His Prior Knowledge amplified his teaching.

4.6.2 *Utilizing students' prior knowledge in teaching*

George seemed to use Curricular Knowledge to draw upon his students' prior knowledge in teaching practice. He reflected that students' prior knowledge is a vital element in the teaching and learning process and he acknowledged that assessing students' prior knowledge is a key element in teaching strategies. He wrote in his pre-topic questionnaire "New teaching replaces prior ideas [of students] that it contradicts. If you do not build from [prior] knowledge, you totally waste your time" (Q-12). I was able to associate his thinking with his pre-topic responses and his classroom teaching. My observations showed that 7 out of 9 of his teaching lessons started with gauging the students' prior knowledge, and then he set his strategies according to the information he gained, which indicates his Curricular Knowledge. It is Curricular Knowledge because it has coherence with the NZC recommended pedagogy 'Making connections to prior learning and experience' (Ministry of Education, 2007, p. 34). The above quote illustrates that he thought that if students have relevant prior knowledge of the concept, then he proceeds with building a concept on it, but if students' prior knowledge is contradicted with a scientific view of that concept, then "new teaching replaces prior ideas" which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of designing a lesson plan according to students' prior knowledge. George also indicated his belief about the process of teaching when he claimed that, 'If you do not build from [prior] knowledge. You totally waste your time'. He linked this belief with students' difficulties to understand:

> No, I really don't think it's a hard concept [he recalled what he had already done in this topic ionic chemistry], but there is a lot of new stuff, new ideas that we haven't talked about before, so they not only have to learn some new ideas but then they have to apply them. They have to remember things and then use them, and that's hard. So I think they just really need more time. (I-8)

George believed that any concept is not hard or easy for the student, but it depends upon students' prior knowledge, and if students have prior knowledge about that concept then it can be easy for them. George believed that some pre-concept teaching may be needed in such cases when students have no prior idea about a concept and that a teacher may need to replace contradictory students' prior knowledge with teaching for students to understand the scientific concept. He wanted to revisit this topic along with the next chemistry topic 'Acid and Base' in the next academic term with these students. He said:

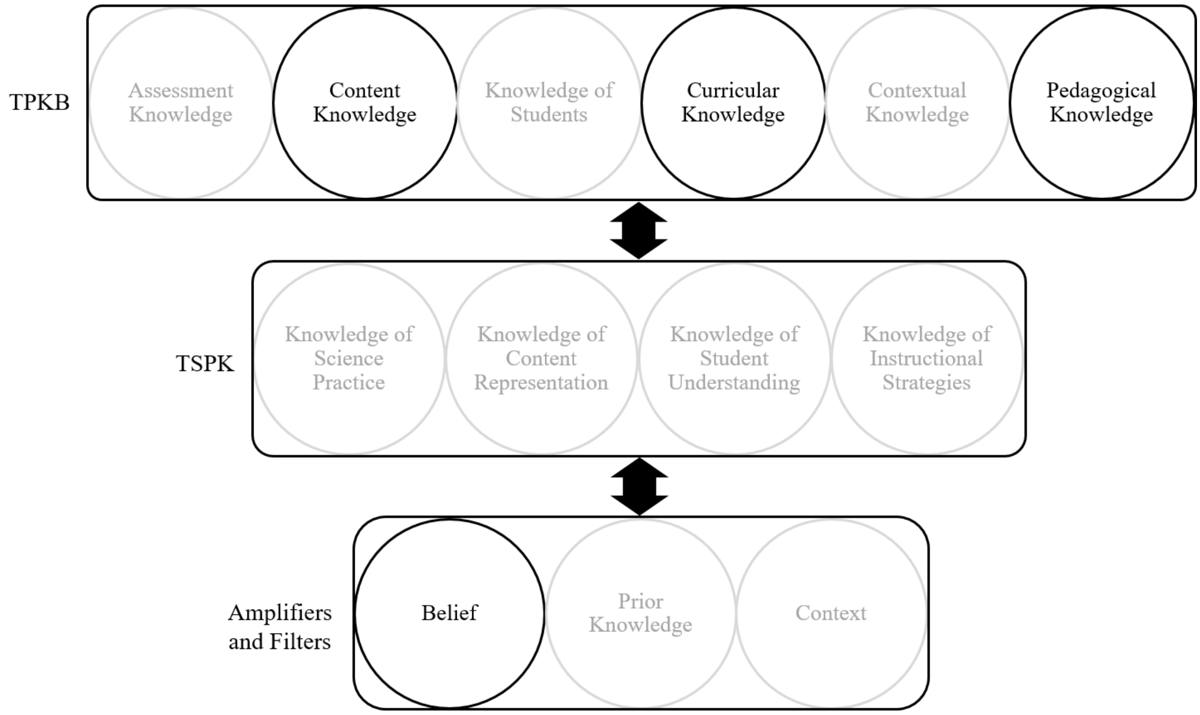
> Because I think there is some cross-over, some of the ideas are similar there. The idea of acids, primarily the idea of acids that we are working with, are going to lose [electrons], so effectively there is a similar process; where we will be talking about neutralizing acids is a pretty similar process to the sort of reactions we were talking about in the ionic chemistry. Different content, but the same ideas. I think having those and relating those ideas will help the boys to understand that, hopefully.

In this statement, he discussed his planning to revisit this topic with concepts of acids and bases in the next term. His knowledge of the coming topic in the school curriculum reflects his Curricular Knowledge. He also explained the interconnection of this topic [ionic chemistry] and acid and bases, which indicates his Content Knowledge. His planning of relating students' learning of those ideas with this topic learning indicates his Pedagogical Knowledge as it reflects his designing future lesson plans.

In these data, his Curricular Knowledge was identified through how he utilized students' prior knowledge in teaching, his Content Knowledge combined with Curricular Knowledge to describe the relationship of concepts within the subject, his Pedagogical Knowledge combined with Curricular Knowledge to explain the next topic planning and engage the students. His teaching beliefs appeared to filter his choice of pedagogy. The combined knowledge components (Curricular Knowledge, Content Knowledge, and Pedagogical Knowledge) and filter are framed in Figure 4.18.

Figure 4.18

George's combined knowledge to use the students' prior knowledge in his teaching



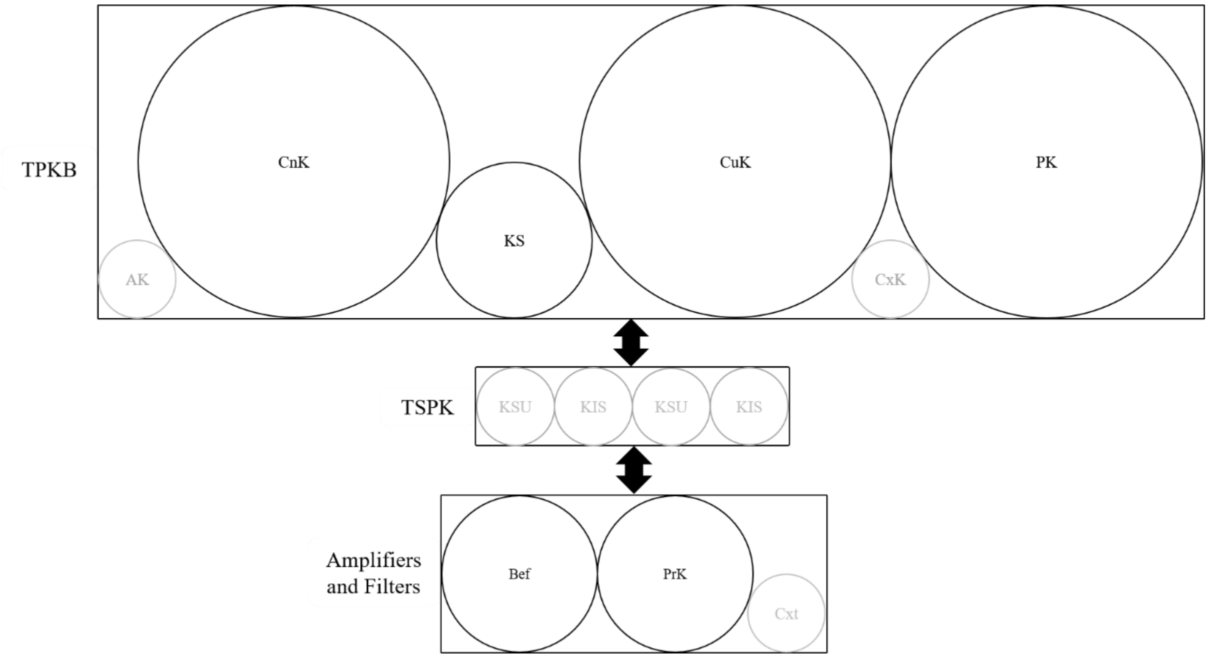
Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. His Belief amplified his Curricular Knowledge.

4.6.3 *Summary of Curricular Knowledge focus*

The two figures (4.17 and 4.18) represent George's PCK in the selected pieces of evidence when his Assessment Knowledge was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Assessment Knowledge. In these figures, Curricular Knowledge naturally appeared two times in this data (2/2), with Content Knowledge and Pedagogical Knowledge also present both times (2/2). His Knowledge of Students appeared once (1/2) while his Assessment Knowledge and Contextual Knowledge were not evident in this data (0/2). Of the TSPK components, no single component appeared. In Amplifiers and Filters, his Belief and Prior Knowledge appeared once in these figures (1/2), while his Context was not evident (0/2). These appearances of components are framed in Figure 4.19.

Figure 4.19

George's combination of knowledge components when his Curricular Knowledge appeared as a prominent knowledge



Note: In this figure the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

4.7 Contextual Knowledge

Some PCK experts have considered Contextual Knowledge as part of teachers' PCK such as Shulman, Grossman, Mahvunga and Rollnick. The consensus model does not foreground this knowledge in teachers' PCK. The observational data of this study indicate that George used his Contextual Knowledge in his classroom. In his teaching practice, he frequently used examples from different contexts, such as classroom context [above discussed under section 4.4], school context, community, and context of the country. This section discusses examples of where his Contextual Knowledge was identified as prominent knowledge in his teaching.

4.7.1 *Contextual Knowledge in experimental safety in the classroom*

George's Contextual Knowledge was identified in the planning and conducting of experiments in the classroom. In Lesson 3, when he explained the reactivity of elements, he said if he took a piece of sodium and lithium and put them in a water pond, and then there will be an explosion in that pond. The students, perhaps not surprisingly, wanted to try it in the laboratory sink, but George refused to do so (L-3). On this occasion a conversation between teacher and students started:

> T: We are not allowed here; it tends to be too dangerous, so we are not allowed here. You [student] suggested to do it in the sink [and then he goes near to the sink]. One, it is not good to drain stuff like that and unpleasant things. [He knocks on the sink and explains] Two, it is stainless steel but 20 mm down it is plastic, and when sodium touches the plastic what will happen?
>
> S: Melt
>
> T: Yes, and I will be in serious trouble. [Students insist but teacher saying No, No, No…]
>
> T: Some reactions are violent, they produce a lot of heat and sometimes explosions, because they are very close to the complete outermost shell and react very fast. The elements of the left and right sides of the periodic table are very reactive (except inert gases). (L-3)

George's reasoning in the above statement illustrates his Contextual Knowledge at the school level. He gave the reason to students of the physical context of the science laboratory sink and school policy that he was 'not allowed' to demonstrate this reaction in the sink, which indicates his Contextual Knowledge. It is Contextual Knowledge because it reflects his knowledge of the school context and policy. He explained why through 'Some reactions are violent, they produce a lot of heat, and sometimes explosion because they are very close to the complete outermost shell and react very fast', which indicates his Content Knowledge. It is Content Knowledge because it reflects his understanding of some chemical reactions.

He discussed in a follow-up interview how the school context assisted him in planning an experiment. He can arrange apparatus and chemical use through using a customized online software:

> We use a program on the internet called *Risk Assess* and it does two things, one is an ordering system, so I can just go to the internet at home and I can type in what I want. But I can also look at what the other teachers have been using, so if another teacher had done this already,

> I could look at it and just click it and pop my name on it and send it again. It makes it very simple. But at the same time, it will list the sorts of precautions that you need, like safety glasses or if you need to wear gloves or aprons or whatever, it will tell you that. (I-7)

This quote shows he arranged a safe experiment in the science laboratory by using the school context. He arranged the apparatus for an experiment in the school's science laboratory by using *Risk Assess* customized internet program, which indicates his Contextual Knowledge. He used the school context in teaching, which indicates his Pedagogical Knowledge in planning an experiment that was safe and appropriate for his students. The school context informed him about available apparatus and precautions for the specific experiment, which indicates the linkage of the country's health and safety policy with the school policy. For instance, the second part of that program 'the sorts of precautions that you need' indicates the projection of New Zealand policy [about safety codes in a science laboratory] in classroom practice, which indicates his Curricular Knowledge it reflects his understanding of the curriculum policy. He further expressed how the national context affects the conduct of laboratory work:

> New Zealand is becoming very conscious of safety; it's a big frustration in a lot of cases because often things that we've done in the past quite safely we are not allowed to do now, which is a pain. But in a way it's good, by using the ordering system, at least I'm reminded of the issues that might come up. (I-7)

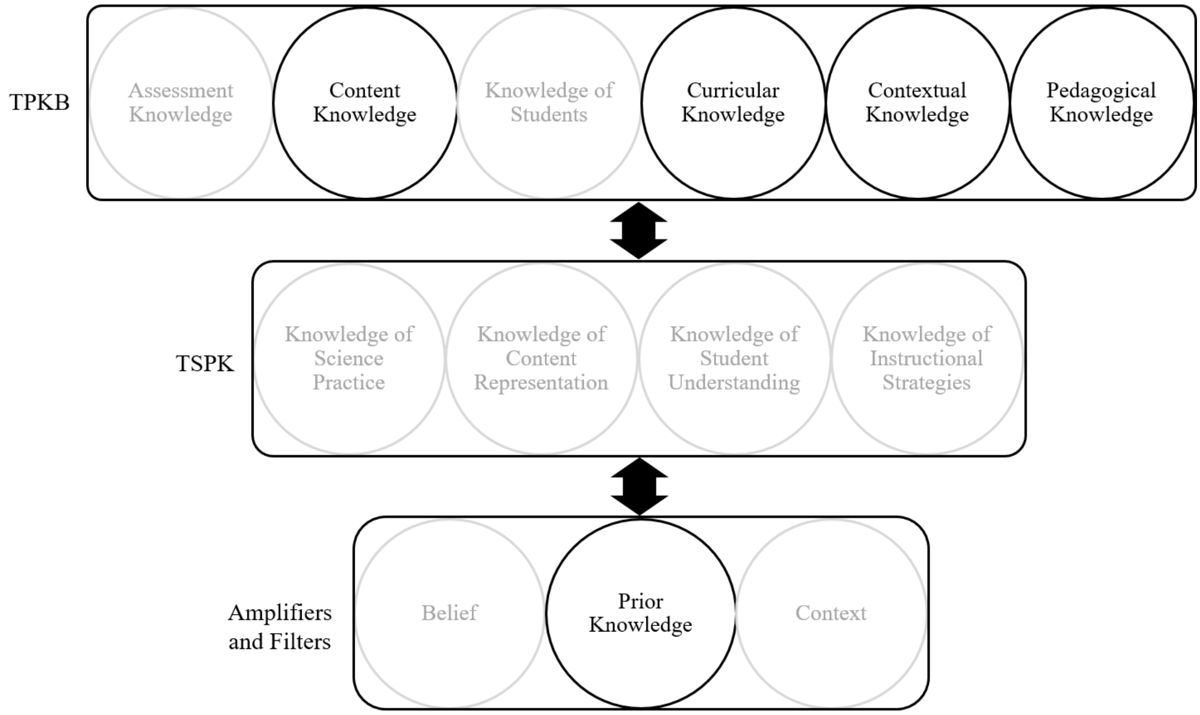
In this statement, he compared his experience in the laboratory 'we have done it in the past quite safely' with recent experience 'we are not allowed to do now', which indicates his Contextual Knowledge because it reflects his knowledge beyond the school that the national context is highly influential in his laboratory work. This statement also indicates his knowledge originates from his teaching experience in New Zealand school science laboratories, which indicates his Prior Knowledge. His Prior Knowledge amplifies this statement through a comparison of old policy and new policy. When a country changes such a policy that would have a direct influence on teaching practice, then teachers do need specific changes in their teaching. George's annoyance shows some reluctance to adopt the country's new policy [general health and safety codes in Science Lab] in the laboratory but he seemed happy with this ordering system of health and safety. It seemed to me that he shaped his knowledge according to the policies and limitations of the classroom and school context.

In these pieces of evidence, George appeared to use his Contextual Knowledge to plan and conduct experiments in the classroom, his Content Knowledge combined with Contextual

Knowledge to explain the chemistry behind his decisions, his Curricular Knowledge combined to highlight the curriculum stance, and his Pedagogical Knowledge combined with Contextual Knowledge to plan safe experiments in the classroom. His Prior Knowledge was amplified through the past and present national policies. The combined knowledge and amplifies and filters in these data are framed in Figure 4.20.

Figure 4.20

George's combined knowledge components in experimental safety in the classroom



Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in the particular classroom. His Prior Knowledge amplified his Contextual Knowledge.

4.7.2 *Generating examples in his teaching practice*

George used his Contextual Knowledge to generate examples from his local and country context in his teaching practice. New Zealand education has a goal related to students' adjustment in society: that would include the requirements of society, the demands of the future, and developing qualities in students to best fit into society (Gluckman, 2011). In a broad sense, it requires teachers to impart information to their students about how to live in their society's context. Therefore, a teacher would need some knowledge of society [context] to create a connection of their teaching with society and formulate their teaching to accomplish this goal. Considering an aspect of this, in Lesson 5, George explained the regional context:

> We need a small amount of metal ion for our body. Most of it comes from our diet, we use red meat and vegetables, and if we have not enough ions in the body then some people can take supplement ions. One problem with New Zealand soil is that it is typically low in cobalt and selenium and Waikato soil is low in copper. For most of these things too much is not good, and not enough is also no good. (L-5)

This statement illustrates he explained scientific content with examples from regional and country contexts. He described the deficiencies of elements in New Zealand soils, and in particular Waikato soil, which indicate his Contextual Knowledge of contexts beyond the school. He described the importance of ions in the body, which indicates his Content Knowledge. He used his contextual knowledge to provide examples to enhance the students' understanding of the concept, which indicated his use of Pedagogical Knowledge to make his teaching relevant to the students' lives. His experience in the farming and horticultural context may have helped him to generate examples relevant to the context beyond the school, which indicates his Context that enabled him to amplify his examples. He also explained the problem and its solution of ion balancing in the body in Lesson 7. He tied the content knowledge with the country's context:

> In New Zealand or other countries in the world, the deficiency of iodine causes a disease called goiter, in this disease the neck swells up. We mix iodine in common salt [NaCl]. When you use iodine, the thyroid gland functions properly. (L-7)

This shows his Contextual Knowledge helped him to determine relevant examples for ionic chemistry and including these examples into teaching practice to achieve the curriculum goal. However, sometimes he found it difficult to find examples for students from multicultural backgrounds, as he explained:

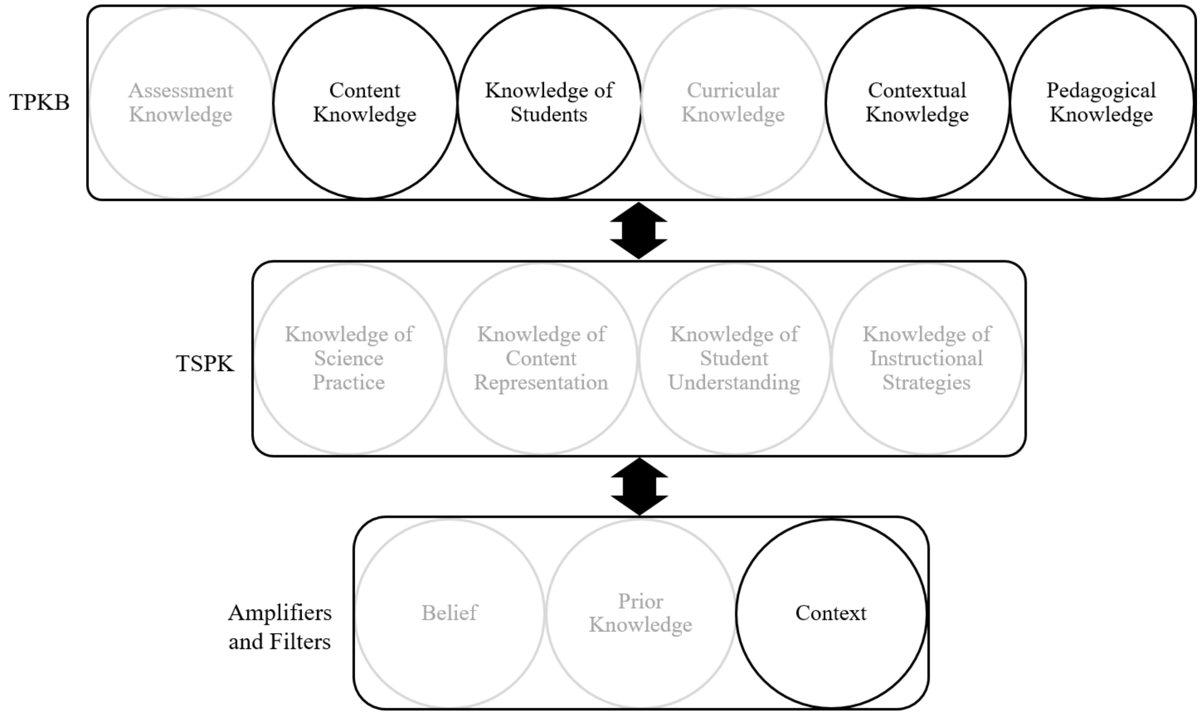
> There are issues when trying to find examples [because of the multicultural background of students] that are relevant to the boys. Sometimes it's easier for me to find examples that fit into my background. So I can talk about farming examples, I can talk about horticulture examples, and I'm not too bad on Māori things. I think I'm pretty reasonable there. But when it comes to boys who spent the first five or ten years of their lives in India or China or somewhere else, I think I don't know that stuff as well, I don't know their backgrounds as well, so finding relevant examples is a bigger problem for me. (I-F)

In this statement, he highlighted the importance of examples which are relevant to the students' background. He discussed his students' background in this response which indicates his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge of their backgrounds.

The aforementioned pieces of evidence show George used his Contextual Knowledge to generate examples in his teaching, his Content Knowledge combined with Contextual Knowledge to explained the ions in soils and their importance for the body, his Knowledge of Students combined with Contextual Knowledge to explain the students' background, and his Pedagogical Knowledge combined with Contextual Knowledge to relate his teaching to students' lives. His Context was identified as an amplifier of the examples in teaching a concept of ions in the body. The combined knowledge in these data is farmed in Figure 4.21.

Figure 4.21

Combination of knowledge when George's Contextual Knowledge was used to generate examples in teaching



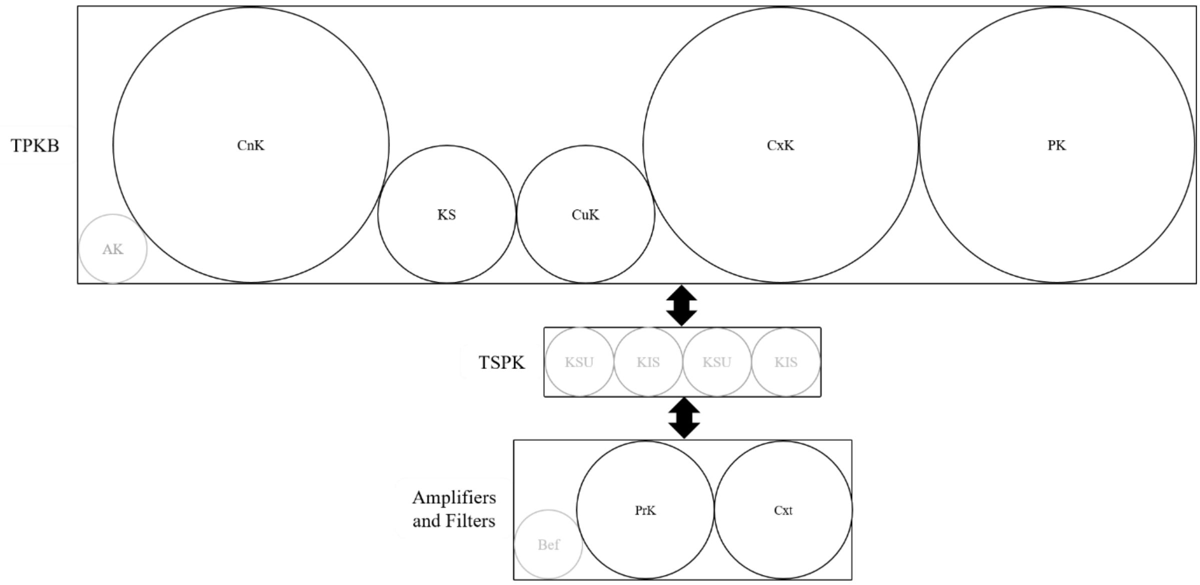
Note: This figure represents George's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. His Context amplified Contextual Knowledge.

4.7.3 *Summary of Contextual Knowledge focus*

The two figures (4.20 and 4.21) represent George's PCK in the selected pieces of evidence when his Assessment Knowledge was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Assessment Knowledge. In these figures, his Contextual Knowledge naturally appeared two times in this data (2/2), with Content Knowledge and Pedagogical Knowledge also present both times (2/2). His Knowledge of Students and Curricular Knowledge both appeared once (1/2) while his Assessment Knowledge was not evident (0/2). Not a single component of TSPK appeared in these figures. In Amplifiers and Filters, his Prior Knowledge and his Context appeared once (1/2), while his Belief was not evident (0/2). These appearances are represented in the form of the size of the circles in Figure 4.22.

Figure 4.22

George's combination of knowledge components when his Contextual Knowledge was prominent



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

This figure shows his Pedagogical Knowledge and Content Knowledge combined more often with Contextual Knowledge as compared to Knowledge of Students and Curricular Knowledge, while Assessment Knowledge did not appear to be used in any combination in these pieces of evidence when his Contextual Knowledge was identified as a prominent knowledge in his teaching. His TSPK components did not combine with his TPKB in any of these data. His Prior Knowledge and Context amplified his teaching. According to these pieces of evidence, Contextual Knowledge is an element of George's knowledge, which contributed to his PCK and helped him to towards his educational goals.

The final section examines George's Pedagogical Knowledge in his classroom practice.

4.8 Pedagogical Knowledge

This knowledge might include teachers' knowledge of strategies for classroom management, student engagement, using assessment results in planning and teaching, personalized responses, and knowledge of the ways that students learn. A teacher's adaptation of instructional strategies and design of lesson plans are examples of classroom management and student engagement (See Section 2.3.5). Teachers' lesson plans indicate their potential teaching practice and can help to illustrate teachers' Pedagogical Knowledge. In George's case, no written lesson plans were available but he did share his topic planning with his students during his teaching practice. This section explains George's use of Pedagogical Knowledge in combination with other sets of knowledge in his teaching.

4.8.1 *Designing lessons*

George's use of Pedagogical Knowledge was identified in his classroom teaching when he discussed his strategies with the class. He wrote in the response to a question [If a student asks a question in your class, what approach you take to responding?] in the pre-topic questionnaire:

> I try to deal with it the right way, I try to involve the students in the discussion, I like to expand it to bring in their prior knowledge and understanding, I like to build it out to link it to further learning. (Q-9)

In this response, he mentioned the steps to respond to students' questions in the classroom. These steps show his intention to make his answers to the students' questions in ways that enhance students' learning, which indicates his thinking in Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of strategies for student engagement in learning by bringing their prior knowledge. This step 'I like to expand it to bring in their prior knowledge and understanding' indicates his Curricular Knowledge. It is Curricular

Knowledge because it reflects his knowledge of recommended pedagogy by NZC "Making connections to prior learning and experience" (Ministry of Education, 2007, p. 34).

I was able to associate his thinking in the questionnaire with his classroom practice. In Lesson 1, he shared a brief topic planning with the students:

> We have the exam in the fifth week, which includes ecology [Biology topic], force [Physics topic], and this topic [Ionic Chemistry]. What I want to do first up guys is, I want to put some questions on the board, and I want to first up guys to work on these, or your own, I don't mind on which, but I don't want it to be a whole-class discussion at the moment. We'll talk through the results [of these questions], so I'm not going to record your results… I'm interested to see what you guys know from last year … I don't want it to be a huge talking today… There are two reasons for doing this, first one is that these questions will be a sort of a key to the topic… the next thing is that if I'm going to be teaching you some new stuff, then I need to know. (L-1)

This statement shows that he shared his topic planning and topic timeframe with the students in the classroom. He discussed why he wrote questions on the whiteboard, the purpose of those questions, and that day's strategy to engage the students through talk of the responses to those questions, which indicates his Pedagogical Knowledge in designing the lesson. His purpose of the lesson in this teaching seemed to be 'I'm interested to see what you guys know from last year' and 'the next thing is that if I'm going to be teaching you some new stuff, then I need to know'. This reflected his Assessment Knowledge because he diagnosed students' prior knowledge. The reasons for investigating students' previous understanding of the content in the questions seemed his objective about making a connection between their prior learning and 'new stuff' which indicates his Curricular Knowledge. It is Curricular Knowledge because it reflects his understanding of effective pedagogy recommended by NZC. Or his understanding of what he knew that students had been taught in the curriculum last year.

George started Lesson 2 with the same questions that he had used in the previous lesson [Lesson 1] and again emphasized, "These questions are the summary of this topic" (L-2). He asked those questions one by one to the students and explained the answers where he felt his students needed that. After doing this, he asked a series of questions to the students, and those questions were derived from the teaching of the previous lesson and generated a link to the upcoming concept (L-2). For example, before the exploration of what NaCl is made of, he created a foundation to explore the formula of sodium oxide (Na_2O) when he asked, "What could the formula of sodium oxide be? Just have a guess" (L-2). Most of the students in the class tried to explain but one student came up with a correct answer. Those passages illustrate his pedagogical process:

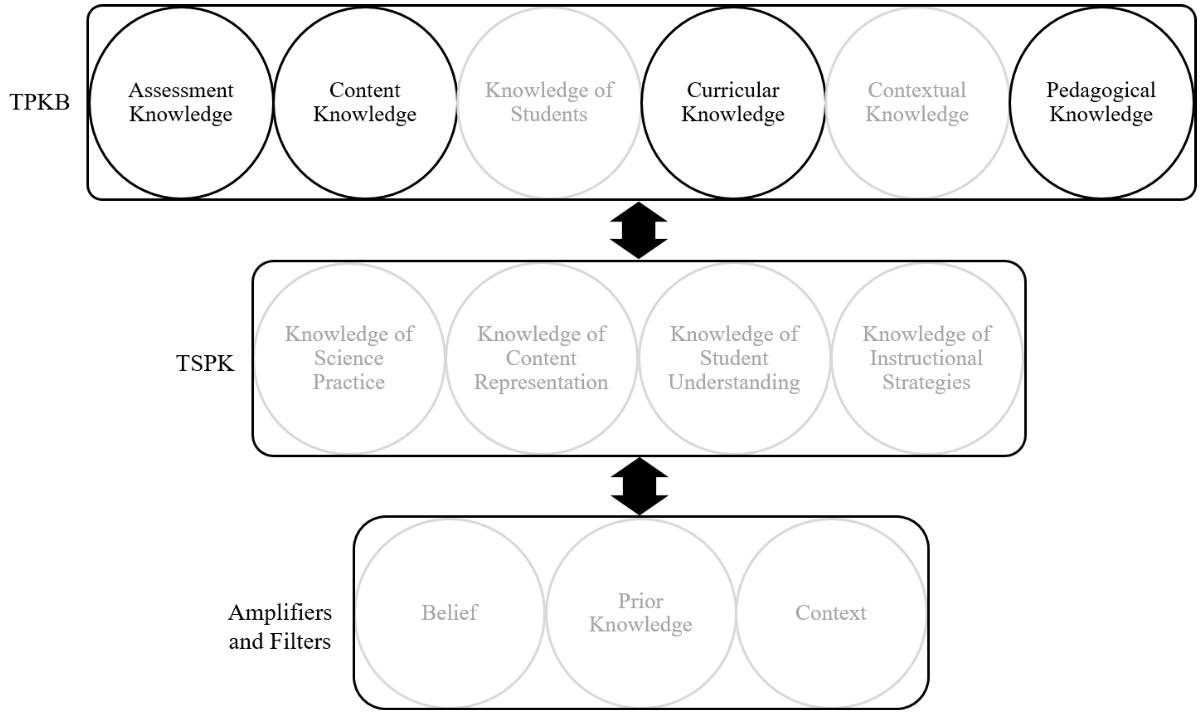
> [He discussed how oxides are formed with oxygen atoms before start of this conversation. He then focussed on how sodium ions are formed:]
>
> T: What is NaCl telling us?
>
> S3: Cl is chlorine
>
> T: Cl chlorine and Na is sodium. How much sodium is in it?
>
> S: one
>
> T: [He wrote Na and Cl on the whiteboard]. Sodium chloride is a compound because two atoms are in it. When they join, chlorine gains one electron, so it is negative and sodium loses one electron. (L-2)

In the above passages, he explained how positive and negative ions are formed by gaining or losing electrons in an atom. His generation of a series of questions involving students to develop students' understanding of the formation of compounds indicates his Pedagogical Knowledge. He explained how sodium and chlorine atoms combined by transferring an electron from sodium to chlorine reflected his Content Knowledge. It is Content Knowledge because it reflects his understanding of chemical bonding. In this episode, he also diagnosed students' prior knowledge like 'What is the charge on an electron?' which indicated his Assessment Knowledge because it reflects his knowledge of implementing diagnostic assessment in the classroom.

These data illustrate his use of Pedagogical Knowledge prominently in his teaching practice for student engagement strategies and designing the lesson plan, his Assessment Knowledge combined with Pedagogical Knowledge to diagnose students' prior knowledge, his Content Knowledge combined with Pedagogical Knowledge to explain the formation of an ionic bond, and his Curricular Knowledge combined with Pedagogical Knowledge to help know what students had previously been taught. The combined knowledge in these selected data is framed in Figure 4.23.

Figure 4.23

Combination of knowledge in designing lesson



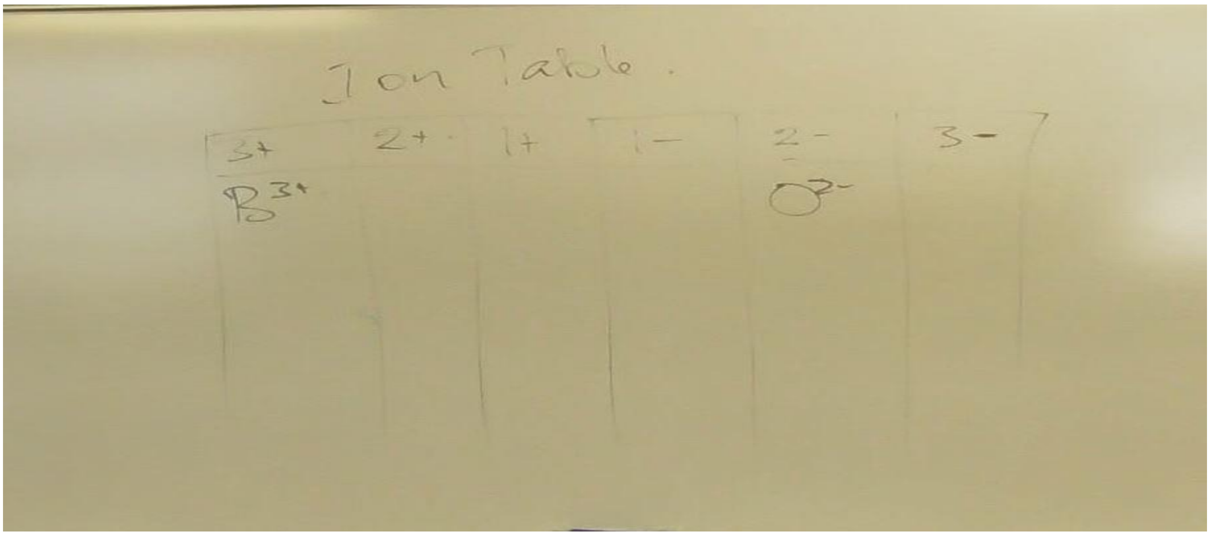
Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students.

4.8.2 ***Conducting class activities***

George's use of Pedagogical Knowledge was identified when he was conducting class activities. In Lesson 4, he drew a table with the heading *Ion Table* on the whiteboard (Figure 4.24). This table consisted of six columns and two rows. The heading of columns represented the possible ionic states of an element [3+, 2+, 1+, 1-, 2-, and 3-]. He wrote two ions, one positive [Boron, B^{3+}] and one negative [Oxygen, O^{2+}] in the table as an example. He also explained how to use the periodic table on the wall of the classroom to fill this table. He asked the students to fill this table by using the periodic table. He started moving around the class to help the students in this activity (L-4).

Figure 4.24

Ion Table drew by George in Lesson 4



Note: This snapshot was in the lesson video of George's Lesson 4.

He involved the students and abiotic context in this activity which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because he created a link for the students between an abiotic factor (the periodic table) and a task to develop an understanding of ions. His explanation of the periodic table and its uses to find out the ions for filling the table indicate his Content Knowledge. It seemed he used his formative assessment knowledge to assess his students' work during observing their table filling because he declared, "Almost all of you did well", and then he started to fill the ionic table with the first twenty atoms (L-4). He represented the content through an ion table which indicates his use of his Knowledge of Content Representation as a way to depict ionic chemistry content. The combined TPKB (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) also combines with Knowledge of Content Representation for this activity. His Knowledge of Content Representation afforded the teacher to use the periodic table on the wall (i.e. context) to find the ions (i.e. content). This combined knowledge of TPKB also combined with his Knowledge of Instructional Strategies by using a chemical table to help the students see how ions compare.

In Lesson 5, he arranged cooking materials on the teaching table, wrote a cooking recipe for making pikelets and its procedure on the whiteboard before students arrived in the classroom. He explained this recipe to students. He said two main chemicals would be used - baking soda [$NaHCO_3$] and cream of tartare [potassium bitartrate ($KHC_4H_4O_6$)] and the reaction of these chemicals will release carbon dioxide (CO_2)(L-5). This activity was not a part of the topic or the school curriculum but he explained the purpose behind this activity in the follow-up interview:

> I thought anything to do with food appeals the most, so I have this food around there, that's going to be interesting anyway. And there is some useful chemistry in there. As I said, those reactions are a little bit harder for the boys to work through, but they get the idea, and it starts them off. But the thing is it's motivational, so they like the idea of food, so if this food is involved then they are interested. (I-5)

This statement illustrates his purpose behind the cooking activity. He organized this activity to develop the students' interest in chemistry, which indicates his Pedagogical Knowledge in designing a lesson. He talked about students' interest in food 'they like the idea of food' which indicates his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge of his students' interests. He demonstrated the use of chemicals in the cooking of pikelets which indicates his Content Knowledge as it reflects his chemical understanding of cooking pikelets.

In Lesson 6, he arranged the apparatus on his table for the demonstration of the identification of common ions. That activity was a practical version of the previous week's lesson. Therefore, he started the lesson with some questions to assess student learning about the previous lesson, for example, what is a cation? The students came up with correct answers. It seemed to me that George was satisfied that the students had the basic learning of the concept, so he moved to explain more about that day's practical activity: "you [students] write the chemical names and then you will mix these chemicals and see what will happen. After that, I'll help you to figure it out. We will discuss the balance of chemical equations later this week" (L-6). He started to demonstrate the experiment in front of the class with instructions:

> We put clear liquid [of cation solution] in the test tube, approximately 1mL [he demonstrated]. You see the written instructions [on the instruction card]. I put in a couple of drops of sodium hydroxide, relatively dilute. A couple of sodium hydroxide drops to put in the test tube and shake it, note the color change. [He wrote practical instructions on the board. He then read these instructions with a brief explanation.] You will need these chemicals, written instructions, a test tube rack, and a couple of test tubes [for this practical]. (L-6)

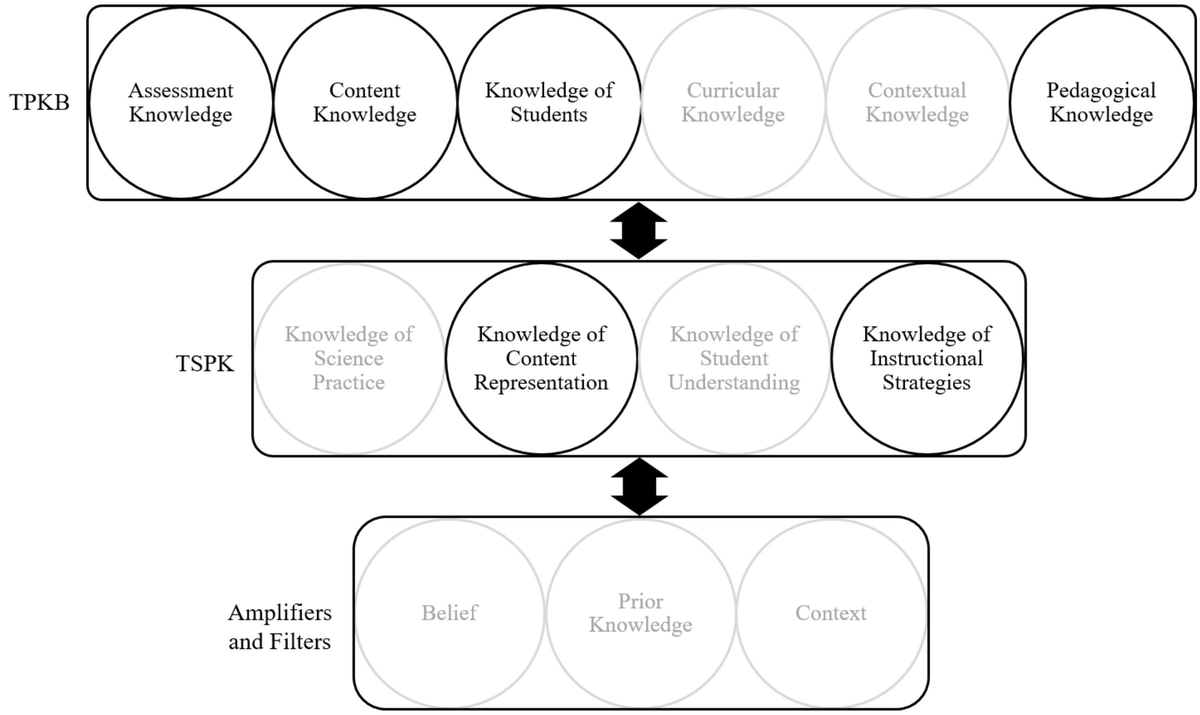
This teaching episode shows his Pedagogical Knowledge to provide students with experiential opportunities to illustrate a concept. He appeared to combine this with Knowledge of

Instructional Strategies specific to chemistry. He started Lesson 6 with the basics of the previously taught concept, linked it with the current experiment instructions, and demonstrate the experiment for the students which indicates his Knowledge of Instructional Strategies to help the students undertake the experiment. He diagnosed students' prior knowledge of the cation concept by asking questions that indicate his use of Assessment Knowledge. His design of the experiment and the likely outcomes indicate his Content Knowledge.

These pieces of data illustrate that George used his Pedagogical Knowledge to organize and conduct activities in the classroom, his Assessment Knowledge combined with Pedagogical Knowledge to implement formative and diagnostic assessment in the classroom, his Content Knowledge combined with his Pedagogical Knowledge to explain the chemistry content and his Knowledge of Students combined to discuss students' interest in chemistry. His Knowledge of Content Representation and KIS combined with the TPKB to present content with ions table filling activity. The combined knowledge components are framed in Figure 4.25.

Figure 4.25

Combination of knowledge components in the class activities



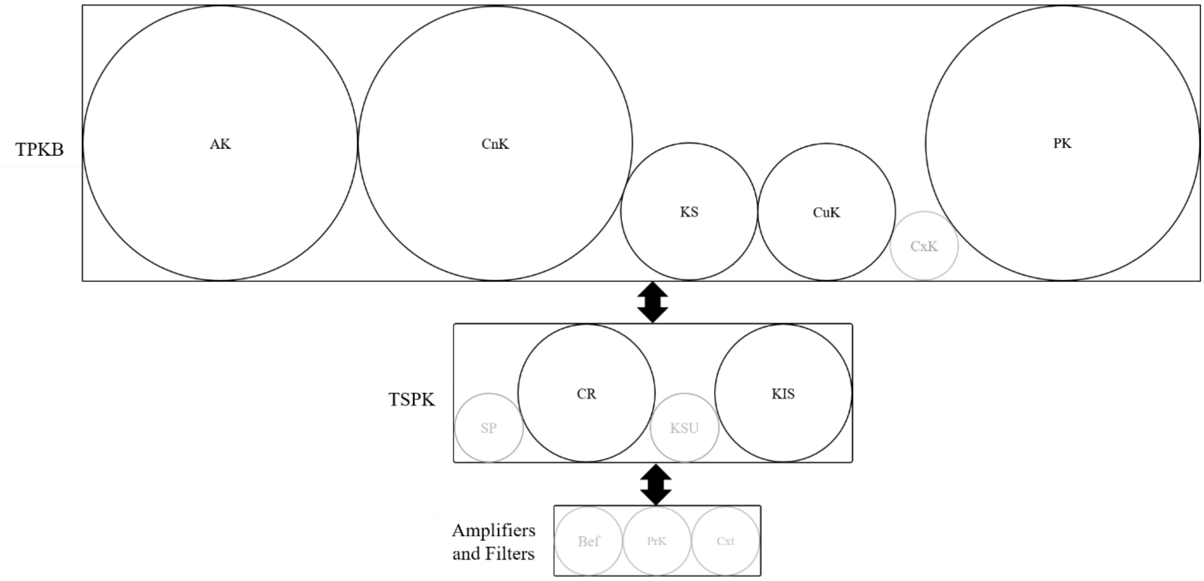
Note: This figure represents George's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Knowledge of Students, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Content Representation and Knowledge of Instructional Strategies in conducting class activities.

4.8.3 *Summary of Pedagogical Knowledge focus*

The two figures (4.23 and 4.25) represent George's PCK in the selected pieces of evidence when his Assessment Knowledge was identified as prominent in his teaching. I compared these figures to illustrate that not all components of TPKB were combining equally with Assessment Knowledge. In these figures, Pedagogical Knowledge naturally appeared two times in this data (2/2), with Assessment Knowledge and Content Knowledge also present both times (2/2). His Knowledge of Students and Curricular Knowledge appeared once (1/2), while his Contextual Knowledge was not evident (0/2). Of the TSPK components: Knowledge of Content Representation and Knowledge of Instructional Strategies appeared once (1/2), while, his Knowledge of Science Practice was not evident (0/2). The appearance of components represents in Figure 4.26.

Figure 4.26

George's combination of knowledge when his Pedagogical Knowledge appeared prominent



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

This figure shows his Content Knowledge and Assessment Knowledge combined more often with Pedagogical Knowledge as compared to Knowledge of Students and Curricular Knowledge, while Contextual Knowledge was not identified in any combination in these pieces of evidence when his Pedagogical Knowledge was identified as a prominent knowledge in his teaching. His Knowledge of Content Representation appears to also combine when Pedagogical Knowledge is prominent. His Amplifiers and Filters did not seem to amplify and filter his teaching.

4.9 Chapter Summary

George has a science background, a professional teaching qualification, and more than 20 years of science teaching experience in New Zealand. The research data for this study were gathered when George taught a chemistry topic ‘Ionic Chemistry’ to Year 10 students. This was a low-ability class consisting of 28 students from multicultural backgrounds.

Evidence from classroom observations and interviews with George indicated that it was possible to identify knowledge components that are part of the PCK Consensus model of 2015. By focussing on each component within TPKB at a time, it was possible to interpret George’s combinations of these knowledge components in his thinking and classroom practice, and how these TPKB components combined with TSPK and amplifiers and filters.

His knowledge components worked in a variety of ways in a combination to facilitate his teaching. These ways indicated different types of combinations in his teaching rather than a fixed combination. Some knowledge components appeared more often in his combinations as compared to others. His combined knowledge components of TPKB also combined with TSPK for a particular teaching, so, the combination between these sets of knowledge did not appear in every combination.

His knowledge components combined to facilitate specific teaching. The purpose of teaching at specific times appeared to determine the nature of the combination. These combinations also indicated that all knowledge components did not combine equally in specific teaching instances. His Amplifiers and Filters identified that amplifying or filtering his teaching practices. The next chapter presents the findings of the other case of this study.

Chapter 5

Philip's Case Study

5.1 Overview

This chapter presents the case study Phillip (participant's pseudonym). Firstly, this chapter presents the context of the study which includes the details of the classroom context, a brief introduction to Philip, and his educational background. Secondly, it deals with combinations of knowledge components of Teacher Professional Knowledge Base (TPKB): Assessment Knowledge, Content Knowledge, Knowledge of Student, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge as contributors to teacher's PCK. Finally, this chapter offers a summary.

5.2 Context of the Study

This case study involved an experienced science teacher from a New Zealand public high school. The research data were collected when Philip was teaching his Year 10 students the topic 'Acids and Bases' in chemistry. The school's science department produced a structured outline of topic content material with student learning objectives (SLO's). The outline encompasses theoretical and experimental aspects of the topic. The school allocated four weeks for this topic, but he had the autonomy to adjust the experiments with theory and alter the sequence of the content outline. Within the given timeframe Philip finished this topic in 12 lessons and each lesson was 50 minutes duration. I observed all these lessons: took observational notes and all were video recorded. The school suggested a science textbook that enabled Philip to assist his teaching. He was free to adopt any teaching method. He taught all lessons in the science laboratory. That means he used the science laboratory as a classroom. The next subsection portrays the context of the classroom.

5.2.1 *Classroom context*

All the 12 lessons were conducted in the school science laboratory next to Philip's office. The laboratory was equipped with scientific apparatus for experiments. The laboratory walls displayed relevant science charts: a periodic table, solar system, internal structure of the earth, different types of fish on a chart, and a chart portrait of the anatomy of the dinosaur. There were photos of metals, the colour of metal flame, owl, Tui (New Zealand native bird) and other birds, and windmill on the wall. A big New Zealand map was on the left of the whiteboard. Some handmade scientific diagrams are also displayed on the walls. These diagrams show the habitat of an elephant, the living adaptation of a lion, and a diagram of a hydropower dam. This room is equipped with a whiteboard, multimedia projector, and a computer. The student benches were arranged in three lanes at the centre of the laboratory and tables for science experiments were fixed along three walls of this room behind the student benches. These tables had sinks, water tap, and gas connections. There was a large teacher table in front of students. This table has a sink, water tap, two gas connections which indicated it could be used to conduct demonstrations.

The observed class of Year 10 included 24 students (age 14-15) from different ethnic backgrounds: most of them seemed to be Pākehā, less than 10 students looked like Māori, and 2-4 appeared to be Asians. This class was in a preparatory year to enter the National Certificate of Educational Achievement (NCEA) for students studying level 1. Philip informed me in our first meeting before data collection, these students have poor learning ability, and a teacher assistant will observe the whole topic to support them. Those students learned some general science concepts in Year 9. In Year 10, they would learn subject-specific concepts e.g., reactions of metals with acids.

The observational data shows that Philip adjusted experiments in theoretical concepts when he felt comfortable with the readiness of the students in the science laboratory. For instance, he explained the properties of acid and base in the first half of Lesson 2. In the second half, he demonstrated an experiment of acid with metal (L-2). He described in the follow-up interview, "Every period is different, so I look to see how we are going in terms of: Do they understand what I'm saying? Are they learning something new?" (I-2). Likewise, he demonstrated adjusts an experiment 'testing acid with universal indicator' in Lesson 4. But student behaviours disturbed the class. . He said in the follow-up interview, "I'm not going to put it (experiment) off again and again; it's not helpful" (I-4).

The content of this topic consisted of: defining acid and base in terms of hydrogen ion transfer; recognising common acids and bases used in a laboratory, listing the properties of acids and bases, using indicators to identify substances as acids, bases, or neutral; explaining acidity and alkalinity in terms of hydrogen and hydroxide ions present; neutralization concerning an everyday use of an acid and base; writing word equation and balanced symbol equations for these reactions: Metals with Acid; Acid with Base, Acid with Metal carbonate. The experimental activities included indicators and common household solutions, reactions of acids, neutralization reactions with universal indicators, making sherbet, making soap, and making red cabbage an indicator. This content was arranged the same as a structure recommended by

The New Zealand Curriculum (Ministry of Education, 2007). The chemistry key concepts linked with *The New Zealand Curriculum* learning strands and learning strands are connected to specific learning outcomes. These key concepts are: all matter is made of particles, the properties of materials derive from the identity, arrangement of particles, energy plays a key role in determining the changes that matter can undergo, and chemistry is everywhere. These key concepts are linked to two learning areas of level 5 *The New Zealand Curriculum*: Nature of Science and Material World. The purpose of the nature of science strand is to achieve Investigation in Science (ask questions, find evidence and carry out appropriate investigations to develop simple explanations) and Communicating in Science (use a wider range of science vocabulary, symbols, and conventions.). The Material world consisted of Properties of Materials (investigating the physical and chemical properties of substances and relate these to their appropriate and safe use, both in their personal and the wider environment) and Chemical Reactions (explore and investigate chemical reactions of a range of substances and identify these occurring in everyday situations). This document described some specific learning objectives to achieve through the teaching of given topic content. By knowing his educational background it would possible to portray his potential teaching practices at some level, therefore the next subsection offers the research participant’s background.

5.2.2 ***Research participant***

Philip had a Bachelor degree in Chemistry and Education from a New Zealand university. He has more than 20 years of national and international teaching experience in secondary schools. In his current working place, he is teaching Year 10 Chemistry; Year 12 Biology and Mathematics; Year 13 Physics, Chemistry, Geology, and Astronomy. He taught 16 to 20 science periods per week. He also took charge of the Badminton club and Christian religious group in the school.

He started his teaching profession in a non-English-speaking country as an English teacher. After one year he came back and joined this school as a science teacher. He has engaged regularly in religious activities since his young age, and he is the author of a book on science and religion. His final interview and pre-topic questionnaire data show that he is interested in acquiring scientific knowledge, teaching chemistry, teaching geology, and teaching religious studies.

The Consensus Model-2015 mentioned knowledge components in the Teachers’ Professional Knowledge Base (TPKB) block. These knowledge components indicate teachers’ general knowledge for teaching. The following sections discuss these knowledge components respectively. The heading of these sections is based on a knowledge component that identified as prominent knowledge in his teaching.

5.3 Assessment Knowledge

Assessment Knowledge encompasses teachers' knowledge of designing assessments and implementing formative and summative assessments in teaching. This section discusses Philip's Assessment Knowledge as a prominent knowledge in his teaching. I also discuss the way Assessment Knowledge combined with other knowledge components of Teacher Professional Knowledge Base (TPKB), and components of Topic Specific Professional Knowledge (TSPK.

5.3.1 *Assessing students' prior knowledge*

Philip assessed students' prior knowledge in his classroom reflected his Assessment Knowledge. The questionnaire data suggest that he assessed his students by "asking questions in the class and gauging their answers" and "Marking their test and then giving feedback" (Q-15). These data reflect his ways of assessment: asking questions in the class and gauging their answers (i.e. formative assessment) and marking their test (i.e. summative assessment) which indicates his Assessment Knowledge. It is Assessment Knowledge because it reflects his awareness of implementing formative and summative assessment in teaching.

I was able to associate his pre-topic questionnaire data with his teaching. Philip started this topic teaching with an activity: he wrote the topic name 'Acid and Base' on the whiteboard, he asked the students to take out two pages from their notebooks and write down what ideas they might have about acids and bases. He gave students 10 minutes to write their ideas. He asked students to share their ideas with the class (L-1). The interactions between Philip and his students are presented below when students shared their ideas:

Student (S): Bunsen burner

Teacher (T): It is just chemistry, anything else

S2: Liquid look like acid

S2: Atoms

T: What are other ideas you want to include?

T: What is inside the battery of a car?

S2: Liquid

T: What is that liquid inside?

S2: Water

T: What is inside of the water?

S3: Battery acid

T: Yes, you are smart.

T: What will happen if you get stung by a bee?

S4: Poisonous

T: Poisonous, what would you put on skin?

S4: Vinegar

T: On bee sting!

S4: (silent)

S5: Baking soda

T: Yes, baking soda. You put it on a bee sting because it is opposite to a bee sting (he pointed his finger towards the S4). We put vinegar on!

S5: Wasp sting

T: Yes, wasp sting (he repeated it loudly for students.) (L-1)

This activity seemed to be organized to assess students' prior knowledge about 'Acid and Base'. At the beginning of this discussion, students' ideas (e.g. Bunsen burner, atom) did not directly refer to acids and bases. Then, Philip asked questions based on students' daily experiences. I observed that students were energetic to answers these questions. He made a connection between their responses and the content by asking more questions. Student responses are an indication of their prior knowledge.

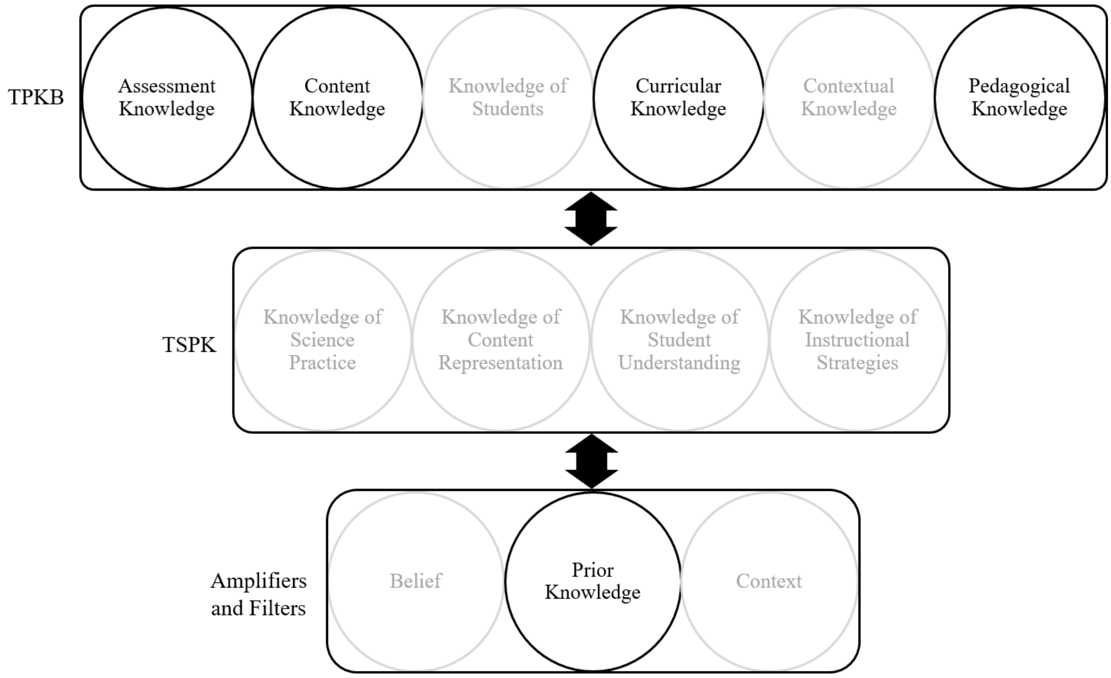
Herein, this teaching episode illustrates his Assessment Knowledge as prominent knowledge in TPKB to diagnose students' prior knowledge. He asked questions to diagnose their prior knowledge about acid and base that indicate his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of implementing diagnostic assessment (i.e.

formative assessment). He generated a link between students' experience and lesson content indicated his Curricular Knowledge. It is Curricular Knowledge because it reflects his understanding of *The New Zealand Curriculum* recommended pedagogy "Making the connection to prior learning and experience" (Ministry of Education, 2015, p. 34). He used discussion as an instructional strategy to promote sharing their ideas of acids and bases which indicate his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his strategies to engage the students in learning. He introduced 'vinegar' as an acid and 'baking soda' as a base and their uses which indicate his Content Knowledge. It is Content Knowledge because chemistry behind the use of vinegar on a wasp sting and use of baking soda on honey bee sting presenting his chemical understanding 'you put it on a bee sting because it is opposite to bee sting'. In this teaching episode, his Prior Knowledge about the use of baking soda on a bee sting and vinegar on a wasp sting amplifies the content. There is an amplification because of the introduction of home remedies which is not explicated stated in the school curriculum. This Prior Knowledge may be acquired from his life experience or society because medical professionals tend not to suggest applying baking soda on bee sting which can damage the skin (Fletcher, 2018).

The pieces of evidence suggest that he knew the implementation of formative assessment in teaching. His Content Knowledge combined with Assessment Knowledge to explain chemistry content, Curricular Knowledge combined with Assessment Knowledge to bring *The New Zealand Curriculum* recommended pedagogy in teaching, and his Pedagogical Knowledge combined with Assessment Knowledge to engage students to share their ideas. His Prior Knowledge amplifies the lesson teaching. The combination of knowledge and amplifiers and filters in this teaching is framed in Figure 5.1 with black colour circles. The grey-coloured circles indicate knowledge that is not explicit in these pieces of evidence.

Figure 5.1

The combined knowledge component in assessing students' prior knowledge



Note: This figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) when he assessed students' prior knowledge. His Prior Knowledge amplifies his content knowledge.

5.3.2 *Presenting content by using powerpoint slides*

Philip's assessed his students' understanding of acids at home by asking questions that reflected his Assessment Knowledge. In Lesson 3, he wrote the topic name 'Acid and Base' and showed the PowerPoint slide to the students. This slide displayed photos of acid bottles, common things like yogurt, orange, rhubarb, sprit bottle, and bottles that have a label of a base on them, apparatus used in chemistry laboratory such as measuring flask, measuring cylinder, conical flask, etc., and a sign of 'DANGER' that indicate the safety issues during chemistry experiments (Figure 5.2). He used this slide and present the content by asking questions:

T: Can you read some signs up there (on slide)?

S: Hazards

S2: Danger

[Teacher indicated towards a photo of three bottles but the label on them are not visible clearly]

T: Can you read? Students!

Class: No

[Teacher used a stick to point label on a bottle]

T: Here is sulfuric acid concentrated, if you put sulfuric acid on your hand, it will burn your complete hand, because it is a reducing agent

S: Where do we store it?

T: In the glass, because it is non-reactive. Glass is used for the storage of a lot of things

T: Can anyone read the sign up there? [He indicates the other bottle]

S: Hydrochloric acid

T: Hydrochloric acid diluted, concentrated means it is concentrated and, diluted means it is diluted. What is the difference? If diluted, what is in it?

S: Water

T: Yes! We add water to make it dilute. (L-3)

Figure 5.2

PowerPoint to show the acids and bases in Lesson 3

Note: This screenshot was taken from Lesson 3.

The display of this slide with discussion seemed to me that he followed the document *Science in The New Zealand Curriculum.* This document recommended an assessment example for this topic as “ability to recognize common acids when they name several common acids found at home and in the laboratory” (Ministry of Education, 1993, p. 101) which indicates his Assessment Knowledge. He gauged the answers of students, corrected their answers, and continuously asked questions. The selection of photos related to chemistry content reflected his Content Knowledge. It is Content Knowledge because the selection of things that contain acid and base in it is specific to the understanding of chemistry is everywhere. He used the classroom projector as a teaching aid which indicates his Contextual Knowledge. It is Contextual Knowledge because it reflects his awareness of the classroom setting. He engaged the students to work out to find acid or base in shown things. He adopted the question-answer strategy as pedagogy to present the content which indicates his pedagogical knowledge. A bit of these questions-answers from that teaching is presented below.

T: What is today’s topic

S: Acid at home

T: Yes, give me an example

S2: Citric acid

T: Citric acid, very good! The citric acid in what?

S2: In our body

S3: Oranges

T: Oranges!

T: [Citric acid also found in] Lemon, lime, grapefruit

T: It is one example of acid at home. What is the other example?

S4: Bleach

T: Bleach is an acid [He gave a surprising gesture]

S4: No

T: No, it is not an acid. It is a base

S: Tartaric acid

T: What acid is in your stomach?

S3: Lactic acid

T: Lactic acid!

S5: Hydrochloric acid

T: Yes! Hydrochloric acid

T: What acid is in the car battery?

S: Battery acid

S2: Sulfuric acid

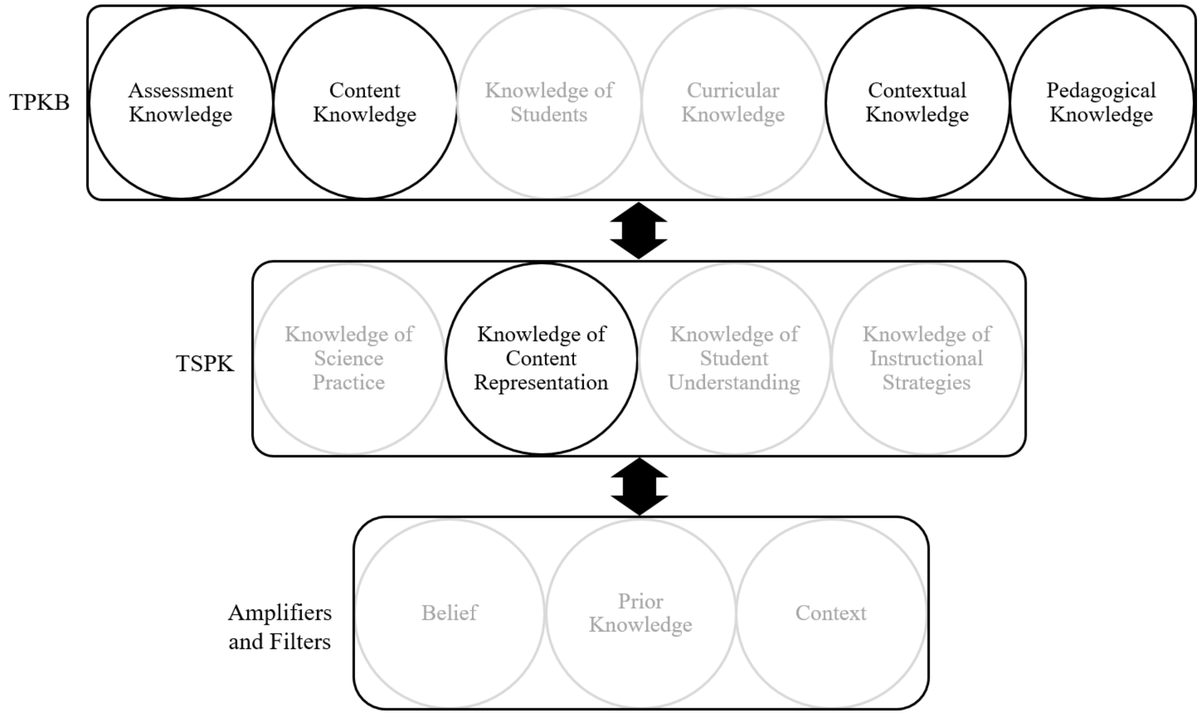
T: Well-done! (L-3)

This teaching episode illustrates formative assessment for diagnosing students' prior knowledge about 'acid at home' which indicates his Assessment Knowledge. It is Assessment Knowledge because it reflects his knowledge of assessing students' prior knowledge through implementing formative assessment. The question-answer strategy was adopted to involve the students to find out the acid and base in displayed things on multimedia that indicate his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects he engaged the students in learning. The content was presented by using classroom context to show the things to develop the students' understanding of acid at home which indicates his Knowledge of Content Representation. It is Knowledge of Content Representation because it reflects his understanding of what instructional strategies will use [he made the power points in advance] and why "They will learn things, they can see" (Q-14). He combined knowledge components (Assessment Knowledge, Pedagogical Knowledge, Curricular Knowledge, and Content Knowledge) to present content. This combination also combined with his Knowledge of Content Representation for presentation acid and base through PowerPoint. His teaching reflected that he has considered these questions: what things will choose those contained acids or base (i.e. content) and how it will be presented (i.e. PowerPoint). How engaged the students (i.e. pedagogy) to find out acid and base in shown things (i.e. question-answer strategy). There is a combination between TPKB and TSPK because combined knowledge informed the Knowledge of Content Representation for what instructional strategy is best for these students to present such content. The Knowledge of Content Representation afforded the teacher to show the actual photos of things that have acid and base on the slide and engaged the students in the discussion to find acid and base in these things.

In this data, his Assessment Knowledge identified to implement a formative assessment to assess the students' prior knowledge, his Content Knowledge combined with Assessment Knowledge to select the things that have acid and base in them, his Contextual Knowledge combine with Assessment Knowledge to use the projector as a teaching aid, and his Pedagogical Knowledge combined with Assessment Knowledge to engage the students to find out acids and base in the displayed things. These combined knowledge components also combine with Knowledge of Content representation to choose the most appropriate method of representation for this concept. The combination of knowledge components in this particular teaching is framed in Figure 5.3.

Figure 5.3

Combined knowledge components to present particular content by using powerpoint



Note: This figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination of knowledge components also combined with his Knowledge of Content Representation in the teaching of the Acid and Base.

5.3.3 *Supporting students to do practical work*

Philip's assessed his students' work and practical skills during an experiment that reflected his Assessment Knowledge. The school curriculum expected students to understand "Neutralization + UI [universal indicator]" through experiment (SC). In a chemistry experiment, indicators were used to change the colour of the colourless base (e.g. Phenolphthalein change the colourless NaOH into pink colour). When an acid was added drop by drop to the base, the solution would be decolourised that indicated the completion of the reaction. In this way, we can calculate the quantity of an acid that is used to neutralize the known quantity of a base. In Lesson 5, Philip organized an experiment to show the neutralization of a base (NaOH) with an acid (HCl) by using a universal indicator. He demonstrated to the students how to use apparatus, measure endpoints, colour changing in this reaction, and draw a table for results in the experiment. The students in the groups took the apparatus and started the experiment. He moved in the class to guide students in the experiment. He assessed that some students were not performing practical in a correct way (L-5). Then he revised some steps of the procedure for the class:

> T: Put base 1 mL here [in test tube] so put a little black mark on that. Ok! And then what we've got to do next?
>
> S: Add indicator
>
> T: Yes! Put two drops [of indicator], its beautiful blue colour
>
> S: Purple colour
>
> T: Strong purple colour
>
> T: Now you start adding drop-by-drop acid in it. (L-5)

This episode showed his knowledge components are combined for conducting this experiment. He asked the students to assess their understanding of change in colour 'what we've got to do next?' in the experiment which indicates his Assessment Knowledge. It is Assessment Knowledge because he was implementing formative assessment to assess students' understanding. He modified the instruction after assessing the students' understanding of experiment steps 'Now you start adding drop-by-drop acid in it'. He demonstrated the change of the colour due to adding of universal indicator for neutralization reaction which indicates his Content Knowledge. It is Content Knowledge because it reflects his understanding of chemistry experiments. He engaged the students to find the quantity of acid that neutralizes the given 1 mL of the base is indicating his Pedagogical Knowledge. It is Pedagogical Knowledge because students were involved to find the scientific fact (quantity of the acid in drops) in the neutralization reaction. The students and teachers tried to confirm the quantity of acid that neutralized 1 mL of the base which indicates his Knowledge of Science Practice. It is Knowledge of Science Practice because it reflects his understanding of exploring the scientific concept through experiment. The combined knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) combine with his Knowledge of Science Practice to find scientific facts through the experiment. There is also a combination between TPKB and TSPK because the combined knowledge components informed the teacher to select the topic-specific activity to find the scientific fact through neutralization reaction (Knowledge of Science Practice). This strategy afforded the teacher and students to calculate the number of drops of acid used to neutralize 1 mL base. His observation during the experiment identified to me that he evaluates the students' practical skills and work in the experiment because he stops the experiment and revised a step.

Philip moved around the class for observation when students performed their experiment without any written document. As a chemistry teacher, I used experimental skills assessment grading scheme [students' apparatus handling, chemical handling, measuring chemicals, mixing chemicals, find results, result table, calculation, etc.] for assessing my students' experimental skills in the laboratory. When I asked in the follow-up interview about how you assessed the students "Do you feel you have achieved your objective for this lesson? How you assess that?" (I-5). He said:

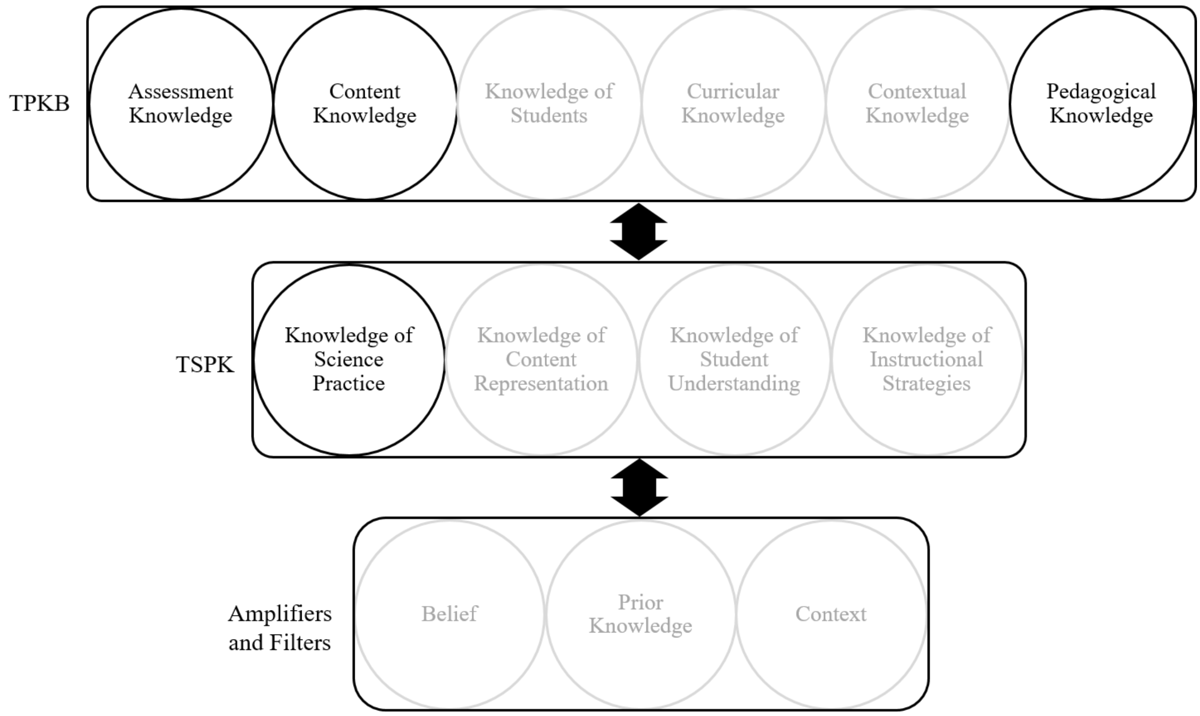
> Yeah, with two things. The first thing is by the [experiment] results, some of the groups got good results. They did perhaps see green (colour appeared in the base during practical in the test tube) and suddenly it changed to red (colour appeared in the same test tube), so there is a positive result. I have told them to copy things down from the board and we will be going over this again later. When I was asking, questions good answers were coming back, so that's good. (I-5)

The classroom data and the follow-up interview data together illustrated he assessed his students' work in the experiment 'there is a positive result' which indicates Assessment Knowledge. It is Assessment Knowledge because he set criteria [colour changing in the students' test tubes] to assess his students' skills. His Content Knowledge combined with Assessment Knowledge to confirm the correct result in the experiment. A similar assessment was observed in Lesson 7, he also assessed his students in the experimental activity. He announced during the activity, “Please follow the step of lighting a burner because I saw someone who didn’t do it correctly. So, do it correctly” (L-7). He observed those students in the previous classroom practice (in lesson 6) but announced it in lesson 7 which indicates his Assessment Knowledge. It is Assessment Knowledge because the result of the assessment modifies the instruction by revised the step of lighting the burner.

These data suggested that his Assessment Knowledge combined with his Content Knowledge to explain neutralization reaction, and his Pedagogical Knowledge combined with Assessment Knowledge to engage the students in learning of acid-base neutralization reaction through experiment. These combined knowledge components also combine with Knowledge of Science Practice to find the scientific facts in this experiment. The combined knowledge components are framed in Figure 5.4.

Figure 5.4

Assessment knowledge identified during experimental activity



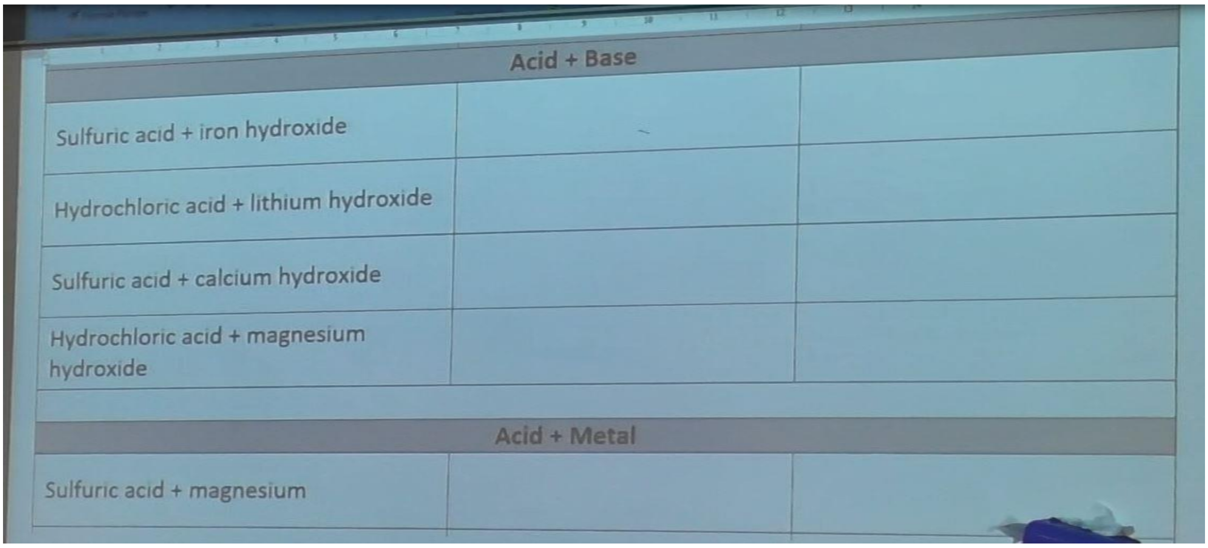
Note: The figure represents Philip’s combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination of knowledge components also combined with his Knowledge of Science Practice in the practical work.

5.3.4 *Assessing student understanding of reactions*

Philip designed PowerPoint slides for class assessment that reflected his Assessment Knowledge. In the last lesson of the topic (Lesson 12), he assessed the students' understanding of chemical reactions by using some ready-made questions that were projected on the screen of the classroom (Figure 5.5). The first page is divided into three columns. The first column has four reactions of acid-base. The second column is left blank for the products of these reactions. The third columns remain blank for writing the observations that were noted in the experiment. The strategy demonstrated his Assessment Knowledge because it reflects his knowledge to design the assessment. When he asked the students to fill the products in the second column but students were silent (L-12). The reason for silence in the class according to me because all four reactions were not taught in previous lessons. Even he asked students to tell me about anyone product in the first reaction. Finally, he started to fill those columns in the front of the class. After completing the first reaction, he involved the students to complete the products in the remaining reactions. He underlined the names of elements in reactions and asked the student what will the products? (Figure 5.6). He described the products will be formed as the result of those reactants indicate his Content Knowledge. It is Content Knowledge because working out the products in the given reactants are specific to the understanding of chemical reactions. He involved the students to find out the products in the results of those reactions to develop students' understanding about reactions which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it engaged the students in the learning. In this episode, the Assessment Knowledge was identified to design the assessment document that combined with Content Knowledge to select the items and explained to students while Pedagogical Knowledge combined for engaging the students in the find out products.

Figure 5.5

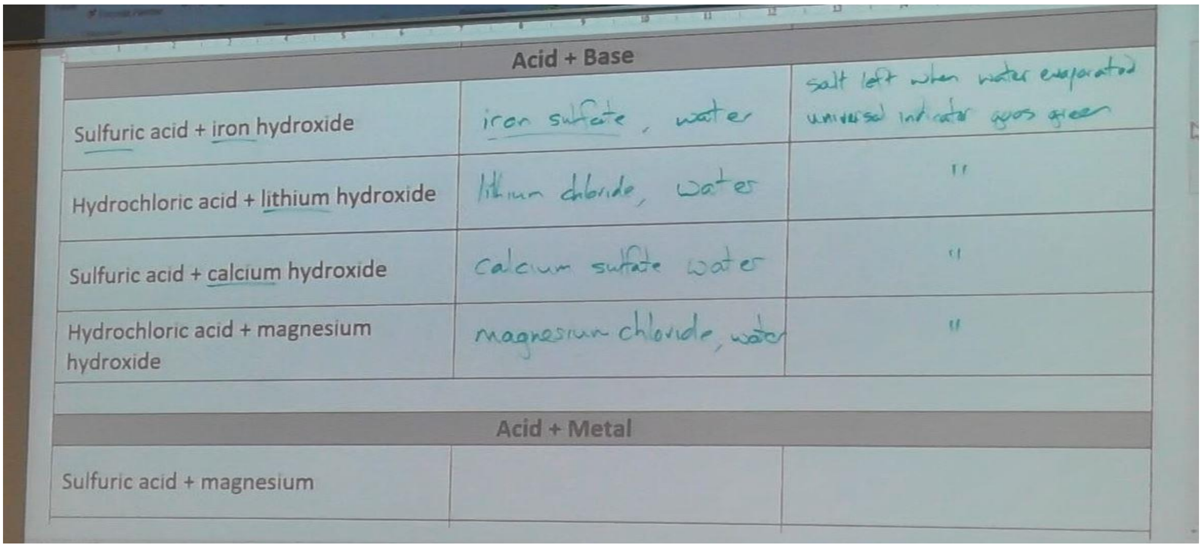
Philip prepared column filling activity for the students



Note: This snapshot was taken from lesson 12 to show the design of the assessment.

Figure 5.6

Philip filled the columns for the students



Note: This snapshot was taken from lesson 12 to show his implementing assessment design.

The next page consisted of some reactions of Acid + metal carbonates (L-12). All headings on these slides are relevant to the school curriculum but the reactions on the slide did not mention in the school curriculum, moreover, he did not teach these reactions in previous lessons. This thing probed in my mind if the reactions are not relevant to the school curriculum and he did not teach in previous lessons then how he will achieve the lesson objectives. I asked in the follow-up interview, how you know that you have achieved the objectives of this lesson? (I-12). He replied, “Mixed, still, I am not confident, lots of boys learned but they shouldn’t have learned. Even we do the same things for many periods. And still many of them have no idea what we doing” (I-12). This part of the assessment ‘lots of boys learned but they shouldn’t have learned’ shows he is not fully satisfied ‘even we do the same things for many periods’. Moreover, he was not sure about his achieving lesson objectives. On the other hand, he gave another reason when he discussed the results of the final topic test in the final follow-up topic interview.

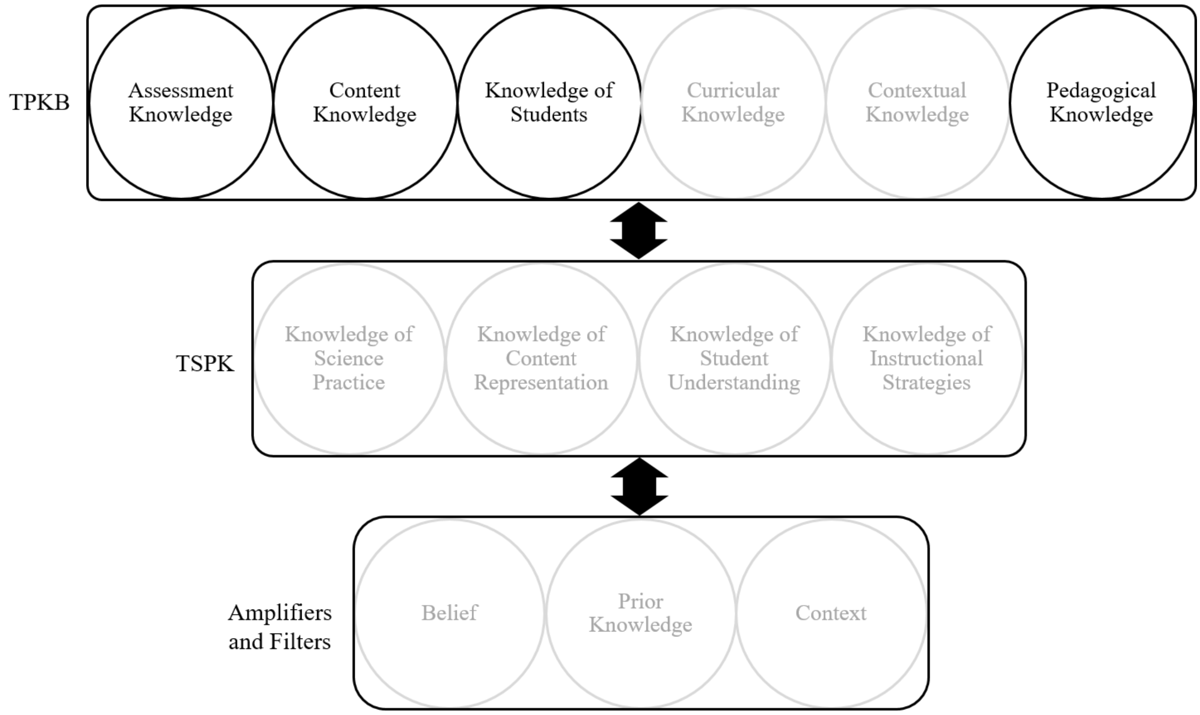
> Well, it varies topic by topic; there is one boy here, who got 75% but in all previous topic tests he was below 50% so, every student is different. Some like Chemistry, some like Biology, and some like practical Physics, so they do well in some topics and don’t care about anything else. This particular student didn’t care about the others and they enjoyed Chemistry very well. (F-I)

This statement indicates his opinion after marking the topic test of his students. He gave the example of one student and interpret the reason why he achieved good marks in this topic, ‘Some like Chemistry, some like Biology, and some like practical Physics’. He discussed a student’s achievement on the basis by comparing his previous marks. It is Assessment Knowledge because it reflected his understanding of the assessment method (i.e. Ipsative assessment and summative assessment) in the classroom. He highlighted why students’ get good marks in this test, ‘they enjoy Chemistry’ and ‘they do well in some topics and don’t care about anything else’ which indicates his Knowledge of Students. It is Knowledge of Students because it deals with students’ interest in learning.

These pieces of evidence reflect his Assessment Knowledge to design the assessment and assess the students, it combined with Content Knowledge to generate content-related questions in the assessment, Pedagogical Knowledge combined for engaging students to learn the chemical reactants and products, and Knowledge of Students combined to discuss their interest. This combination presented his PCK for assessing his students in the class which is framed in Figure 5.7.

Figure 5.7

Assessment Knowledge in assessing students' understanding of reactions



Note: This figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Knowledge of Students, and Pedagogical Knowledge) in his classroom practice for particular students.

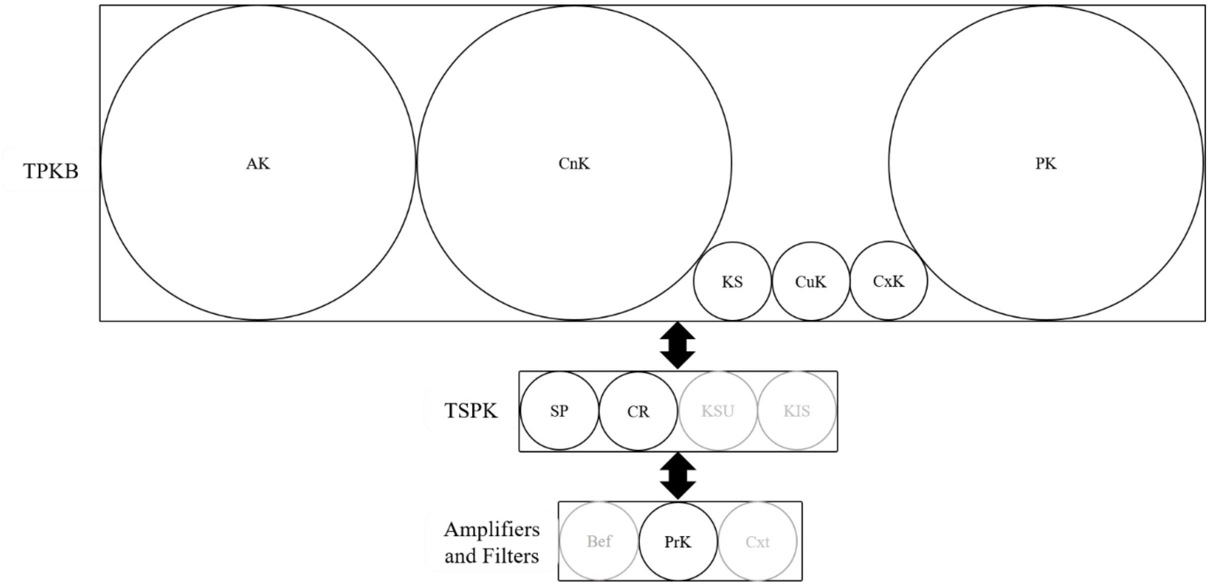
5.3.5 *Summary of Assessment Knowledge Focus*

Philip's combined Knowledge in his teaching is shown in Figure 5.8. The four figures (5.1, 5.3, 5.4, and 5.7) presented the knowledge combinations. These figures revealed that all knowledge components in TPKB were not combined equally with his Assessment Knowledge in the teaching of 'Acid and Base'. I compared these four combinations and check the involvements of knowledge components in combinations. Assessment Knowledge appeared in these pieces of evidence (4/4). There were four occasions when it involved Content Knowledge and Pedagogical Knowledge (4/4) Knowledge of Student, Curricular Knowledge, and Contextual Knowledge present once (1/4). The TSPK components: Knowledge of Science Practice and Knowledge of Content Representation both appeared once (1/4),. In amplifiers and filters, teacher's Prior Knowledge appeared once (1/4) and Belief and teacher's Context was not evident in these four figures (0/4). These numbers of components are represented in the form of the relative size of the circle (Figure 5.8).

I am aware that it is not the exact quantitative relationship among Philip's knowledge combination in combinations for his teaching. The diagram aims to represent the relative strength among them. Furthermore, the size of circles in TSPK are not representing the relationship with each other, it shows the strength with TPKB combination and vice versa. Likewise, the size of circles in Amplifiers and Filters are not representing the combination with each other actually, it presents their combining strengthen with combinations of TPKB and TSPK.

Figure 5.8

The relationship of Philip's Knowledge components to design and implement assessment



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

5.4 Content Knowledge

Content Knowledge in this research is considered as teachers' knowledge of academic content, and relationships among concepts within and cross-subject. Many topics and concepts are interlinked with other concepts within the domain of science, for instance, calculation of atomic mass is a concept in secondary school chemistry but physics deals with what is 'mass' and mathematics deals with its calculation. This section discusses Philip's combination of knowledge for teaching when his Content Knowledge is identified as prominent knowledge in his teaching of ‘Acid and Base’.

5.4.1 *Explaining roles of base in cleaning materials*

Philip’s explained the roles of chemicals in cleaning that reflected his Content Knowledge. He teaches chemistry to Years 9, 10, and 13 in this school and he performs administrative duty as a teacher-in-charge of NCEA science (Q-6). His schooling, chemistry teaching experience, and NCEA related duty experience reflected in his response in the pre-topic questionnaire (In general, how do you determine what to teach and what not to teach to your students?). He stated, “Curriculum (NZQA) sets the topics. The depth of coverage is vague, so past exams is an indicator of the depth” (Q-7). His chemistry background helped him to identify the ambiguous coverage of the topic and his knowledge of *The New Zealand Curriculum* helped him to find out its ‘indicators’ of content. In the questionnaire it was also asked ‘please give two examples of chemistry from society’ and he explained the daily life phenomenon with particular chemistry content. He reported these examples with chemistry content “Painting: mixing solvent water-oil base, Construction: Galvanising: Metal reaction and physical properties” (Q-17b). His descriptions of these examples with scientific terms indicate his Content Knowledge. It is Content Knowledge because the general chemical composition of paint and metal reaction involved in galvanizing is specific to the understanding of chemistry. These responses suggested that his chemistry teaching in the classroom, like, teaching would be exam orientated or give importance to those concepts which already appeared in past NCEA exam, and he could bring chemistry example from society into class.

I was able to associate his responses in the questionnaire and his classroom teaching. In Lesson 1, he used PowerPoint slides that show some photos of things that contain acid and base in them, like a bottle of baking soda, oven cleaner, toothpaste, etc. (L-1). The students looked excited and Philip tried to involve all students with displayed photos through questioning. He asked questions about those things and relate them to the lesson content (L-1). A bit of the question-answer session is presented here.

> T: What is another example (of a base in your home)? (He gave a hint) it should be in your bathroom
>
> S1: Toothbrush
>
> T: (he smiles) Toothbrush!

S1: No, toothpaste

T: Why do you think, toothpaste has a base in it?

S1: It cleans teeth

T: When you brush your teeth, there are many food particles in your teeth

S2: Yellow stuff

T: When food particles are in teeth, what (happen)?

T: Food particles in your teeth produce bacteria, bacteria excrete, and this excretion is often acidic. If you do not clean your teeth, your teeth will start decaying. So, you need to neutralize it. (He wrote toothpaste under the baking soda. He also wrote about the function of toothpaste.) Cleaning materials in your home are mostly basics, strong basic! You do not touch it with your hand because it creates corrosion. If you feel, soap or hand-wash is oilier or slippery it doesn't have a strong base. Which (cleaning materials) things you should not touch?

S3: Bleach

T: What are other things, which you may use in your kitchen?

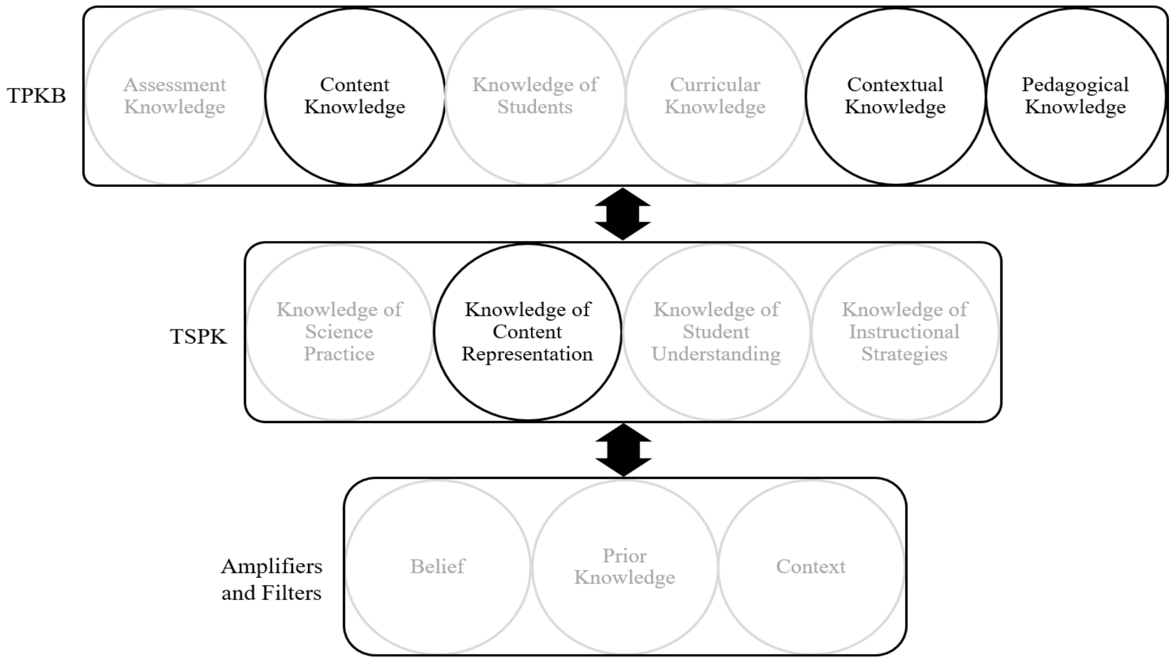
S4: Oven cleaner (L-1)

This episode shows that he used students' prior knowledge to clarify the concept of function of a base in toothpaste and made a connection between lesson content and their household things. His content expertise keeps the lesson in a direction to achieve the curriculum objective. He also clarified the functions of chemicals in the products that indicated his Content Knowledge. It is Content Knowledge because explaining the role of the base in toothpaste that uses for neutralizing the acidic material on teeth is specific to chemistry content. He relates the content with society and students' daily experiences, which indicates his Contextual Knowledge. It is Contextual Knowledge because it reflects his knowledge beyond the school context. He delivered the content by question-answers as pedagogy which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because he engaged the students through questioning to develop their understanding of acids and bases in daily usage things. He represented the content through multimedia which represented his Knowledge of Content Representation. It is Knowledge of Content Representation because it reflects his understanding of presenting content through photos, engage the students in the photos to develop their understandings of chemicals and their functions in the products. The combined knowledge (Content Knowledge, Contextual Knowledge, and Pedagogical Knowledge) is also combined with Knowledge of Content Representation in this teaching. There is a combination between TPKB and TSPK because the combined knowledge might have informed the teacher about appropriate representation methods while representation through displayed photos and engaged students in learning afforded to make the content visual and engage the students in questioning by using these specific photos.

In these pieces of data, explanation of chemicals in cleaning agents (e.g. base in toothpaste and its function) reflected his Content Knowledge. His Contextual Knowledge combined with Content Knowledge to bring content-related examples from context beyond the school, and his Pedagogical Knowledge combined with Content Knowledge to engage the students in learning. These combined knowledge components also combined with his Knowledge of Content Representation to present content through showing Photos. The combined knowledge is framed in Figure 5.9.

Figure 5.9

Philip's combined knowledge to generate content related example



Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Content Representation when he taught Acid at Home.

5.4.2 *Teaching chemical formulae*

Philip's explanation of chemical formulae in the classroom reflected his content knowledge. In Lesson 3 Philip explained, how to write chemical formulae. He asked students 'what is the meaning of numeric digit in the formula'. But there was no response from students. Then he started to develop their understanding of numbers in formulae (L-3).

> T: (He asked verbally) Formula of water is H_2O. What is the meaning of H_2O, and what is the mean of 2 (in this formula)?
>
> (Silence in the class)
>
> (Teacher wrote the formula of water on the whiteboard and repeated the same question)
>
> S1: Two hydrogen
>
> T: Yes, it means the number at the end means something. How many particles (atoms) of oxygen are in it (water molecule)?
>
> S1: Only one
>
> T: Yes! we can draw the formula (he started drawing the structural formula of water). We'll draw oxygen first and then hydrogen. The water molecule is like a numeric shape. Carbon dioxide is a little bit different (he drew the structural formula of carbon dioxide). I write carbon first and one oxygen on either side, it looks like a straight line, you will learn this (in detail) in level 2 Chemistry. (L-3)

This teaching episode illustrates he diagnosed students prior learning (i.e. assessment) through questioning. The questions helped Philip to acquire knowledge about students' requirements for writing a chemical formula (i.e. Knowledge of Students Understanding). He explained the numbers of atoms in the formula of water and carbon dioxide which indicate his Content Knowledge. It is Content Knowledge because explaining the numbers of hydrogen atoms and oxygen in the water molecule and elaborates it by drawing its structure is specific to chemistry content. He diagnosed the students' prior knowledge about chemical formula indicate his Assessment Knowledge. It is Assessment Knowledge because he assessed students' learning by using formative assessment. He engaged the students to work out what is meaning of numbers in the formulae which indicates his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflects his knowledge to engage students in chemical formula learning. To get an understanding of what students need to learn before writing chemical formulae indicate his Knowledge of Students Understanding. It is Knowledge of Students Understanding because it reflects his understanding of students' areas of learning difficulty to write a chemical formula. The combination of Content Knowledge and Assessment Knowledge help him to draw a benchmark for where this concept would start by investigating student learning difficulty. There is a combination between combined knowledge components of TPKB and Knowledge of Students Understanding because the combined knowledge of TPKB identified the students' areas of learning difficulty. Knowledge of Students Understanding afforded the teacher to develop the meaning of numbers in the chemical formula before starting to teach writing the chemical formula. The school curriculum expected students' learn to write the balanced chemical equation rather than to write chemical formulae. He may have an aim to develop their foundation to teach balanced chemical equations. Philip's subject expertise (i.e. teacher's context) amplifies his Content Knowledge. There is amplification because he drew the structural formula of water and carbon dioxide and their comparison seemed to deliver more chemistry content in teaching at this school level. Similarly, in the same lesson, he spent the time to calculate the number of atoms in the compounds and write the empirical formulae.

T: What is the formula of sulfuric acid?

S1: It is in the battery

T: Yes, it is in the battery but what is the formula?

T: It is H_2SO_4

T: How many atoms are there in one molecule of sulfuric acid?

S2: Six

S3: Seven

T: (Calculated the numbers of atom in the formula) Two Hydrogen, One sulfur (so on)

T: How much oxygen is in it?

S2: Four

T: Total of seven. (L-3)

This episode indicates his context amplifies the concept by calculating the atoms in a chemical formula. Furthermore, Philip extended that activity to calculate the number of atoms in ethanoic acid (CH_3COOH) and how to write its empirical formula (CH_2O) from its chemical formula

(L-3). It seemed in this lesson chemistry content everywhere but not relevant to the school curriculum. He explained the formulae of H_2SO_4, HNO_3, and number of atoms which are not in the school curriculum, when I asked in the follow-up interview, "You mentioned during teaching that some formulas are needed to be learned (for students) and some just the names of the formulas, why is that?" he explained,

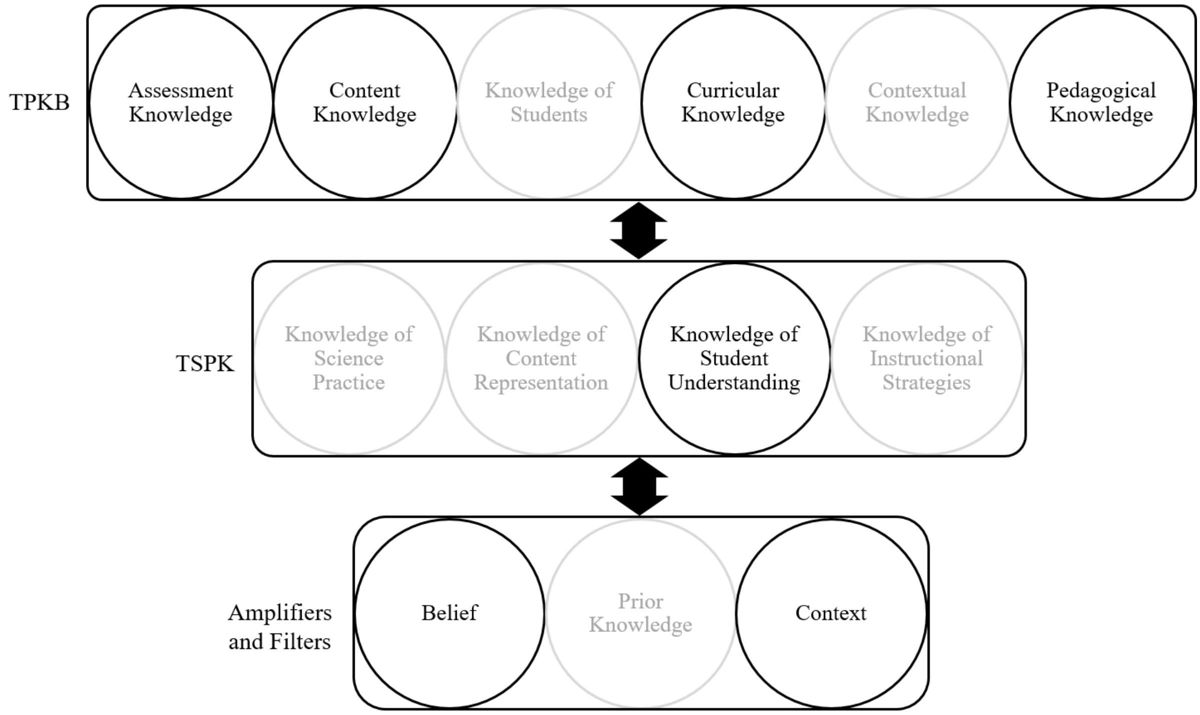
> Because the school syllabus from Wellington says, you must learn these ones for NCEA level 1. So, hydrochloric (acid) is the common one, sulfuric acid is the other common one. They used to have nitric acid, but that's been removed, but I still think it's important that students know that there are more than those just two acids. So, I give them some common ones, like vinegar or citric acid, that's why. So, I give them a bigger list than what they need. But I don't make them learn the formulas, this is a low ability class, two acids are all they need. (I-3)

Philip pointed that the school syllabus from Wellington (i.e. New Zealand Ministry of Education) recommends only two acids (hydrochloric acid and sulfuric acid). This reflected his Curricular Knowledge because it demonstrated his understanding of the requirement of the school curriculum from the government (i.e. curriculum structure). His belief about goals of science teaching at this level 'It's important that students know that there are more than just two acids'. This belief amplifies the concept because he 'give them a bigger list than what they need'. On the other end of the scale, he also admitted that 'this is a low ability class' which means it required to make the content simple and easy for them with reinforcement rather than the addition of extra content.

These discussed data reveal he is a content expert, so he presented the water molecule with its chemical formula and structural formula. The Content Knowledge combined with Assessment Knowledge to diagnose students' prior knowledge. His Curricular Knowledge combined with Content Knowledge to describe the requirement of the school curriculum. His Pedagogical Knowledge combined with Content Knowledge to engage students in the learning. These knowledge components of TPKB also combined with Knowledge of Students Understanding which afforded the teacher to diagnose the students' area of difficulty in learning of the chemical formulae. His chemistry background amplifies his teaching by calculating atoms in formula and present its empirical formula which is not part of the school curriculum. His belief about the purpose of learning common acids at this level also amplifies the content. This knowledge combination in these data is framed in Figure 5.10.

Figure 5.10

Philip's combined knowledge to teach chemical formulae



Note: This figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge). This combination of knowledge components also combined with his Knowledge of Students Understanding when he taught students to write the chemical formulae. The teacher's belief and context amplify this teaching.

5.4.3 *Giving instructions for practical work*

Philip's explanation of a chemistry practical that reflected his Content Knowledge. In Lesson 7, he said, 'today we will confirm through experiment that when an acid reacts with a base it will produce salt and water'. He involved the students to teach the procedure, collect the apparatus, and write the observations (L-7). A piece of that teaching is presented below.

> T: We are doing an experiment, it is the last experiment of the week. It is up to you we do it or not. In this experiment we are going to use a Bunsen burner, mixing chemicals, and very carefully using acid and base. [He draws the diagram, write the procedure on the whiteboard, but did not tell them what apparatus are going to use] What safety equipment should we use?
>
> S1: Safety goggles

T: Thank you very much [then he explained we need an equal amount of acid and base to get accurate results]

T: Who will tell me the name of the acid which we are going to use?

S2: Sulfuric acid

T: NO

S1: Hydrochloric acid

T: Now tell me the formula of Hydrochloric acid

S3: Cl_2

T: Not right

S2: HCl

T: Well done! The teacher picks the acid bottle and shows it to the students, HCl written on it. You need to know the formula

T: ‘H’ is the most important part it comes first, HCl, it starts with H

T: You need a test tube rack and one test tube. You need one bottle of hydrochloric acid and one bottle of sodium hydroxide. You need one measuring cylinder and one of this, what is this called?

S5: Evaporating dish

T: Well done, it is evaporating dish. It is used for?

S6: Evaporating dish

T: [Smiled]

S4: Acid

S1: Evaporating water

T: Yes evaporating water and what chemical left? [He gave options] Liquid, solid, gas

S7: Liquid

S1: Gas

T: Gas should be in the air; liquid converts into gas and a solid left

T: [Teacher shows equipment] you'll need one of these, what we call this?

S1: Tripod stand

T: Good

T: [He shows another equipment] what is it called?

[Silence in the class]

T: It's called a gauze. We'll quickly write down what we will do [He writes on the whiteboard Acid + base makes] what we call it?

S8: Sodium chloride

T: No, just general word

S2: A salt

T: Salt [he writes on board] what are we going to evaporate out?

S1: Water

T: You are going to prove this statement [Acid +base makes salt and water]

[Then he writes the title of the experiment, label diagram, procedure of the experiment, and at the end of the experiment he writes the observations of this experiment]. (L-7)

His explanation involved what pieces of apparatus were needed in this experiment, its procedure, chemical use in the experiments, reactants, and products of the reaction. The knowledge of chemistry experiments reflected his Content Knowledge. His teaching also emphasized safety measures in the laboratory. It reflected his Contextual Knowledge because he demonstrated his understanding of the New Zealand government policy that emphasizes the safety of laboratory work. He explained the theme of that day's experiment 'we are going to use Bunsen burner, mixing chemicals, and very carefully using acid and base' but did not completely describe the procedure about how to use the equipment, what types of the chemical will be used, how to mix the chemical. It seemed to me, he tried to arouse student curiosity about that experiment. The strategy indicates his Curricular Knowledge. It is may his Curricular Knowledge because the NZC suggest intellectual curiosity as the heart of *Thinking* [a Key Competencies in NZC], moreover, this competency also reflected in recommended pedagogy

"Effective teachers stimulate the curiosity of their students, require them to search for relevant information" (Ministry of Education, 2007, p. 34). He stimulated the students' curiosity and then engaged them in relevant information about that experiment by question-answer pedagogy. This reflected his Pedagogical Knowledge because he engaged the students in learning the experiment. He taught and conducted this experiment in this lesson. This experiment is not a part of the school curriculum when I asked in the follow-up interview "Why did you add this experiment in the planning because school planning shows neutralization reactions by adding universal indicators?" (I-7) he justified,

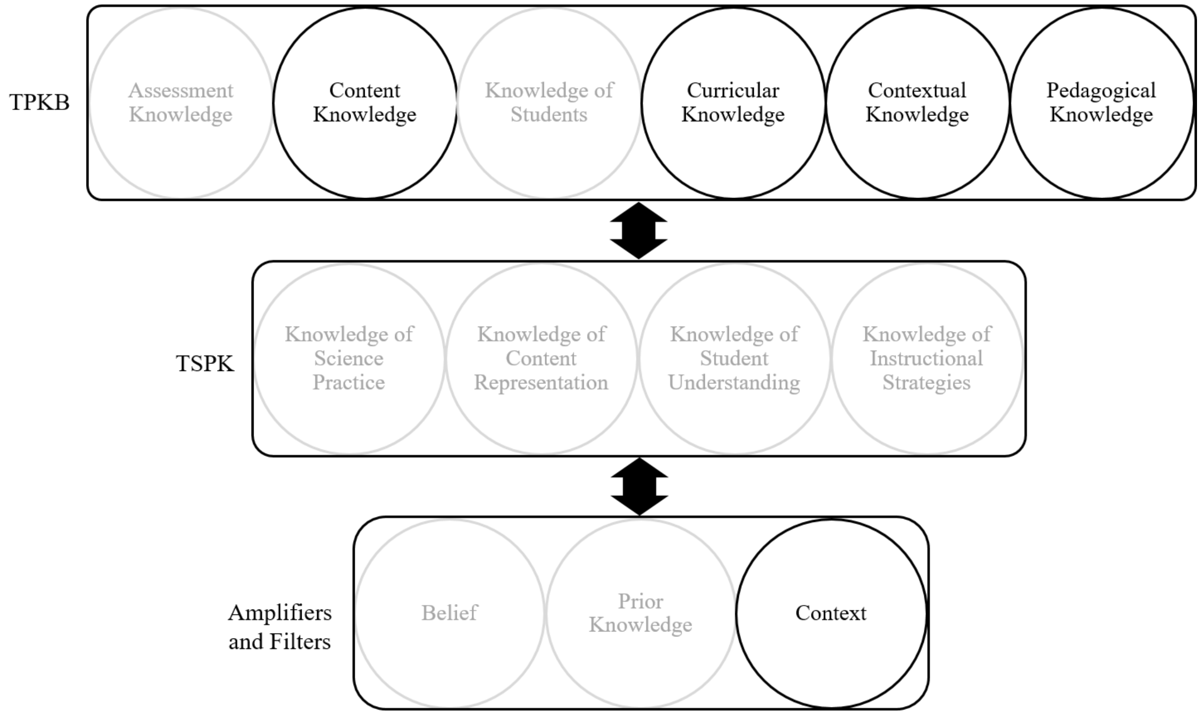
> Number one, I wanted to keep the experiment short. We have already used indicators previously so I didn't want to do it a second time, and besides as soon you use universal indicators you change the colour of the salt and therefore you are not able to recognize that sodium chloride has been made here, which is a white salt. (L-7)

This statement shows his Content Knowledge as he described pedagogical reasoning 'you use universal indicators you change the colour of the salt and you do not recognize that sodium chloride has been made here, which is a white salt'. This reflected his Content Knowledge because the description of the effect of universal indicator on salt is knowledge of using chemicals in a chemistry experiment. He said, he used universal indicators in the previous experiment [in Lesson 4] but the universal indicator did not use for neutralization reaction. The teacher's content expertise (i.e. context) amplifies his Content Knowledge in this episode. There is amplification because he adds the extra experiment in the topic of 'Acid and Base'.

His explanation of the experiment procedure for practical work reflected his Content Knowledge. His Curricular Knowledge combined with Content Knowledge to make coherence with the curriculum. His Contextual Knowledge combined with Content Knowledge to give priority to country health and safety policy. His Pedagogical Knowledge combined with Content Knowledge to engage the students to develop their understanding of the experiment. His Context amplifies the topic by teaching an extra experiment. The combined knowledge and amplifier for this teaching are framed in Figure 5.11.

Figure 5.11

Philip's combined knowledge components to teach an experiment



Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. The teacher's context amplifies his Content teaching Chemical Reaction.

5.4.4 *Assessing student learning*

Philip's Content Knowledge was identified as prominent knowledge when he assessed their students' learning. At the start of Lesson 6, he revised the poster-making project that was already discussed in Lesson 4. This time he explained poster size, font size, types of photos, type of information, and resources of information that would use on the poster. This explanation took half of the lesson time (approximately 30 minutes). Then he opened the textbook and asked some questions related to previous lessons and explained their answers. The teaching episode is presented below.

> [He read questions from the book and writes the answer on the whiteboard. It is just a revision of what he did last week. He counted the number of atoms in a formula. He starts writing on the whiteboard 'When Acid react…']
>
> T: When an acid reacts does it change or remain the same?

S1: Does it change!

T: We'll find out what does it can change into. When it reacts it loses something, what does it lose? Which part of the acid is reactive?

S2: Oxygen [after a while] Carbon

T: What most of the acids have in common?

S2: Carbon; S3: Hydroxide; S2: Metal

T: Look at your acid in last week. [He opened a student's notebook] look at the 28th of Aug

S3: Hydrogen

T: [He write on the whiteboard: It loses hydrogen]. What is the formula of sulfuric acid?

[Silence in the class]

T: H_2SO_4 [he speaks loudly, and students repeat after him]

T: When sulfuric acid reacts, it loses its hydrogen. Look at the formula, what is left?

S1: SO_4

T: He rubbed hydrogen from the formula of H_2SO_4 and write it separately. It is a hydrogen ion or in other words, it is a charge. How many hydrogen ions are removed?

S4: two

T: Writes on the front [of hydrogen charge like $2H^+$]

[He asked the same questions to work out SO_4^{2-}]

T: What is the difference between H-two and H-plus-two? [He was also indicating toward written H_2 and H^{+2} on the whiteboard]

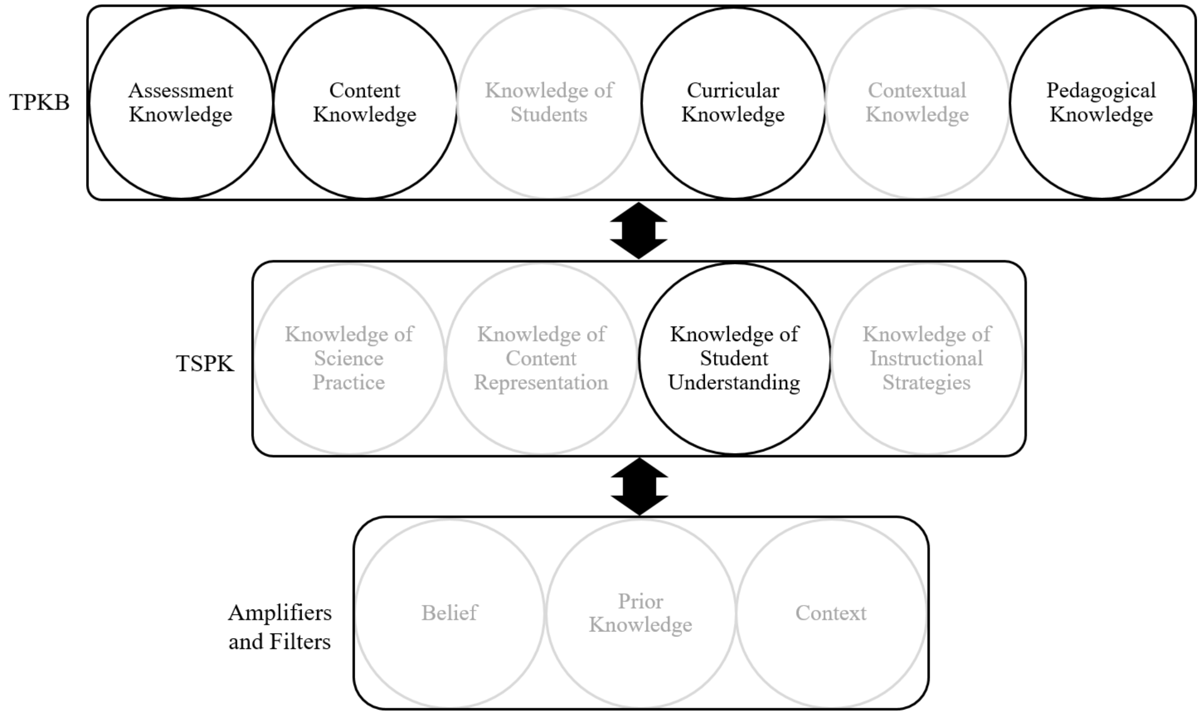
T: If you find 2 in front of a symbol [e.g. 2Mg], it means two times of everything behind it. If 2 is at the end of any symbol [like H_2] then it means two [atoms] join together [he draws the H-H on the board]. (L-6)

This teaching episode illustrates he developed the students' understanding of how acid reacts at particle level in a chemical reaction. He discussed an acid split into its positive and negative ions, the meaning of digits in the formula, and work out the part of the acid that is reactive. This reflected his Content Knowledge because he explained the content related to a chemical reaction that demonstrated his understanding of chemical reactions. He assessed the students' prior knowledge about acid by asking questions. This indicated his Assessment Knowledge because he implemented formative assessment to diagnose the students' prior knowledge. He developed the concept (how acids react) among the students by asking questions and elaborated on their answers. This reflected his Pedagogical Knowledge because he engaged the students in working out the part of an acid that was reactive. He connected students' understanding of acid and connect it in today's lesson. This reflected his Curricular Knowledge because it is coherent with NZC recommended pedagogy. He wrote the title of that day's lesson as "When Acid reacts…" then he asked series of questions (i.e. pedagogy) about acid's split into its ions (i.e. content) that seemed he tried to know the students' area of learning difficulty. This indicated his Knowledge of Students Understanding because he investigated the students' understanding of this concept. The combined knowledge components of TPKB (Assessment Knowledge, Pedagogical Knowledge, Content Knowledge, and Curricular Knowledge) also combined with Knowledge of Students Understanding for this teaching. There is a combination between TPKB and TSPK because the combined knowledge informed the requirement of students' learning through asking questions while Knowledge of Students Understanding afforded the teacher to start the concept after making the foundation of 'how acid react'.

Herein, his Content Knowledge with various knowledge components, namely, his Assessment Knowledge contributed to diagnosing students' prior knowledge, his Curricular Knowledge contributed to pedagogy recommended by *The New Zealand Curriculum*, and his Pedagogical Knowledge contributed to engaging students to work out the part of acid that was reactive. These knowledge components of TPKB are also combined with Knowledge of Students Understanding to assess the students'. The combined knowledge components are framed in Figure 5.12.

Figure 5.12

Philip's combined knowledge components in teaching of chemical reaction



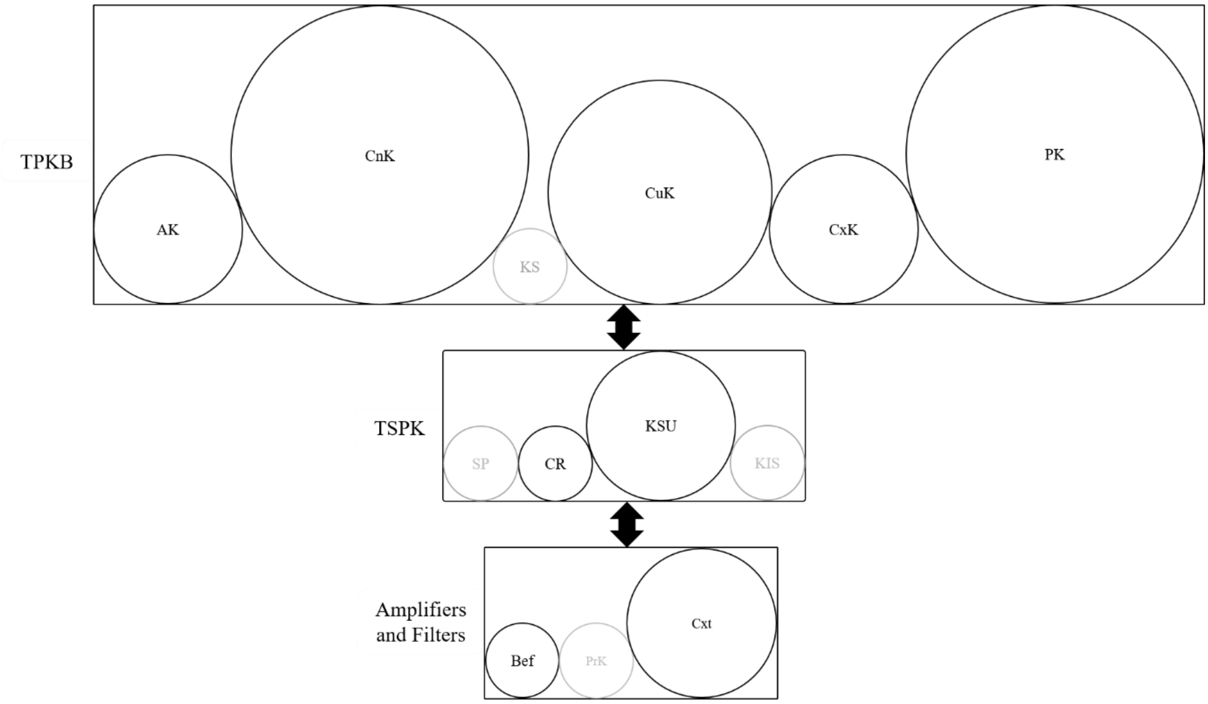
Note: The figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination of knowledge components also combined with his Knowledge of Student Understanding in the teaching of chemical reactions.

5.4.5 *Summary of Content Knowledge focus*

The four figures (5.9, 5.10, 5.11, and 5.12) represented the knowledge combinations in different episodes. The knowledge components in TPKB did not contribute equally in the combination. His Content Knowledge and Pedagogical Knowledge appeared in all these figures (4/4). His Curricular Knowledge appeared three times (3/4). His Assessment Knowledge and Contextual knowledge both appeared two times (2/4) while his Knowledge of Students was not evident (0/4). Of the TSPK components: Knowledge of Student Understanding appeared two times (2/4) and Knowledge of Content Representation appeared once (1/4) while Knowledge of Science Practice and Knowledge of Instructional Strategies were not evident (0/4). Of the Amplifiers and Filters: teacher's Context appeared two times (2/4) and the teacher's Belief appeared once (1/4) while Prior Knowledge was not evident. Not evident components are presented grey colour.

Figure 5.13

Philip's PCK when Content Knowledge as a prominent component in his teaching



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

The Knowledge of Students did combine with the Content Knowledge component in this data. The Knowledge of Students is less visible in his classroom practice sometimes it is identified as a prominent component in teaching. The upcoming section discusses Philip's knowledge of students as a prominent knowledge in his teaching.

5.5 Knowledge of Students

Experience contributes to teachers' PCK (Mavhunga & Rollnick, 2016; Neumann et al., 2019). Philip has been teaching chemistry at the same school for more than 20 years that experience might have developed his Knowledge of Students. This section discusses Philip's Knowledge of Students as a prominent knowledge in the Teacher Professional Knowledge Base (TPKB). I also discuss the way that his Knowledge of Students combined with knowledge components in TPKB and with components of TSPK in his teaching.

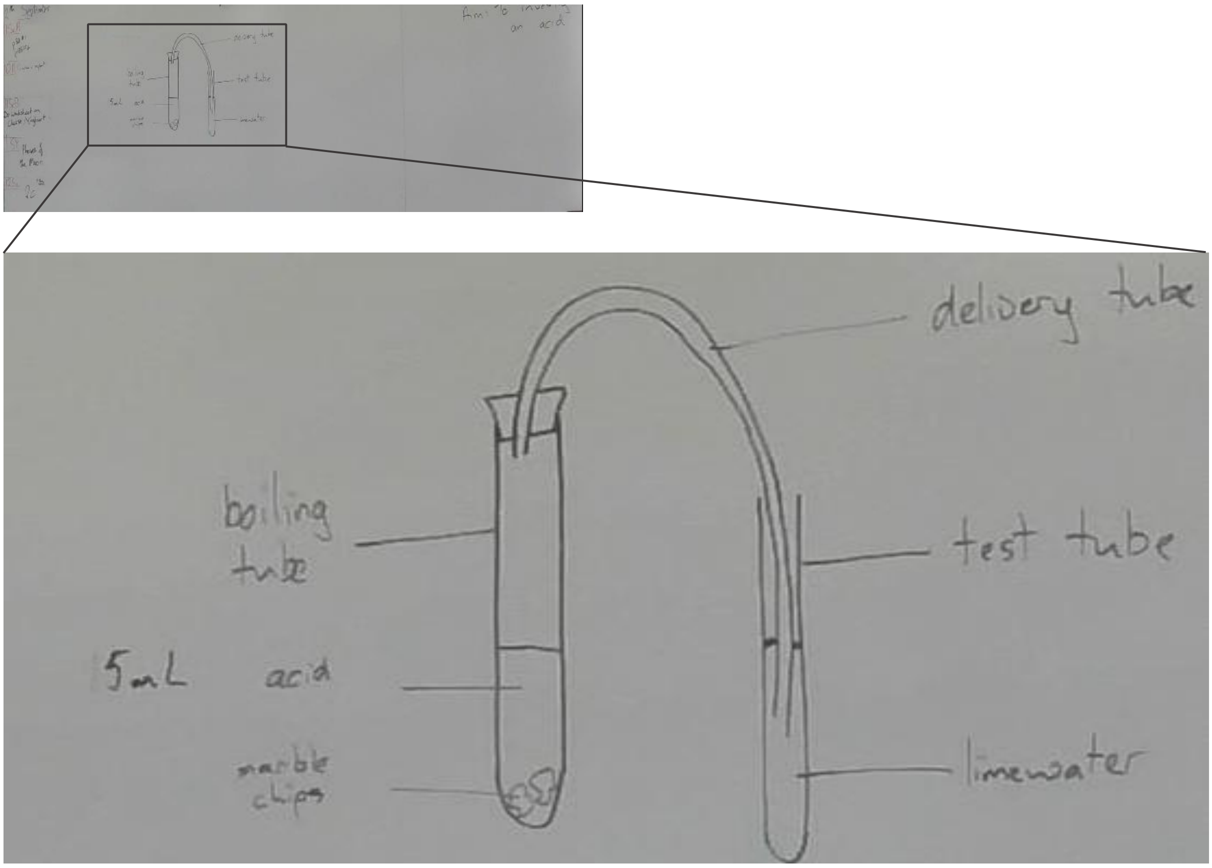
5.5.1 *Planning and conducting teaching practice*

The pre-topic questionnaire data indicated that Philip has taught the observed class in the previous academic term, “Having taught them for 6 months, I know their work habit and interest levels” (Q-13). He elaborated, “[t]hey are generally a low ability class, but keen to learn. They will learn things; they can see and if the diagrams are drawn” (Q-14). The school authority informed him of the class as a ‘low ability class’. The second part of this statement reflects Philip’s acquired knowledge about these students they ‘keen to learn’, ‘they will learn things’ and their ‘habit and interest levels’. It is Knowledge of Students because it reflects the teacher’s knowledge about the interest of these students. It seems the role of Knowledge of Students to plans his teaching according to their interest ‘draw the diagrams’.

I was able to associate his thinking that reflected in the responses to questions in the pre-topic questionnaire and his classroom practice. An example of this association can be observed in Lesson 10. At the start of Lesson 10, he revised the reactions of magnesium with sulfuric acid and the reaction of calcium with hydrochloric acid, which he has taught in Lesson 9. After the revision, he wrote on the whiteboard, “Acid + Carbonate” (L-10). According to the school curriculum, students were expected to “identify products, write the word and balanced symbol equation for Acid + Metal Carbonate” (SC). He lifted the projector screen and there was on the whiteboard a labeled experiment setup diagram for this reaction (screenshot of this diagram shown in Figure 5.14). In the diagram, there were a boiling tube and a test tube. They were connected through a delivery tube. The boiling tube contained acid and marble chips while the test tube contains lime water (L-10).

Figure 5.14

Philip Drew this Diagram in Lesson 10



Note: This screenshot is captured from the video of Lesson 10.

He drew this diagram on the whiteboard behind the projector screen before the lesson. He hid the diagram from students until he explained the title of this reaction. The students were excited to see the diagram. From my perspective, he hid the diagram from students because students could focus on the revision and students would not be distracted by the diagram. In the follow-up interview, he explained why he drew that diagram before the class started,

> To save time, and also I can make a good job of it, so the students know what they should be drawing. And even walking around I still saw all sorts of funny-shaped diagrams but I do what I can to get things organized. I knew there will be students, as soon as I turn my back, they do silly things so I just try to prevent that sometimes and it was one of those times. (I-10)

After showing the diagram, he told the class, “What do we need for this practical by using the diagram and actual equipment?” (L-10). He brought the apparatus on the table and arranged them by using that diagram and demonstrated the practical for the students. He put marble chips in the boiling tube and poured some hydrochloric acid in it. There were some bubbles in the solution. Then, some gas bubbles came out from the delivery tube in the test tube. The lime water turned 'milky'. He announced it turned milky because of the reaction gave out carbon dioxide. Then, he engaged the students to work out the word equation of the reaction with students. He wrote the reactants and left three blanks for products: Hydrochloric acid + Calcium carbonate → ______ + ______ +______. He asked the students what three products of this reaction were. The students were silent. He wrote and said, 'they formed carbon dioxide and water. What is the remaining one?' He pointed at the *calcium* in calcium carbonate and *chloric* in hydrochloric acid and wrote *calcium chloride* in the reminding blank (L-10). This episode showed that he was keen to help students to learn through demonstration rather than through verbal explanation only. The act of drawing the diagram for students indicates his Knowledge of Students. It is Knowledge of Students because he was aware of students' learning style, '[t]hey will learn things, they can see, and if the diagrams are drawn'. The selection of the teaching method 'draw the diagram' from his repertoire of teaching methods indicates the role of Knowledge of Students in teaching. Drawing the diagram in advance and hid it behind the screen while not teaching the reaction indicate his Pedagogical Knowledge. It is Pedagogical Knowledge because he planned this lesson according to students' interest. He asked students about the products to complete the equation. These teaching strategies reflected his Pedagogical Knowledge because he engaged the students in the learning by questioning. He demonstrated to students a strategy to work out calcium chloride as a product. The teaching of the strategy reflected his Content Knowledge because working out products from a chemical reaction was specific to the chemical understanding. The reaction was presented through: showing the diagram, demonstration and working out the word equation. In the diagram presentation: students could see the arrangement of apparatus and the name of the reactants (Figure 5.14). In the demonstration, students could observe the fizzing in the marble pieces, gas evolved in the boiling tube and lime water turned into milky. Nevertheless, it did not guarantee that the students knew the three products. In the word equation, it represented the name of the products. These three modes of representations (i.e. the diagram, the demonstration, and the word equation) seemed reflected his Knowledge of Content Representation because it demonstrated his awareness of what instructional strategies would better work for these students. As he claimed, "They will learn things, they can see and if the diagrams are drawn" (Q-14), and "[…] I think the other thing is, with this class, they like to do practical things" (I-4).

The pieces of evidence suggest that he knew his students well enough Knowledge of Students such that he planned and conducted his lesson accordingly. He avoided distracting the students and kept them focus on the revision (i.e. Pedagogical Knowledge), and represent the content through the diagram, the demonstration, and word equation (i.e. Knowledge of Content Representation). He seemed to know these students (i.e. Knowledge of Students) about how ‘they will learn things’. These pieces of evidence suggest that a combination of his Knowledge of Students and Pedagogical Knowledge for teaching.

The combined Knowledge of Students, Pedagogical Knowledge, and Content Knowledge also combined with his Knowledge of Content Representation to represent the content. His teaching reflected that he has considered these questions: What did the diagram (i.e. a representation) help students to learn about the experimental setup of the reaction (i.e. content)? How should the diagram (i.e. a representation) be shown to students (i.e. pedagogy)? There was a combination because the combined knowledge might have informed the use of the diagram as the most appropriate form of representation for these students in introducing the experimental setup, and the diagram afforded the teacher to use questioning as a pedagogy to develop students’ understanding of the apparatus that was needed.

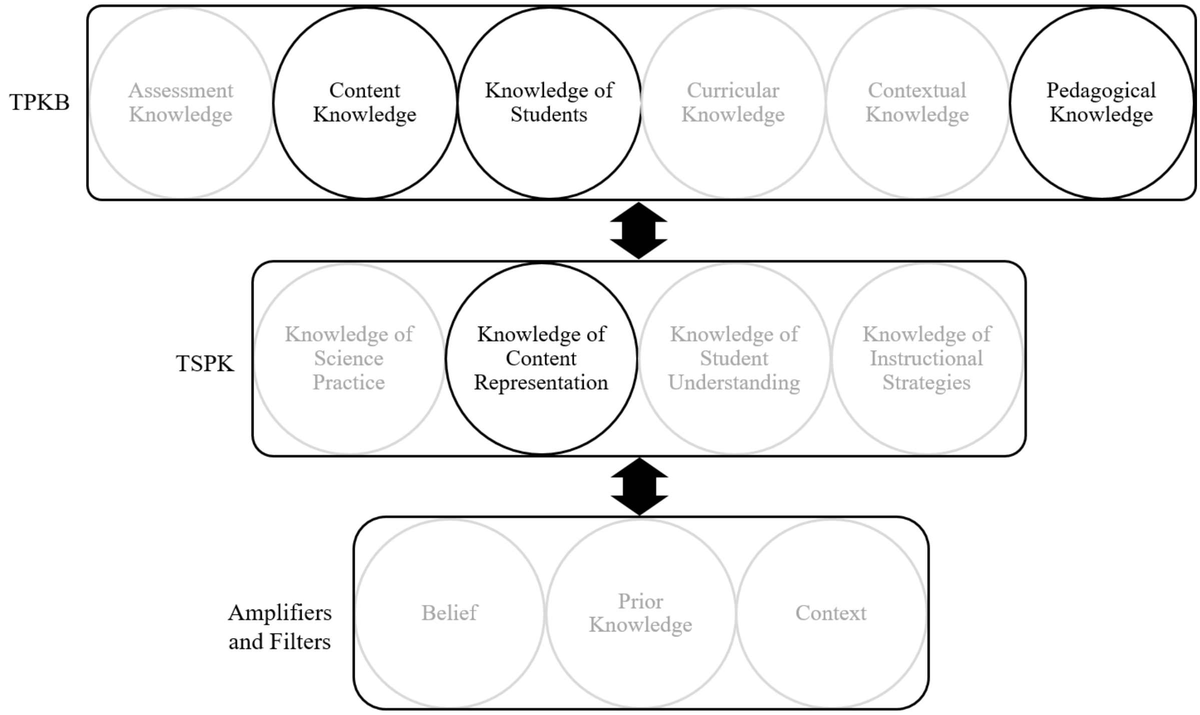
He linked the diagram with the demonstration by asking questions ‘What do we need for this practical by using the diagram and actual equipment?’ He set up the apparatus according to the diagram. The demonstration (i.e. representation) showed what happened in the boiling tube and test tube (i.e. content). There was also a combination because the combined knowledge might have informed the use of the demonstration as an appropriate method to show the reaction; while the demonstration afforded the teacher to show the formation of gas from reactants to enhance the students’ understanding of reaction.

He showed the experiment setup diagram first, then he demonstrated the reaction, and finally, he presented the reaction by using word equation. The content presented through diagram and demonstration were not fulfilling the school curriculum requirement “identify products, write the word and balanced symbol equation for Acid + Metal Carbonate” (SC). The combined knowledge might have informed the use of the word equation (i.e. a representation). There was a combination because the combined knowledge informed the use of the word equation as the content representation for this low ability class to fulfil the school curriculum requirement while the word equation afforded the teacher to point the *calcium* in calcium carbonate and *chloric* in hydrochloric acid to wrote the calcium chloride in the products by engaging students for their understanding.

This knowledge combination in the TPKB and with TSPK reflects his PCK for particular students. The combination of knowledge components is framed in Figure 5.15.

Figure 5.15

Philip's combined knowledge components to plan and conduct teaching practice



Note: This figure represents Philip's combination of TPKB knowledge components (Knowledge of Students, Content Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination of knowledge components also combined with his Knowledge of Content Representation in the teaching of the 'Acid + Carbonate' reaction.

Philip's combined knowledge components (Knowledge of Students, Content Knowledge, and Pedagogical Knowledge) of TPKB combined with Knowledge of Content Representation of TSPK in particular teaching.

5.5.2 ***Motivating Students***

Philip's preferred word equations to chemical equations when he explained chemical reactions reflected his Knowledge of Students. He taught two concepts in Lesson 8, "what happens when an acid reacts", and "Testing Litmus Indicator" (L-8). He asked the class, "we can do it by word equation and chemical equation" (L-8). The students gave preference to the chemical equation. He introduced the chemical reaction with word equation and balancing chemical equation [$HCl + NaOH \rightarrow NaCl + H_2O$] for describing 'what happens when an acid reacts' (L-8). He engaged the students through questioning as pedagogy to elaborate on how HCl reacts. The following fragment of teaching illustrated those questions.

> [He explained which part of the acid is reactive. He wrote HCl on the whiteboard and asked students which part of acid is reactive]
>
> S: Cl
>
> T: Remember, hydrogen is a reactive part of acid. He emphasized the definition of acid: 'Donate hydrogen or give away hydrogen'.
>
> T: When hydrogen is released it has a charge, what charge it has?
>
> [Silence in the class]
>
> T: Positive or negative?
>
> S: Positive
>
> T: If hydrogen is positive then what charge is on chloride?
>
> S: Negative
>
> T: They have opposite charges, the reason of that together they make neutral. There is no charge here [he drew a circle around HCl with his finger]. (L-8)

This teaching episode illustrates that he developed a foundation to teach chemical reactions. He taught chemical reactions with balancing chemical equations after asking his students' choices. This reflected his Knowledge of Students because he considered students' interest in learning. He diagnosed students' prior knowledge by asking questions. This reflected his Assessment Knowledge because he implemented an assessment strategy. He corrected his students' responses and generated relevant questions. This reflected his Content Knowledge because he explained dissociation of HCl into H^+ and Cl^- are specific to chemistry content. He made a connection of students' prior knowledge about ionization with the current concept. This reflected his Curricular Knowledge because it has coherence with *The New Zealand Curriculum* recommended pedagogy "Making connections to prior learning and experience: Students learn best when they are able to integrate new learning with what they already understand" (Ministry of Education, 2007, p. 34). The connection between students' prior knowledge with the current concept by adopting questioning. This reflected his Pedagogical Knowledge because this strategy engaged his students in learning of dissociation components of HCl. In the follow-up interview, he highlighted some reasons why he engaged the students,

> This is the low ability class, science is not high in their experience or interest, and besides, they are interested in it is made fun, and I think if you want them to learn you've got to be enthusiastic all the time. (I-8)

It shows that he engaged the students because he knew the students' interest in science is not high, moreover, 'they are interested in it is made fun'. This awareness reflected his Knowledge of Students because it related to students' interest in classroom learning. He reached a solution to deal with his students through a teaching strategy 'if you want them to learn you've got to be enthusiastic all the time' in the classroom. This reflected his Pedagogical Knowledge because this strategy was related to class management and students' engagement in learning. The classroom observation and follow-up interview data suggested a combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge) in his teaching practice to achieving a core objective of teaching 'you want them to learn'.

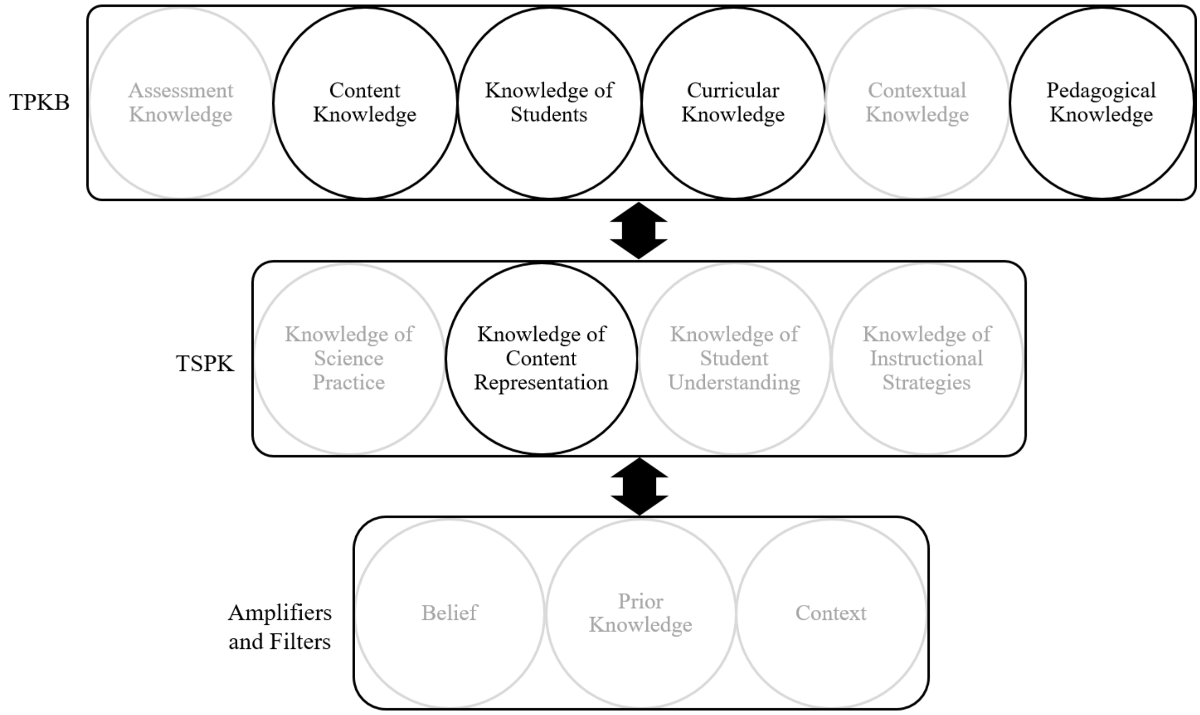
In Lesson 8, he taught by using word equations and balancing chemical equations. It may happen because his class wanted to learn it through balanced chemical equations. On the other hand, his Knowledge of Students might have informed to teach chemical reactions through word equation because he knew the ability and interest of these students in science was low. The observed lesson data suggested mostly he adopted word equation as an appropriate method for these students to teach chemical reactions. For example, in Lesson 5, "Hydrochloric acid + Sodium hydroxide and you get salt and water; I write water and find out what salt we get?" (L-5). In Lesson 7, "Hydrochloric acid + Sodium Hydroxide → ____+____" (L-7). For explaining the word equations in the classroom Philip wrote the reactants and asked the students to work out to find the products. Sometimes he gave clues completing the products e.g. 'I write water and find out what salt we get'. It knocked my head why he gave preference to word equation on balancing chemical equation because the school curriculum expected the teacher to teach the reactions by using word equations and balancing chemical equations. As a chemistry teacher, I interpreted some pieces of knowledge working in his mind were not completely explicit. So, I asked why you explained chemical reactions with word equations only (I-11) then he said,

> For this level, all they have to do is write equations because it's simple; soon it goes to chemical equations that have too many numbers for them to remember. So that's just the kind of low band class so I keep Chemistry simple. They only need to know the formulas; they don't need to know how to use the formulas. (I-11)

This statement illustrates his Knowledge of Students helped him to highlight the students' attributes 'this level', 'the kind of low band class' and planned his teaching accordingly. He planned to keep the 'chemistry simple' (i.e. Pedagogical Knowledge) accordingly he chose the content representation 'word equations' (Knowledge of Content Representation). There is a combination of combined knowledge of TPKB components and Knowledge of Content Representation because combined knowledge informed teachers to decide to present a chemical reaction through a word equation rather than a balanced chemical equation. This representation afforded the teacher to ignore the complexity of the numbers involved in the chemical equation and kept chemistry simple for these students. This combination of knowledge was not visible in the classroom practice because of the tacit nature of PCK (Park & Chen, 2012). It is tacit because in the classroom he was teaching word equations but why he did. The reason was explored in the interview. This combination of knowledge components for presenting the chemical reaction in the classroom indicates Philip's PCK in the classroom practice. These pieces of evidence suggested a combination of TPKB knowledge components with Knowledge of Content Representation shown in Figure 5.16.

Figure 5.16

Knowledge combination for teaching word equations



Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination also combined with his Knowledge of Content Representation in the teaching of word equations.

5.5.3 ***Addressing students' behavioural issues***

Philip solved class management issues by considering students' behaviour reflected his Knowledge of Students. He was well aware of behaviour of this class as his thinking reflected "it's a very challenging class" (I-1). This thinking would help him to address the issues in the classroom. He discussed different challenges with the class in the classroom,

> For this class, it's not the content, it's more about the management of the students which is probably the most important thing. If you can't manage this class then they are not going to learn anything and then you've got to keep on top of them, you have got to keep on pushing them. Otherwise, they could not get their hands off and those who want to learn will not learn. (I-1)

This statement shows his belief about the importance of managing the class for teaching 'which is probably the most important thing', moreover, 'if you can't manage this class then they are not going to learn’. He highlighted content is not an issue for them but managing them for learning is a problem. This is Knowledge of Students because it reflected his understanding of an area of strength and weakness of these students. He interlinked class management with students’ learning. He pointed a strategy to engage them ‘you have got to keep on pushing them’. This reflected his Pedagogical Knowledge because the purpose of ‘pushing’ seems t to engaging the students in the learning.

Some management issues were also noted in Lesson 9. At the start of this lesson he was busy with another person in front of the class, meanwhile, some boys were playing fighting in their benches (L-9). When other person went from the classroom, he said to the class,

> I was busy to talk to someone in front of the class and I do not expect some behavior to play fight [he indicates towards a particular student group] or anything like that in class…. I expect a little bit more responsibility or maturity than I have seen so far. (L-9)

In the follow-up interview, he described why it happened and how it influenced his lesson planning and teaching,

> Tuesday afternoon, Wednesday afternoon, both times the boys were unsettled, so the usual waiting and waiting for them to settle down. I think that’s the main thing – straight after lunchtime, still quite a lot of energy, yeah that was it. It was lunchtime before, they’ve still got a lot of energy, and they just needed to settle down. The kids were outside just before the class started, to just get them into order and not just coming in a higgledy-piggledy kind of format, so I did want them settled before they come in, but it didn’t work. (I-9)

This statement exemplifies the school context and students’ behavior that have impacted his teaching. He pinpointed a cause of disturbance in the classroom is lesson timing because students attend this chemistry period ‘straight after lunchtime’. This reflected his Contextual Knowledge because it was about the school setting. In my point of view, the other factor for this situation was his discussion with another person without assigning any work to students but he only blamed to class with some excuses. In that disturbing situation, he evaluated the classroom context as a ‘higgledy-piggledy kind of format’. He handled this situation by dictated 10 questions related to acid and base. He gave some time to students for writing the answers to these questions. After that, he started asking students to share their written answers (L-9). He explained why he adopted the ‘questions quiz’ strategy in the class,

> If I didn't do that the students just make a lot of noise. So I had to give them something to do and in this case, that was to prepare a ten-question quiz, which I was going to do anyway but this worked that I do the quiz and the detention as well. (I-9)

This statement indicates that he analysed the situation and engaged students 'a ten-question quiz' (i.e. Pedagogical Knowledge) and prepared questions related to acid and base (i.e. Content Knowledge). Similarly, in Lesson 4 he arranged a practical to examine strong and weak acids and bases. He organized the relevant apparatus and safety glasses on the teacher table for students but suddenly Philip cancelled that practical (L-4). When I asked a question in the follow-up interview to understand the reason behind this cancellation, he said,

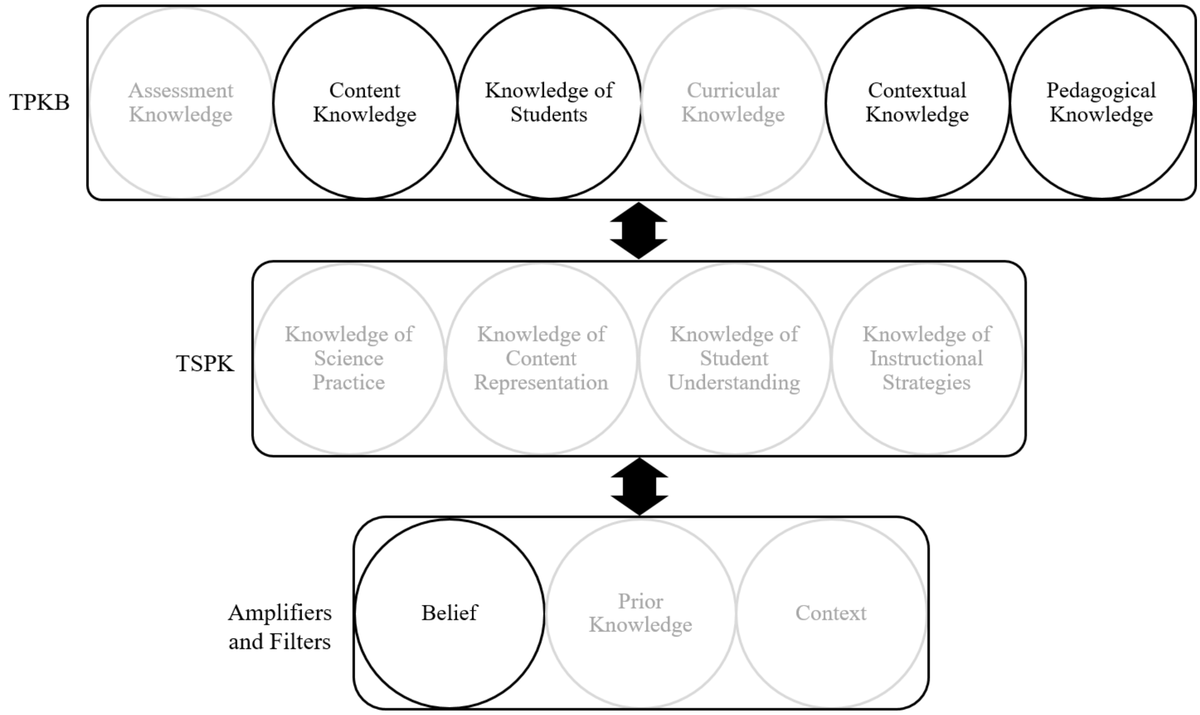
> Six or seven students scattered around the room, they were not paying them attention. One of the important things about science experiments is safety, if you can't trust the class, you can't do something. So, I did not feel that I can trust this class at that time…They got too much energy, so as a teacher you have to be aware of what they can do and what they can't do, and adapt the lesson accordingly. (I-4)

This statement highlights management issue impacted his teaching. He thought this is not a perfect time to continue for that practical, "So, I did not feel that I can trust this class at that time. Friday morning, I think they'll be able to do some more practical work than today" (I-4). When I investigated further [If, on Friday morning the class behave same, will you postpone the activity again?] then he replied, "No, if this happens second time, then the experiment is out, and I'll just give them book work for the next week also" (I-4). That practical was filtered from Lesson 4 because he has belief class management is the most important thing before teaching 'If you can't manage this class then they are not going to learn anything'.

These pieces of evidence suggest that he knew his students well enough such that he planned and conducted his lesson accordingly. He addressed his students' behaviour (i.e. Knowledge of Students). He adopted 'question quiz' to engage students (i.e. Pedagogical Knowledge), and represented the content through a quiz (i.e. Content Knowledge). He was aware that the lesson timing was not suitable for chemistry experiments (i.e. Contextual Knowledge). He thought class management was important for teaching (i.e. Belief) that filtered practical in that lesson. The combination of knowledge components identified in these pieces of evidence is framed with black colours in Figure 5.17.

Figure 5.17

Combination of knowledge in managing students' behavioural issues in the classroom



Note: This figure represents Philip's combination of knowledge components (Content Knowledge, Knowledge of Students, Contextual Knowledge, and Pedagogical Knowledge) in his classroom for particular students that identified during managing students in a particular situation. His Belief filtered a practical from that lesson.

5.5.4 ***Acquiring Knowledge of Students***

The consensus model shows that TPKB and TSPK components would develop after classroom practice (see section 2.3.5). After analysing his own topic teaching, he identified and discussed the best teaching strategy in the classroom for these students reflected his development in his Knowledge of Students. The data indicated some development in Philip's knowledge of TPKB in his reflective process. In Lesson 2, he showed some names of acids and their formulae through PowerPoint slides. One slide was displayed names "sulfuric acid, hydrochloric acid, nitric acid, ethanoic acid, phosphoric acid and methanoic acid' (L-2). He asked the students about the formulae of these acids. He was pronouncing the name of acid slowly but in loud voice like *sulfuric acid.* He was also helped his students for working out its formula, then formula of sulfuric acid was appeared on the slide. He was well aware of the learning ability of the students. This reflected his Knowledge of Students because he used PowerPoint slides with segmental phonemes to teach name of acids indicated his understanding of students' difficulty to understand or pronounce acid names. Similarly, in Lesson 5, students felt difficult to pronounce *hydrochloric acid* so he spent some times repeating it in the classroom for students: he was pronouncing very slowly in loud voice and in chunks as *hydrooo, chloooric, acid,* and the students were repeating after the teacher (L-5). He expressed the reason for these segmental phonemes in teaching,

> They didn't know how to pronounce some (names) of the acids, so we just spent time going through that, which I wouldn't normally do. But yeah, when I see there are gaps in what they do know then I do tend to take a bit of time to go over that. (I-2)

The classroom observation and interview data indicate he found learning 'gaps' and spent some time filling them. The process of finding learning gaps and spend some time improving reflected his Curricular Knowledge because it has a coherence of *The New Zealand Curriculum* recommended pedagogy that discussed under "Teaching as inquiry" and one aspect deal as "What is important and therefore worth spending time one, given where my students are at." (Ministry of Education, 2007, p. 35). He assessed 'they don't know how to pronounce of the acids' and his assessment on it as 'there are gaps in what they do know'. This reflected his Knowledge of Students Understanding because he identified the area of student difficulty in the learning of acid names. This Knowledge of Students Understanding developed during the classroom practice. He assessed their students in the ongoing teaching practice. This formative assessment approach reflected his Assessment Knowledge. He tried to fill the learning gap through phonics teaching. This reflected his Pedagogical Knowledge because this strategy engaged the students in repeating and learning acid names. The area of students' difficulty (i.e. Knowledge of Students Understanding) was developed after formative assessment (i.e. Assessment Knowledge) and tried to minimize it through phonics teaching (i.e. Pedagogical Knowledge). There was a combination between Knowledge of Students Understanding and combined knowledge of TPKB components because the combined knowledge informed the teacher to find students' area of difficulty (i.e. Knowledge of Students Understanding) by assessing ongoing classroom practice while Knowledge of Students Understanding informed to fill the gap by spending some time on it through phonic teaching.

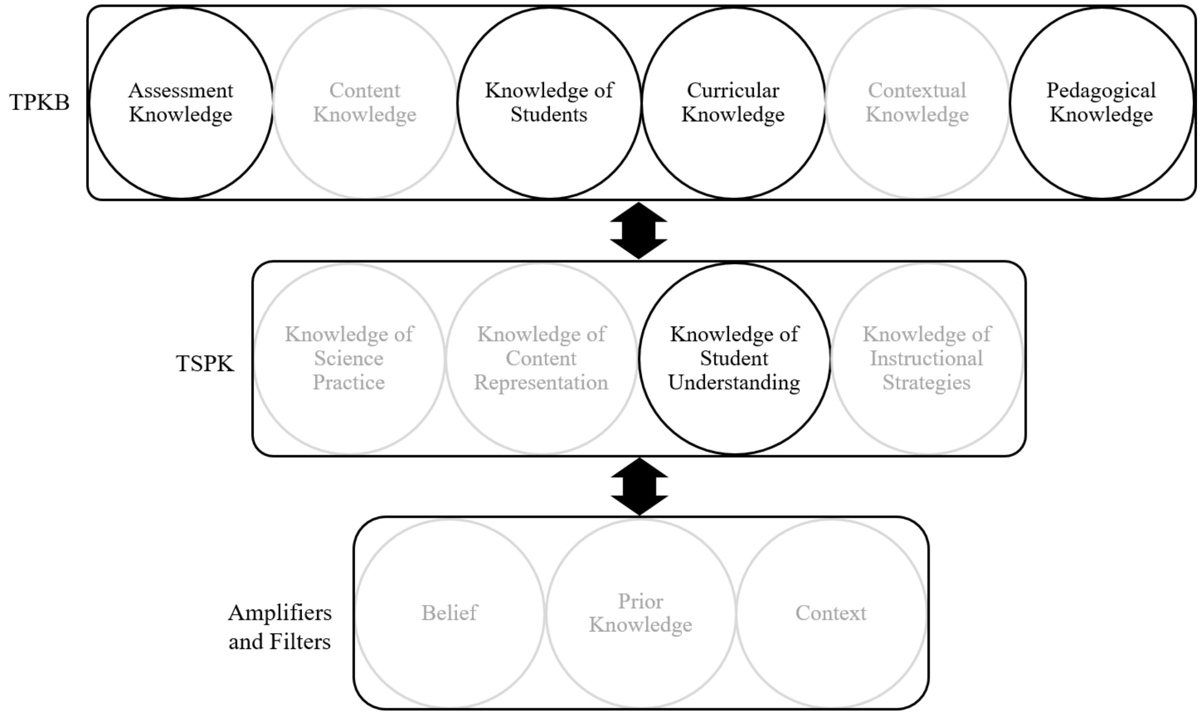
The interaction of Philip with these students in each lesson of this topic have developed his Knowledge of Students. The piece of final interview data suggested how Knowledge of Students developed from the teaching of this topic,

> Generally, I have taught a low band year 10, so my expectation has not been high, but I think that the class did very well. Some things could have been done but it is difficult to gauge the outcomes because the ability of the students is not high. To keep them engaged is important, to keep them interested, to give them things that they remember is important. (F-I)

This statement presents his overall general view of the topic of teaching. This part of the statement ‘I have taught a low band year 10, so my expectation has not been high’ illustrates a connection between Knowledge of Students and expectation because his ‘expectation’ based on his Knowledge of Students ‘my expectation has not been high’. On the other hand, he admired ‘the class did very well’ (i.e. Knowledge of Students) which developed during topic teaching. This reflected his Knowledge of Students because he discussed the overall learning trend in these students from ‘low ability’ to ‘did well’. In the final interview, he indicated the most suitable teaching strategies for these students ‘to keep them engaged is important, to keep interested, to give them things that they remember is important’ (i.e. Pedagogical Knowledge). Before the start of this topic teaching, he thought the important thing for the learning of these students, “They will learn things, they can see, and if the diagrams are drawn” (Q-14). It indicates his thinking about these students in the classroom has been changed during this topic of teaching. The pieces of evidence show development in his knowledge of teaching. Figure 5.18 shows the combination of knowledge components in this discussed data.

Figure 5.18

Philip's knowledge components for acquiring knowledge of students



Note: The figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge). This combined knowledge also combined with Knowledge of Students Understanding in discussed particular data.

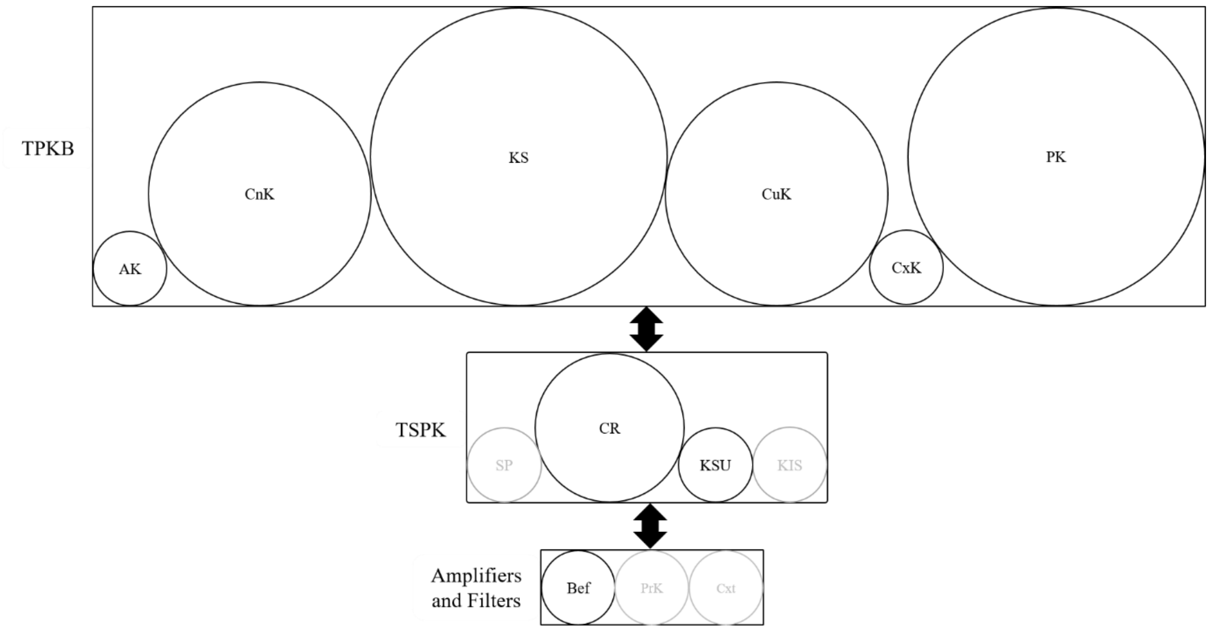
Overall data suggested Philip's Knowledge of Students combined with other knowledge components of TPKB and TSPK for planning and conducting teaching. The data suggest Knowledge of Students is less visible in Philip's observed teaching practices but it works in his mind, therefore, frequently it is identified in his follow-up interviews. The Knowledge of Students and Knowledge of Students Understanding developed in topic teaching that supports the one postulate of the two-way arrow between teaching practice and TPKB in consensus model-2015 (CM).

5.5.5 ***Summary of Knowledge of Students focus***

The four figures (5.15, 5.16, 5.17, and 5.18) represent Philip's knowledge combinations in the discussed pieces of evidence. I compared these figures together to illustrate that not all components of TPKB were combining equally with Knowledge of Students. In these figures, Knowledge of Students and Pedagogical Knowledge appeared four times (4/4), and Content Knowledge appeared three times (3/4). His Curricular Knowledge appeared two times (2/4) while his Assessment Knowledge and Contextual Knowledge appeared once in these figures (1/4). Of the TSPK components: Knowledge of Content Representation appeared two times (2/4), and Knowledge of Students Understanding appeared once (1/4), while his Knowledge of Science Practice and Knowledge of Instructional Strategies was not evident (0/4). In amplifiers and filters, his Belief appeared once (1/4), while teacher's Prior Knowledge and teacher's Context was not evident (0/4). These numbers of appearances are represented in the form of the size of circles in Figure 5.19.

Figure 5.19

The representation of the combination of knowledge components



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

The next section discusses his Curricular Knowledge as prominent knowledge in his topic teaching.

5.6 Curricular Knowledge

Curricular Knowledge includes teachers' knowledge of curriculum structure, curriculum goals, objectives, and the relationship between the school curriculum and the national curriculum. This section discusses Philip's Curricular Knowledge as prominent knowledge when it combined with other knowledge components for the teaching of 'Acid and Base'.

5.6.1 *Reflection of national curriculum in teaching*

Philip's reference to the school curriculum and national curriculum in his teaching that reflected his Curricular Knowledge. He was also performed as teacher-in-charge of NCEA science in the school. This task might provide him with a chance to look deep into *The New Zealand Curriculum* structure. He responded a question [In general, how do you determine what to teach and what not to teach to your students?] in the pre-topic questionnaire as "Curriculum (NZQA) sets the topics. The depth of coverage is vague, so past exams are indicators of the depth. New ideas and approaches are often added, so it is a dynamic learning-teaching environment" (Q-7). This statement reflects his eye on *The New Zealand Curriculum* structure 'New ideas and approaches are often added, so it is dynamic learning-teaching environment'. This reflected his Curricular Knowledge because of his understanding of curriculum structure.

The competency in *The New Zealand Curriculum* structure 'Thinking' focuses to develop critical understanding among students. Philip expected his students, "They (students) need to understand concept and application how to solve new challenges despite not having come across them before" (Q-7b). His expectations from students have coherence with *The New Zealand Curriculum* competency. This is a projection of *The New Zealand Curriculum* in his planning. This projection also noted in his response to question 11 [What do you believe effective chemistry teaching at this level or especially for this topic looks like?] in the pre-topic questionnaire he wrote, "Learning basic skills of measurement and observation. Developing an appreciation of domestic chemistry, mostly hands-on" (Q-11). The questionnaire data suggested he has a deep understanding of *The New Zealand Curriculum*.

I was able to associate his questionnaire responses and classroom practice. In Lesson 3, he taught formulae of HNO_3, H_2SO_4, HCl, H_2O, NaCl, CO_2, and CH_3COOH. Most of them were not part of the school curriculum. He said to students you need to learn formulae of HCl and H_2SO_4 and names of others. When I asked (Why you said students need to learn chemical formulae of two acids and names of other) in the follow-up interview then he said,

> They used to have nitric acid, but that's been removed, but I still think it's important that students know that there are more than those just two acids. So I give them some common ones, like vinegar or citric acid, that's why. So I give them a bigger list than what they need. But I don't make them learn the formulas, this is a low ability class, two acids is all they need. (I-3)

This statement illustrates he justified why he added a list of formulae in his teaching. He taught acid formulae to develop students' understanding of some common acids but focused on two that were part of the school curriculum. This reflected his Curricular Knowledge because of his understanding of expected teaching and learning content in the school curriculum. He also gave another reason 'this is a low ability class two acids is all they need'. His awareness of students' learning ability reflected his Knowledge of Students. He planned topic content according to his students' ability which indicates his Pedagogical Knowledge. He taught formulae of acid [e.g. HNO_3, H_2SO_4, HCl, H_2O, NaCl, CO_2, and CH_3COOH]. This reflected his Content Knowledge because it illustrates his understanding of chemical formulae. In Lesson 11, he also taught formulae of acids that were not part of the school curriculum. He explained in the follow-up interview why he did that, "We are not teaching to the test. We are putting in lots of other things as well, but we make sure that we emphasize the things that'll be in the test" (I-11). This argument shows his aim of teaching 'common acids' not focus the exam. He planned to develop his students' understanding of 'Acid and Base' rather than preparing them for examination.

'Teaching as inquiry' is one of the recommended pedagogy to teach science in *The New Zealand Curriculum* is. This pedagogy suggests to a teacher to consider this question "what happened as a result of the teaching, and what is the implication for future teaching?" (Ministry of Education, 2007, p. 35). For the answer to this question, Philip needed to investigate his success in teaching in terms of prioritized outcomes. When I asked in the follow-up interview of Lesson 11, "Do you want any change in your teaching for the next year for the low ability for the same lesson?" then he said,

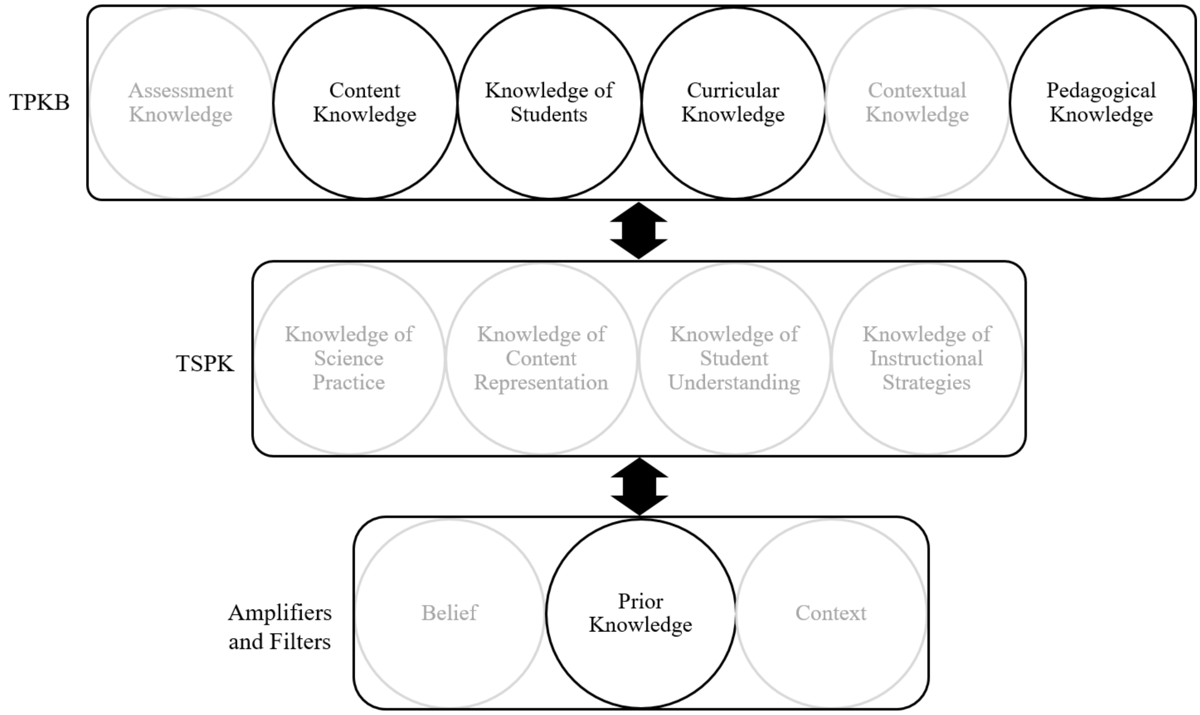
> No, this is probably about as good as it gets. I'm happy with what is going on, so no changes. Because there is sort of a fixed agenda. Like, I have a test here; they do the same test every year (he showed me a test sheet). It's written on the test, they've got to know formulas, names mention them, writing formulas, word equations, and universal indicator, examples, colors, general equations, and again some things at home. (I-11)

This statement reflects his teaching experience at the same level ‘same test every year’. He was not willing to bring changes in his teaching because of a ‘fixed agenda’ in a test. The same test each year or a fixed agenda in the curriculum stops him to investigate his teaching. He knew the same test every year reflected his Curricular Knowledge because of his understanding of the structure of *The New Zealand Curriculum* as a ‘fixed agenda’. He discussed the content of this topic in the test ‘writing formulas, word equations, and universal indicator, examples, colors, general equations, and again some things at home’. This reflected his Content Knowledge because of chemistry content in the test. His experience of chemistry tests every year convinced him to not need to bring change in his teaching. This reflected his Prior Knowledge because this knowledge originated from his experience. His Prior Knowledge filtered ‘teaching as inquiry’ from his evaluation as recommended in *The New Zealand Curriculum*. There is filtration because he filtered a step from teaching as inquiry “is there something I need to change” (Ministry of Education, 2007, p. 35).

These pieces of data show his Curricular Knowledge identified for teaching to develop his students’ understanding of common acid. His Content Knowledge combined with Curricular Knowledge to teach chemical formulae. His Knowledge of Students combined with Curricular Knowledge to discuss his students’ learning ability. His Prior Knowledge filtered his evaluation of his teaching. The combination of these knowledge components is framed in Figure 5.20.

Figure 5.20

Philip's knowledge combination when his Curricular Knowledge as prominent knowledge



Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, and Pedagogical Knowledge) in teaching acid formulae. His Prior Knowledge filtered his teaching evaluation process.

5.6.2 *Planning of teaching schedule*

Philip planned his teaching schedule based on the school curriculum reflected his Curricular Knowledge. He was not interested in writing lesson plans. Therefore, I have no evidence of his written teaching planning. I captured some pieces of evidence from his interview data as what he had a plan for teaching. When I asked (what is your planning for the next lesson?) in the follow-up interview of Lesson 7, He discussed as,

> Next lesson I'm going to pick up on what happened yesterday. So yesterday we started looking at two acids, one was hydrochloric acid and the other was sulfuric acid. I want to develop nitric acid (concept) and it is going into the hydroxide the base, and then that'll finish the acid and bases and in the next week, we'll be going through the acid and metal reactions. (I-7)

This statement shows a link between his taught lesson and the planning of the next lesson. It seems that he was well aware of what he has done, what was going on, and what he aimed to achieve next. In this response, he discussed the topic outlines related to acid in the school curriculum indicated his Curricular Knowledge because this reflected his understanding of the school curriculum. Herein, he made a connection of students' previous learning with current content. This reflected his Curricular Knowledge because it has coherence with *The New Zealand Curriculum* recommended pedagogy. He explained his lesson planning based on the previous lesson. This reflected his Pedagogical Knowledge because it is about his understanding of designing a lesson plan. He discussed the content related to acid in the school curriculum.

He interlinked the previous lesson with current lesson as he said, 'I'm going to pick up on what happened yesterday'. He started Lesson 8 by introducing the lesson planning,

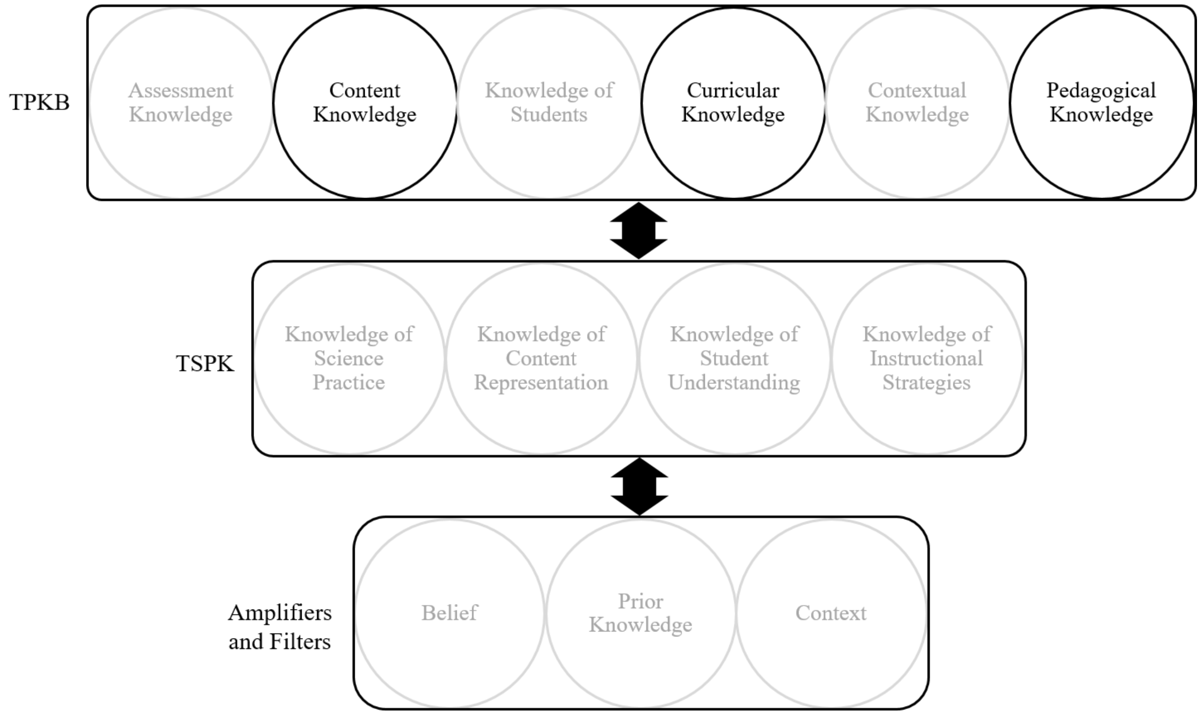
> We will do two things today, one thing is just reinforcing 'what happens when an acid reacts', and then we will do a practical. Next week maybe there is a topic test. So giving you a warning may there be the topic test. Open your books, what we did on Wednesday in the last period. [He checks the notebook of a student] We did two equations, hydrochloric acid, and sodium hydroxide. (L-8)

He revised the concept 'what happens when an acid reacts' that he already taught in Lesson 6 and shared the planning of Lesson 8. He revised the concept and planned the lesson according to a given timeframe in the school curriculum for completing this topic. This reflected his Curricular Knowledge because it reflects his understanding of the structure of the school curriculum. He discussed the planning of that lesson which is connecting with the previous lesson 'what we did on Wednesday'. It is Pedagogical Knowledge because it reflected his understanding of lesson planning. He underpinned two concepts in planning 'we did two equations, hydrochloric acid, and sodium hydroxide' which is specific to the chemistry that reflected his Content Knowledge.

The pieces of evidence suggest that he was well aware of the structures of the national and the school curriculum (i.e. Curricular Knowledge) such that he planned and conducted his lesson accordingly. His teaching was based on what was taught earlier (i.e. Pedagogical Knowledge; Content Knowledge). His Pedagogical Knowledge combined with Curricular Knowledge to implement the school curriculum in his teaching while Content Knowledge combined with them when he planned the teaching of specific concepts. The combination of his knowledge of TPKB for planning is framed in Figure 5.21.

Figure 5.21

Philip's combination of knowledge components for planning



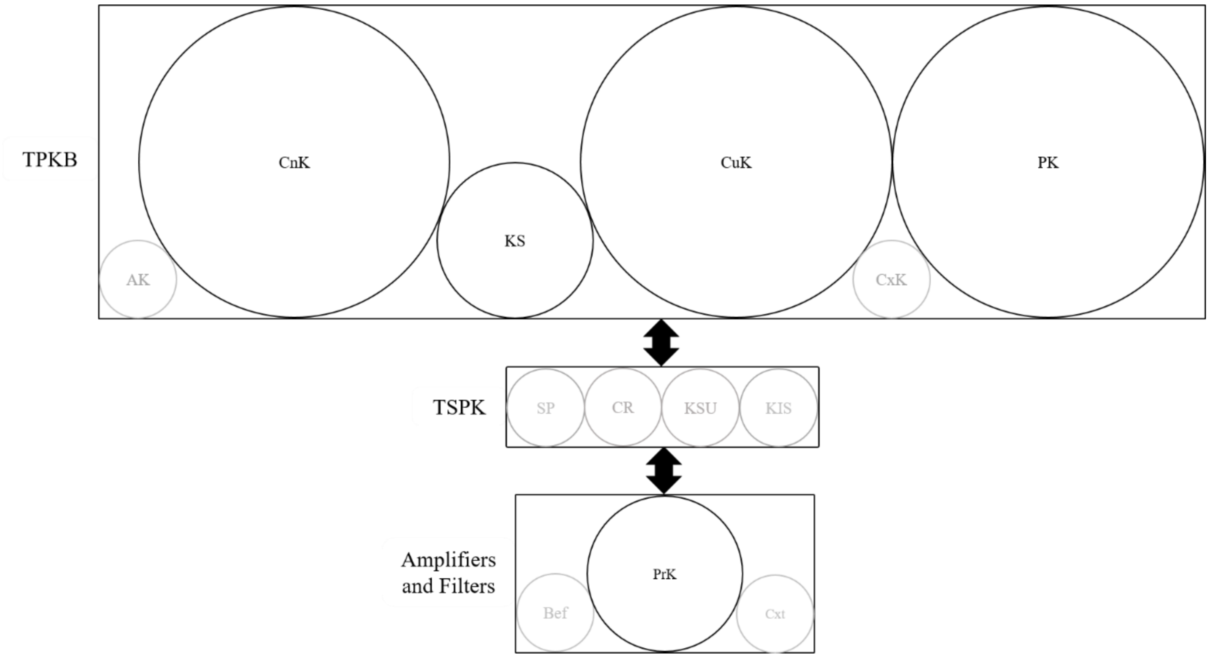
Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge) in his to meet the deadline.

5.6.3 *Summary of Curricular Knowledge focus*

The two figures above (5.20 and 5.21) represent Philip's PCK when his Curricular Knowledge was identified as prominent in his teaching. I compared these figures together to illustrate that not all components of TPKB were combining equally with his Curricular Knowledge. In these figures, Curricular Knowledge naturally appeared two times in this data (2/2), with Content Knowledge and Pedagogical Knowledge also present both times (2/2). His Knowledge of Students appeared once (1/2) while his Assessment Knowledge and Contextual Knowledge was not evident (0/2). His TSPK knowledge components were not evident in these pieces of data. Of the Amplifier and Filters: his Prior Knowledge appeared once (1/2) while his belief and context were not evident. These appearances represent in Figure 5.22.

Figure 5.22

Philip's Curricular Knowledge combined with other Knowledge Components



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

5.7 Contextual Knowledge

This teacher knowledge refers to knowledge contexts within the school (e.g. classroom, science laboratory, colleague, students, etc.) and beyond the school (e.g. district, province, country). This knowledge was not part of the Consensus Model but it has been identified as an important knowledge in the participants' teaching. In all the observed lessons, Philip gave examples from context of the school and context beyond the school that reflected his Contextual Knowledge in classroom practices. This section discusses Philip's use of Contextual Knowledge with the combination of other knowledge components.

5.7.1 *Assigning student knowledge of daily life chemistry*

Philip assigned assignments by involving their contexts that reflected his Contextual Knowledge. From his pre-topic questionnaire response, Philip wrote a detailed answer to a question [please describe two examples of the application of chemistry or topic in New

Zealand?] (Q-17b). He explained nine examples from the New Zealand context with brief descriptions. The six examples out of nine were related to the topic 'Acid and Base'. His responses included the followings.

- Cooking: Baking soda & reactions
- Painting: Mixing solvent water/oil bases
- Building: Treating timber
- Construction: Galvanising
- Farming: Fertilizer
- Fabrics/ plastics
- Fuel: Uses and dangerous
- Metals: Reacting and physical properties
- pH: Oven cleaner (Q-17b)

In this written responses, he used scientific terminology to describe chemistry-related daily examples. This reflected his Contextual Knowledge, Content Knowledge, and the ability to create a connection between them. These examples were picked from surroundings that reflected his Contextual Knowledge. He also described general chemistry in these provided examples. This reflected his Content Knowledge because scientific descriptions like 'Mixing solvent water/oil bases' specific to chemistry content.

I was able to identify his ability to make connections between chemistry contents and their contexts from the questionnaire and his classroom practice. An example of his Contextual Knowledge with other knowledge components of TPKB was observed in his teaching. This topic started with questions that probed into students' prior knowledge about 'Acid and Base' in Lesson 1. He asked the students to share "what idea do you have about acid at home" (L-1). Asking general questions at the start of the topic would develop students' interest in the topic. He marked three small lines on the whiteboard and asked students, "Tell me three things that have acid in it at your home" (L-1) then he converted this question to their homework and told them that they can ask their mom, dad, brother, or sister (L-1). At the end of Lesson 1, he also assigned a short assignment "to find the chemical formula of baking soda on baking soda bottle in your kitchen, you can use phone a friend or google, etc." (L-1) further, he suggested they can use a phone or google it or seek help from parents and siblings to complete the assignment (L-1). The homework and short assignment involved their phones, google, and family members to complete the assignment reflected his Contextual Knowledge because involving of his students' context beyond the school. The involvement of students' family members in learning is NZC recommended pedagogy (i.e. Facilitating shared learning)] that reflected his Curricular Knowledge. It is Curricular Knowledge because it reflects coherence with the national curriculum. The strategy of conversion of classwork into homework reflected his Pedagogical Knowledge because it was for engaging the students in investigating acid in things in their home.

He wanted to engage his students in science learning from their context. In that way, he could achieve the learning objective with the involvement of their home context (i.e. kitchen and phone) and community participation (i.e. parents and siblings) through social interaction. When I asked in the follow-up interview [formula of baking soda was not in the school curriculum then why you spent time on that]. He said,

> Because I think students need to know about what they have at home, it's just familiar and quite common to them. I do spend time doing things that are not related to the course but they just help them to understand a bit more something about science at home. (I-1)

This statement illustrates that he expected his students 'to know about what they have at home' through their science lens that reflected his clear direction of contextual-based learning 'science at home'. This thinking –may come from *The New Zealand Curriculum* key concept 'Chemistry is everywhere'. This reflected his Curricular Knowledge because it presented his understanding of the national curriculum. The purpose of the assignment was to engage the students to get familiarity with science at home. This reflected his Pedagogical Knowledge because it shows his purpose to engage students in learning through home assignments.

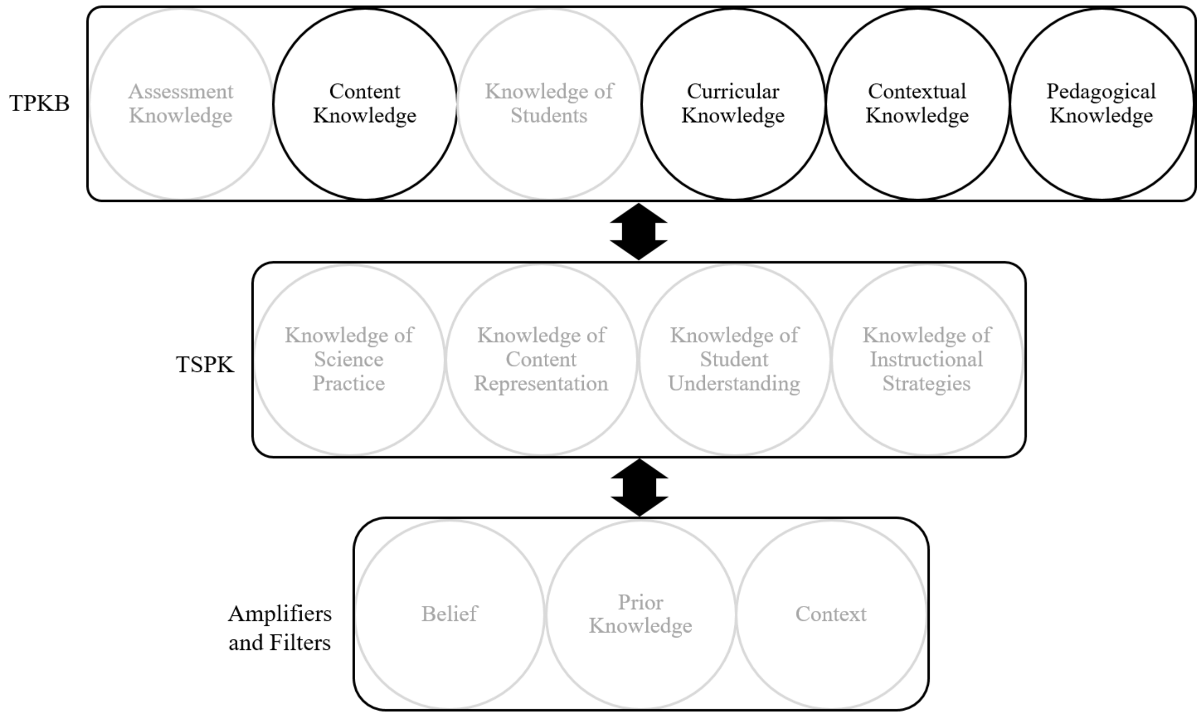
In Lesson 4, he assigned a poster-making project to the students. He explained to the students how to make a poster. He described: poster size, visibility, topic heading, font size, coloring scheme, and types of science pictures that will use. He was describing, the main body of the poster would consist of a "picture from a magazine, newspaper and anything like that of chemicals that you may have at home, especially acid and bases from the whole magazine" (L-4). The poster-making project also involved students' context 'anything like that of chemicals that you may have at home' in learning that reflected his Contextual Knowledge. His assigning of this poster-making project was to engage students in learning reflected his Pedagogical

Knowledge. It is Pedagogical Knowledge because it reflects his knowledge of engaging students in a project to develop their understanding of science.

These discussed pieces of evidence revealed that his Contextual Knowledge was identified to describe relevant examples and involved students' context in a project. His Content Knowledge combined with Contextual Knowledge to explain chemistry beyond things. His Curricular Knowledge combines with Contextual Knowledge to adopt the recommended pedagogy by the curriculum, and his Pedagogical Knowledge combined to engage the students in science learning through assigning activities. The combined knowledge components in this data is framed in Figure 5.23.

Figure 5.23

Combined knowledge components contextual based assignment



Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in assigning a contextual-based assignment.

5.7.2 ***Conducting practical work***

Philip made a connection between teaching and context that reflected his Contextual Knowledge. In Lesson 10, he briefly introduced that day's planning: I will check your homework and then we will do the last reaction of acid in this topic 'Acid and carbonate'. He wrote the name of the reaction ‘Acid + carbonate’ on the whiteboard at the start of Lesson 10. He checked their homework, he said, we are using HCl and marble chips in this experiment, then he asked some questions to the students:

> T: We will use carbonate for this experiment, actually marble chips. Do you know where marble is found in New Zealand?
>
> S1: South island
>
> T: Where specifically?
>
> S1: Dunedin (a city in New Zealand)
>
> (Philip took a big wooden roller measuring scale and made a circle on the New Zealand map to highlight the location where marble is found in New Zealand.) (L-10)

This teaching episode suggests his knowledge of New Zealand context, and he brought that knowledge into chemistry class to make a connection between country context and content. This reflected his Contextual Knowledge because it indicated his knowledge of context beyond the school. He also used the New Zealand map in the classroom to locate the location of Dunedin also reflected his Contextual Knowledge. He told the class ‘We will use carbonate for this experiment, actually marble chips’. This reflected his Content Knowledge because it illustrated his understanding of the chemical composition of marble chips (i.e. calcium carbonate). He involved the students in searching the city on the map where marble was found in New Zealand by asking questions. This reflected his Pedagogical Knowledge because he engaged the students in learning through questions. He asked this question ‘Do you know where marble is found in New Zealand?’ that would develop an interest in the students that indicated his context. He also did graduation in Geology. In this episode, his schooling was identified as an amplifier. There is an amplification of explaining the instruction of the experiment by adding stuff about where chemical ‘marble chips’ are found and working out to point to the exact location.

He gave importance to make a linkage between content with his students’ context. He expressed his views in the response to the question “How you made this topic easy and interesting today?” in the follow-up interview,

> Easy is a relative world. This class is not easy, the lesson is easy, but the class finds concentration and comprehension of abstract ideas difficult, so they can do the experiment

> but why are they doing it, they have no idea… for example finishing off the equation, what is actually happening? So on Friday, we'll be reinforcing everything that we've done so far, we'll be doing something more practical with pieces of paper and stuff like that. (I-10)

This statement illustrates his views of how these students can understand abstract ideas in chemistry. He thinks, he made the concept easy by connecting to the real world. This reflected his Contextual Knowledge because it referred to his understanding of context beyond the school 'real-world'. He pointed out the students' feeling of difficulty to understand abstract ideas that reflected his Knowledge of Students. It is Knowledge of Students because it reflects his knowledge of students' abilities to understand abstract ideas. As a researcher, I wanted to know more about why the students feel difficulty in learning equations so, I asked further "Why students are not good at learning equations?" Then he said,

> Because they just don't come across it in real life. It's a theory, it's abstract. They just don't see it in their lives, so they are not confident, and they are not familiar with it, so they find it hard. And also, I think those classes who are the upper band, usually get support from parents. Whereas I doubt if there has been much support from the parents of these students in terms of doing science, science is not seeing as an important thing, maybe reading a book, yes, but doing science maybe not. (I-10)

He believed that abstract ideas were difficult to understand for these students "Because they just don't come across it in real life" (I-10). He emphasised the importance of the connections between real life contexts and abstract concepts. He has a clear justification to bring contexts beyond the school in his teaching. Finally, he indicated that involving parents would enhance student learning. This reflected his Knowledge of students.

Philip didn't conduct all experiments which were written in the school curriculum such as preparation of sherbet, making soap, etc. When I asked why he eliminated those experiments in the final topic interview, he replied, "…for the sherbet, sherbet is one, which we are not supposed to do anymore; we are not allowed to have food chemicals in the classroom, that's the law" (F-I). In this statement, he gave a reason why he excluded 'making sherbet' from the school curriculum because 'we are not allowed to have food chemicals in the classroom' that indicated his Contextual Knowledge. It is Contextual Knowledge because it reflected his understanding of the school's setting. I asked another question, 'why the school put these experiments in planning'. Then he described,

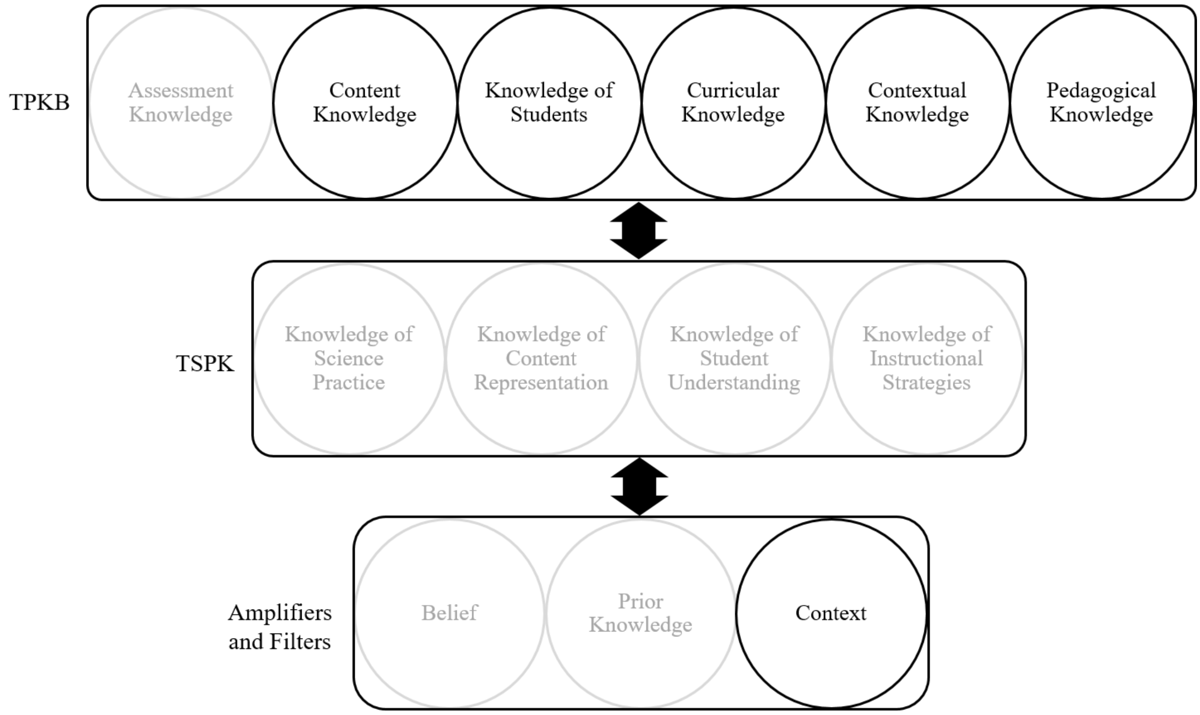
> Because it (the school planning) has been there for many years but the law was only made in the last few years. And the Government, it tightened up, no food is allowed to be done in the chemistry laboratory, even in the taps in the lab, they say, non-potable, in other words, you can't fill your water bottle from the tap in the science laboratory, in case of contamination. So, I don't do that (sherbet making). I used to do the hokey pokey, just how the carbonate, using baking soda to make the toffee rise, but because of the law, I don't do that anymore. (F-I)

This statement shows his up-to-date knowledge of government regulations related to laboratory safety. This reflected his Contextual Knowledge because the knowledge was beyond the school contexts. His awareness of outdated experiments in the school curriculum according to the recent regulations in science laboratories indicated his Curricular Knowledge. It is Curricular Knowledge because it reflected his understanding of the school curriculum structure. His discussion of experience in the science laboratory demonstrated the use of chemicals in cooking and the impact of reform in use of food law in school laboratories (i.e. context) on this topic.

In these pieces of evidence, his Content Knowledge combined with Contextual Knowledge to explain the chemical composition of marble chips. His Curricular Knowledge combined with Contextual Knowledge to evaluate the school curriculum. His Knowledge of Students combined with Contextual Knowledge to discuss students' abilities to understand abstract ideas. His Pedagogical Knowledge combined with Contextual Knowledge to engage the students in finding the location of marble on the New Zealand map. His schooling identified as amplifiers in these discussed data. His PCK in this pieces of data is framed in Figure 5.24.

Figure 5.24

Philip's combined knowledge for conducting the experiment



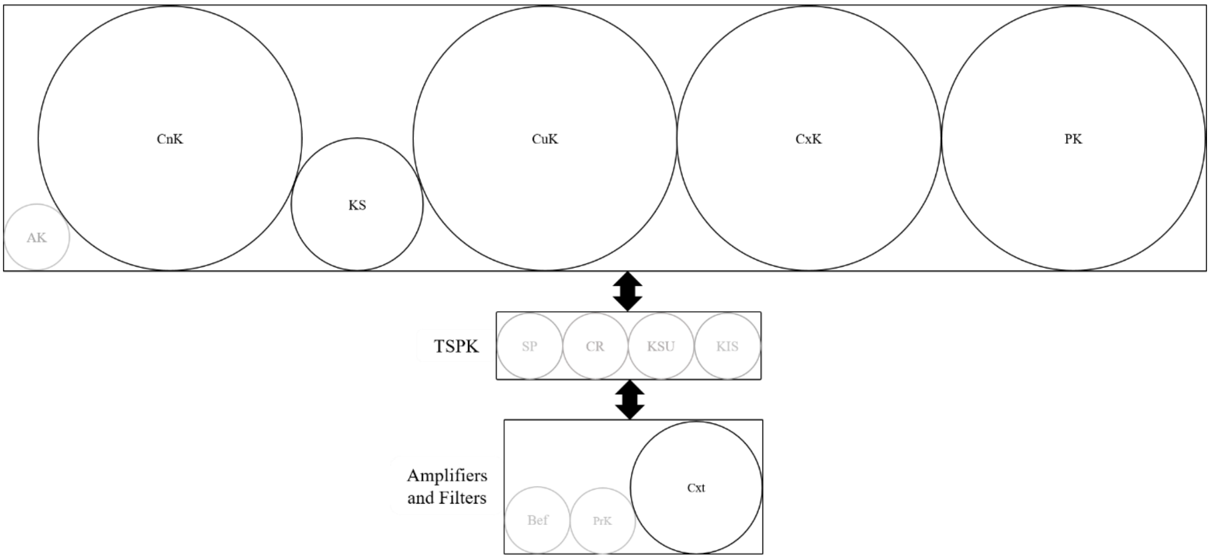
Note: This figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in practical work. His Context amplifies lesson content.

5.7.3 *Summary of Contextual Knowledge focus*

The two figures above (5.23 and 5.24) represent Philip's PCK in the selected pieces of evidence when his Contextual Knowledge was identified as prominent in his teaching. In these figures, Contextual Knowledge naturally appeared two times in this data (2/2), with Content Knowledge, Curricular Knowledge, and Pedagogical Knowledge also present two times (2/2). Knowledge of Students appeared once (1/2) while his Assessment Knowledge was not evident (0/2). The knowledge components of TSPK were not evident in these data. In Amplifiers and Filters, only his Context appeared once (1/2). Figure 5.25 represents the occurrences of knowledge components in relation to contextual knowledge.

Figure 5.25

Combined knowledge components when his Contextual Knowledge identified prominent



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

5.8 Pedagogical Knowledge

Pedagogical knowledge includes knowledge of strategies for classroom management and students' engagement. The classroom observation data show he adopted a variety of teaching strategies in his classroom practice but questioning was dominant in his teaching. Besides, he used PowerPoints, laboratory equipment, science charts, group discussion, and assigned short assignments in his teaching. He adopted his pedagogy based on students readiness, "They (students) have too much energy, so as a teacher you have to be aware of what they can do and what they can't do and adapt the lesson accordingly" (I-4). This section discusses his Pedagogical Knowledge combined with other knowledge components in his teaching.

5.8.1 *Using daily life examples*

Philip used the classroom context as a teaching aid in his teaching to engage students reflected his Pedagogical Knowledge. In Lesson 1, he asked some questions about daily life chemistry, e.g., "what idea do you have about acid at home" (L-1). He wrote the title of that day's lesson as "Acid @ Home (Acid at home)" on the whiteboard. Then, he showed a slide on the multimedia projector. This slide displayed photos of soft drinks, yogurt, vinegar, a bottle of creamy tartar, orange, rhubarb, and names of some acids in the box (Figure 5.26). He asked students to pick an object (e.g., yogurt) and write down the name of an acids that the object had. He gave few minutes to students for that activity (L-1).

Figure 5.26

Philip's showed slide to develop understanding about acid at home

Note: This snapshot is taken from Lesson-1 to show Philip's use of context as a teaching aid.

He engaged students with this slide for approximately 30 minutes (more than half of the lesson time). This activity seemed to have captured students' interest because of its relevance to their daily life. This teaching approach indicated his Pedagogical Knowledge. It is Pedagogical Knowledge because it reflected his understanding of the use of instructional techniques (i.e. engage students with the photos) according to the need of the content (i.e. things at home that have acid). Again, he focused on the slide and asked questions related to the photos in the slide. A piece of this conversation discussed below,

T: What is carbonic acid?

S1: Sprite

S2: Soft drink

S3: Vinegar

S4: Citrus fruit

T: Let’s find out

(He clicked, and carbonic acid appeared under the photo of a soft drink (sprite cane). He explained carbon dioxide with water in a soft drink that any fizzy drink has carbonic acid in it.)

T: If you drink Coca-Cola for a long time, then what will happen to your mouth? (Whole class became attentiveness to hear the answer)

T: It will make your teeth sour and will cause tooth decay because of the acid in them. (L-1)

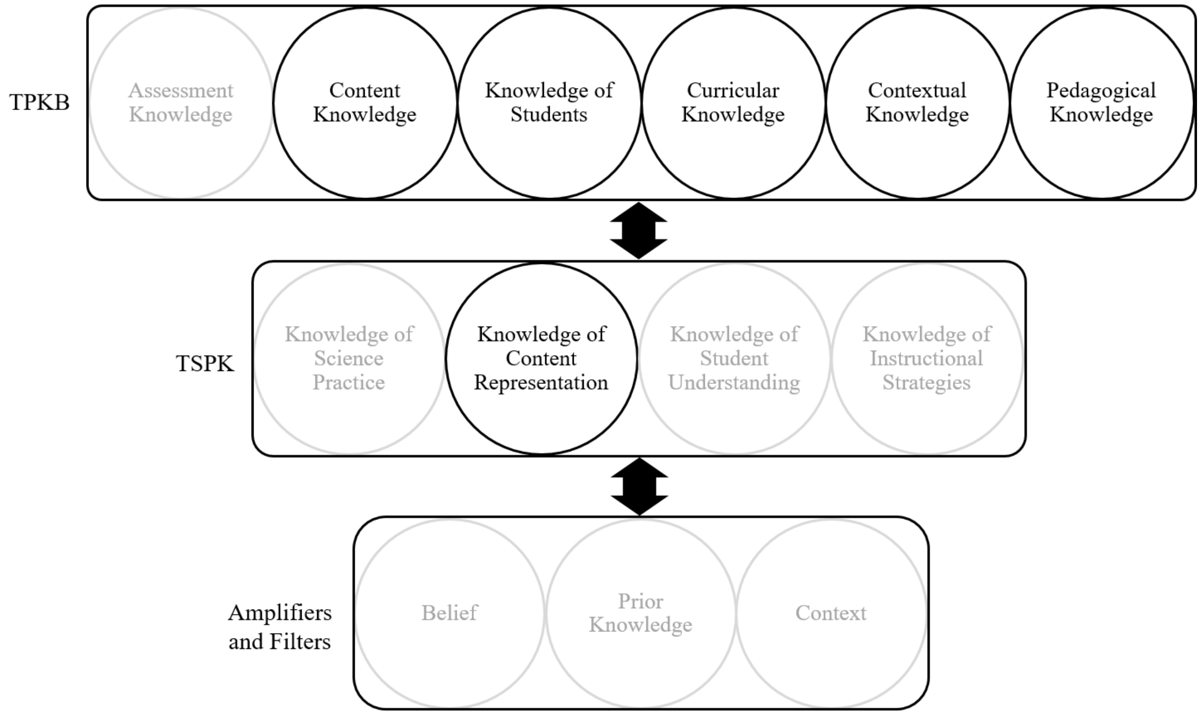
His questioning indicated his Pedagogical Knowledge. It is Pedagogical Knowledge because it engaged the students in learning acids that can be found in daily life. This also indicated his making of connections between students’ daily life experiences and the current content that indicated his Curricular Knowledge. It is Curricular Knowledge because it has coherence with *The New Zealand Curriculum* recommended pedagogy “Students learn best when they are able to integrate new learning with what they already understand. When teacher deliberately build on what their students know and have experienced” (Ministry of Education, 2015, p. 34). He presented the photos related to content because he knew how his students learn best “They will learn things, they can see, and if the diagrams are drawn” (Q-14). This reflected his Knowledge of Students because it illustrated his consideration of students’ interests. The photos of things on the slide were selected from local society (i.e. context) and showed through multimedia (i.e. classroom abiotic context) that indicated his Contextual Knowledge. It is Contextual Knowledge because it reflects using of context in teaching. He involved the students to work out to find things that have carbonic acid in them that indicated his Content Knowledge. It is Content Knowledge because it reflected his chemical understanding of the role of chemicals in making a soft drink ‘carbon dioxide with water in a soft drink’.

The combination of TPKB knowledge components (Pedagogical Knowledge, Content Knowledge, Knowledge of Students, Curricular Knowledge, and Contextual Knowledge) in the classroom practice to open the topic, capture students’ prior knowledge, and develop an interest in the topic. The content was represented by showing the photos on multimedia that indicated his Knowledge of Content Representation. It is Knowledge of Content Representation because it reflected his teaching planning what strategy will be use and why.

The selection of content-related photos from society (i.e. context), present through multimedia (i.e. presentation), and engaged the students (i.e. pedagogy) for developing an understanding of acid at home (i.e. content). The combined knowledge components of TPKB also combined with his Knowledge of Content Representation on this occasion. There is a combination between TPKB and TSPK because the combined knowledge might have informed the use of photos on multimedia as an appropriate type of representation for this particular content for these students. The photos on the multimedia afforded the teacher to make the content visible and engaged the students by questioning. The identified combination of knowledge components in this particular teaching is framed in Figure 5.27.

Figure 5.27

Combined knowledge for explaining content by using classroom context



Note: The figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combined Knowledge also combined with Knowledge of Content Representation of TSPK for using the context in the teaching of Acid at Home.

5.8.2 *Using students' prior knowledge in teaching*

Philip made a connection between students' prior knowledge and lesson teaching that reflected his Pedagogical Knowledge. In Lesson 2, he spent first 20 minutes checking and making corrections in the students' homework by involving students. Then he announced that day's lesson "how to write the formula" (L-2) and wrote sodium hydrogen carbonate on the whiteboard. He started this concept with the basics of writing the chemical formula of sodium hydrogen carbonate. He started to ask basic questions which will help to write this formula,

T: We did a little bit of chemistry last year you have done the symbol of elements. What is the symbol of carbon?

S1: Ca

S2: C

S3: CO

S4: CO_2

T: Symbol of carbon, not carbon oxide

T: Gentleman it is just 'C'

T: Now tell me the symbol of oxygen, what is it?

S5: O

T: O! We have the formula of sodium hydrogen carbonate (he already printed this name on the whiteboard). What is the symbol of sodium?

(Students came up with different answers such as S, Se, and Ce)

Teacher: Actually, it is Natrium so Na. (He wrote Na under sodium, and asked about the symbol of hydrogen)

S2: H

(He wrote 'H' under hydrogen, and turned toward 'CARBONATE' and explained that carbonate is the mixture of carbon and 'ate'. The 'ate' in this name indicate oxygen with carbon)

T: What do you think? I will give you marks, if you tell me, what carbonate is?

S5: CO

S5: CO_3

T: Yes, it is CO_3 (he wrote CO_3 under carbonate and completed the formula of sodium hydrogen carbonate.) (L-2)

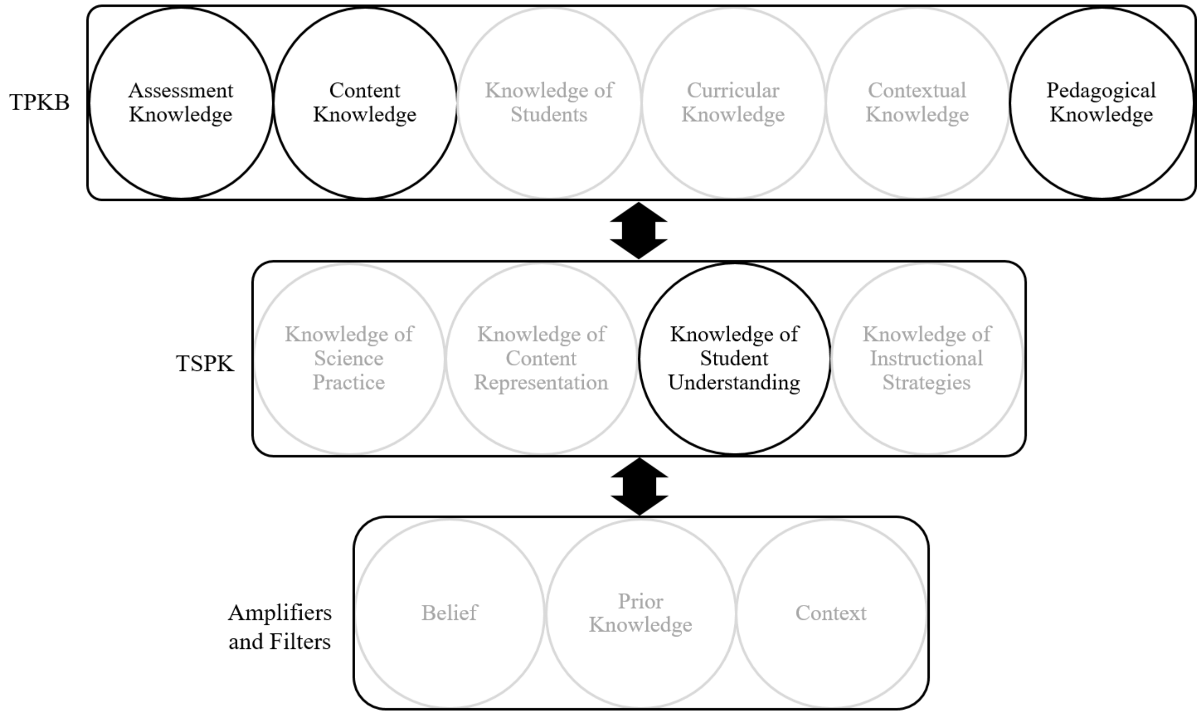
In this teaching episode, he involved students in questioning to work out the formula of sodium hydrogen carbonate. This reflected his Pedagogical Knowledge because it engaged the students to use their knowledge of chemical symbols of elements in writing the formula of sodium hydrogen carbonate. He probed into students' prior knowledge about symbols of elements. This reflected his Assessment Knowledge because it illustrated the use of formative assessment in ongoing teaching. He corrected the students' responses about symbols. This reflected his Content Knowledge because symbols of elements and chemical formula are specific to chemistry content.

He triggered his students' prior knowledge because he knew what they had done in the previous academic year. This reflected his Knowledge of Students Understanding because it showed his awareness of students' prior knowledge of symbols that would be used in writing the formula. At the start of this teaching episode, he reminded the students, we have learned symbols of some elements in the last year (i.e. Knowledge of Students Understanding) and assessed their prior knowledge by asking questions (i.e. assessment) and then engaged the students (i.e. pedagogy) to complete the formula (i.e. content). The combination of TPKB knowledge components also combined with his Knowledge of Students Understanding for this teaching. There is a combination between TPKB and TSPK components because TPKB combined knowledge might have informed the teacher to use students' prior knowledge of symbols into writing the formula of sodium hydrogen carbonate, while his Knowledge of Students' Understanding afforded the teacher to engage the students to use their prior knowledge in the completing the formula of the compound.

Herein, his Pedagogical Knowledge was identified to engage the students in the writing chemical formula. His Assessment Knowledge combined with Pedagogical Knowledge to assess their prior knowledge about symbols. His Content Knowledge combined with Pedagogical Knowledge to correct the students' responses. His Knowledge of Students Understanding combined with Pedagogical Knowledge to identify what they need to know to write the formulae. The combination of knowledge components is framed in Figure 5.28.

Figure 5.28

Philip's Pedagogical Knowledge in using the students' prior knowledge



Note: The figure represents Philip's combination of TPKB knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. This combination of knowledge components also combined with his Knowledge of Student Understanding in the teaching of writing chemical formulae.

5.8.3 *Adjusting teaching activities baesed on student behaviour*

In Lesson 4, he put some bottles on the teacher's table. A student threw something on the whiteboard but he ignored it. He brought test tubes into the test tube rack. He showed a bottle of acid in one hand and a bottle of a base in the other hand. Then he said, chemicals involved in today's experiment are an acid and a base. He asked students to tell the formula of hydrochloric acid. The class came with the correct answer. Again a student threw a paper ball on the whiteboard. Philip said, "I will put all these things away" (L-4). He started writing steps of acid-base neutralization reaction by using a universal indicator on the whiteboard (L-4). This reflected his Content Knowledge because the steps involved in an acid-base neutralization reaction are specific to chemistry content. He said to the class, please copy these steps. There was some noise in the class. He then said, "If you are not finished till 3:15 pm then it's your homework" (L-4). He wrote and explained the complete instruction for the experiment but he did not conduct it. He explained the reason in the follow-up interview,

> As I said before, it (lesson planning) is fluid we have to go where the students are. It is also my style. I am the teacher, so I set the level and expectations for my students. If they do not cooperate, then I'm gonna do something else. (I-4)

In this statement, he reported his planning as 'fluid' because he modified his lesson planning according to students' behvaiour 'If they do not cooperate' because it is his 'style' to achieve his own set 'level and expectations' of lesson learning. Philip's understanding of the teaching-learning situation in the class and changed the teaching strategy 'I am gonna do something else'. This reflected his Pedagogical Knowledge because it is about crafting the planning according to students. In the follow-up interview, I asked why you change your lesson plan, then he explained,

> One of the important things about science experiments is safety, if you can't trust the class, you can't do something. So, I did not feel that I can trust this class at that time. Friday morning I think they'll be able to do some more practical work than today. (I-4)

This statement shows his dissatisfaction with students' behaviour in the class toward practical work at that time so, he postponed the experiment. The first sentence of this statement 'One of the important things about science experiments is safety' represents his importance of safety during laboratory work because New Zealand education system also gave priority to this aspect of the laboratory work that guided by laboratory code [Guidance to the Code of Practice for School Exempt Laboratories overlaid with information about duties under the Health and Safety at Work Act 2015].This reflected his Contextual Knowledge because it showed his awareness of the country's educational context to conduct experiments in a school laboratory. Another example was noticed of such a situation at the start of Lesson 5, Philip spent some time to settle the students to start the teaching. However, this time, the teacher blamed the school context,

> Obviously, it was not a good period, we were a little bit over-talkative, just after the English period, and I think you were very enthusiastic which carried on here in the science period. So practical, if we will not do it in this period then we will not do it again. (L-5)

This statement shows his thinking about the suitability of timing for practical work 'it was not a good period, we were a little bit over-talkative, just after the English period'. This reflected his Contextual Knowledge because it showed his awareness of the school setting for the chemistry period. He evaluated the students' behavior for practical work 'little bit over-talkative'. This reflected his Knowledge of Students because it showed his awareness of his students’ extroverted behavior (i.e. personality trait). This statement again shows his plan according to the classroom situation and taking a strict decision ‘we will not do it again’. During the experiment in Lesson 5, a disturbance raised due to the breakage of an evaporating dish by a group, so he stopped the experiment and said,

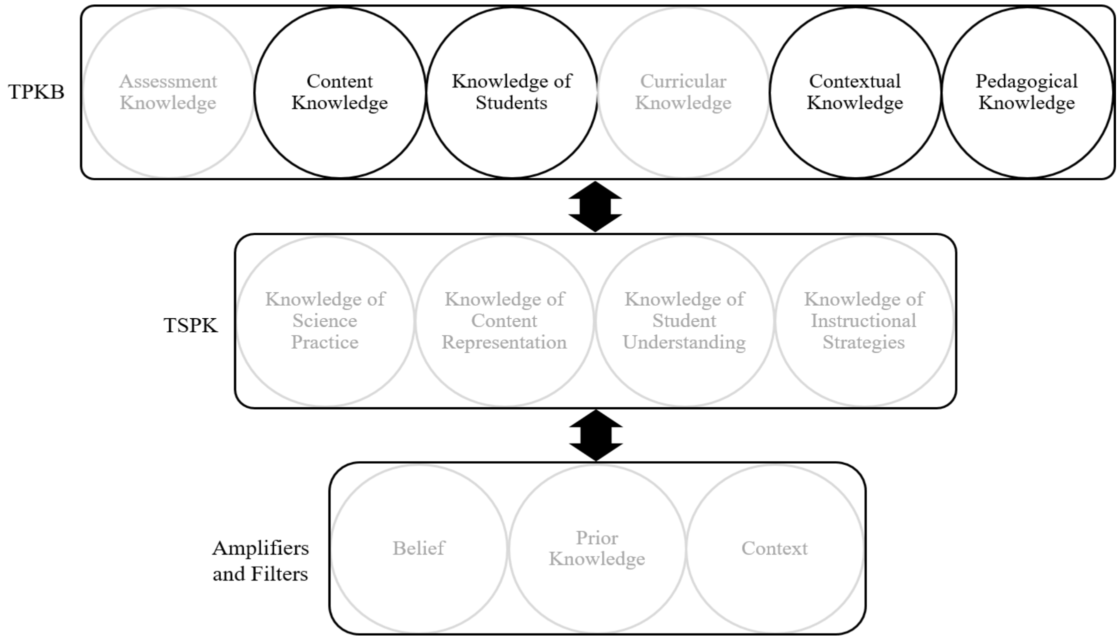
> Please stop work and sit down everyone. I am trying to talk to the whole class. Ok, everything went pretty good until something gets broken. One group breaks it, and everyone stopped. That group will no longer experiment. (L-5)

This teaching episode illustrates his decision ‘stop the activity’ after analysing the situation. It could be treated as to let the class complete the experiment or only put restrictions on the specific group rather than ‘One group breaks it, and everyone stopped’. Moreover, it seemed unnecessary to explain the above views though at the start he already said, “if the apparatus breaks you will pay a fine equal to the price of equipment” (L-5). He collected equipment from students and stopped the experiment. He demonstrated the second part of this experiment, “Experiments require a little bit of passion. So, I will do it for your second one” (L-5). He stopped practical work and demonstrated it for students’ learning. It is Pedagogical Knowledge because it reflects the adaptation of instructional strategies according to the class situation.

In this data, his Pedagogical Knowledge was identified to modify the teaching according to the class’s behavior. His Content Knowledge combined with Pedagogical Knowledge to write the steps of an acid-base neutralization reaction. His Knowledge of Students combined with Pedagogical Knowledge to evaluate the class behavior in the classroom practice. His Contextual Knowledge combined to inform the school setting. The combination of knowledge components framed in Figure 5.29.

Figure 5.29

Philip's combination of knowledge components to modify the teaching



Note: The figure represents Philip's combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students in the practical work.

5.8.4 *Solving textbook lesson exercise*

In Lesson 6, he announced that day's title acid and base. Before starting the lesson teaching he reminded the class, "I've asked you last week to bring about pictures of acid and base, so, how many bring it to raise your hand" (L-6). In Lesson 4, he assigned each student to bring a poster. Unfortunately, only three students came with posters in Lesson 6. "It is not enough to do today. It is disappointing, however, these three people will get 10 marks for competition [he noted in note book]" (L-6). He said,

> I said we are not going to do this class period because only 3 people out of 24 did their work. It is an assignment for one week for you, you get pictures today or tomorrow. Now it's an assignment for the poster, take out your homework diary from bags. Write on your exercise book. (L-6)

After that announcement he spent more than half of the period (approximately 30 minutes) recapping the poster activity, he explained the poster size, its preparations, available sources for making posters, etc. He already discussed these things in detail about poster activity in

Lesson 4. In the second half of Lesson 6 he repeated his change mind about today's lesson planning, "You don't have equipment [poster] today, so we'll do something different today. Please open this book [text book, he shows to all students]. Turn to page number 41 [he also wrote page 41 on the whiteboard]" (L-6). He showed that page to students and said, "Bonding and ionic compounds understanding, there is a table there [he shows the table in the book]. Copy and complete that table [Students started completing]" (L-6). This book is recommended by the school as a science textbook. There was a lesson exercise table on page 41 that consisted of four columns and six rows. The first column has names and formulae of compounds and the second column displayed the atoms present in the compounds. The third and fourth columns remained blank, the third column needed to fill with the number of atoms in compounds, and the fourth column with a total number of atoms in the compound. This table and content in the table were not part of the school curriculum. It seemed to me, this completing table activity keeps busy the class rather to achieve the school curriculum objective. It could be a kind of punishment in the form of extra work in return for not completing the assignment 'You don't have equipment [poster] today, so we'll do something different today' because at the start of the lesson he had announced 'Acid and Bases'. This table filling activity kept the students learning about ionic formulae. This reflected his Pedagogical Knowledge because it engaged the students in learning. He changed his mind because students did not complete the assigned poster project and decide 'we'll do something different today'. It appeared to me he has objectives for this poster-making project. I asked in the follow-up interview, what are your objectives of this poster-making project? He explained, "The objective is just to be familiar with acids that they find around the home. One is that and the other reason is I needed new posters in the classroom [laughing]. Just being honest." (L-6). He assigned the activity for enhancing the students' understanding of 'Acids at Home'. This reflected his Curricular Knowledge because it has coherence with *The New Zealand Curriculum* recommendation "Teachers can help students to make a connection across learning areas as well as to home practice and the wider world" (Ministry of Education, 2007, p. 34).

He emphasized this poster activity in Lesson-4, Lesson-6, and Lesson-11 which consumed time of lessons. *The New Zealand Curriculum* suggests to teachers to avoid the unnecessary duplication of content (Ministry of Education, 2007). This consumption of time would impact topic planning for the teaching of all content expected in the school curriculum. At the end of the topic, when all the practical works were not covered like making soap, sherbet, making red cabbage indicators, and indicators and common household solutions. I highlighted these practical activities on the school curriculum, I showed him and asked in the follow-up topic interview why you filtered these parts of the school curriculum. He justified as,

> Mainly because we have not enough time to do things like that? Because I need to start a new topic this week and it is, I'm studying at the last of the week. So, we didn't have enough time to do everything, but we still did enough practical, so they did get the value of those. But also, for the sherbet, sherbet is one, which we are not supposed to do anymore; we are not allowed to have food chemicals in the classroom, that's the law. (F-I)

This statement shows 'time factor' is one of the main reasons for the elimination of the activities from the school curriculum. He also pointed out a contextual factor 'we are not allowed to have food chemicals in the classroom, that's law'. This reflected his Contextual Knowledge because it illustrated his awareness about the country's safety laws for experiments in the school laboratory. He explained the reason why he did not allow to sherbet experiment in the laboratory, 'we are not allowed to have food chemicals in the classroom, that's the law'. The official document related to food safety in New Zealand schools laboratory [Guidance to the Code of Practice for School Exempt Laboratories overlaid with information about duties under the Health and Safety at Work Act 2015] guided as, "Food intended for human consumption shall not be consumed or stored where hazardous substances are handled" (Ministry of Education, 2016, p. 22). According to this clause, foods are prohibited in the science laboratory for consumption and storing. Some experiments that were not related to food (e.g. making soap) also skipped due to a shortage of time. Philip tried to clarify his actions and decisions in this teaching. For instance, he said 'we didn't have enough time', 'we still did enough practical' and 'we are not allowed to have food chemicals in the classroom'. This thinking may be provided him an inner satisfaction 'we still did enough practical, so they did get the value of those'. But, the part of topic content that was not covered in these lessons may never repeat in students' academic life that would create a learning gap. Interestingly, he wanted to remain stick to the same teaching strategies in the future with the low-ability students of year 10. I asked in the follow-up topic interview, 'will you bring some changes in your teaching in the next academic year for teaching this topic' (F-I). He stated,

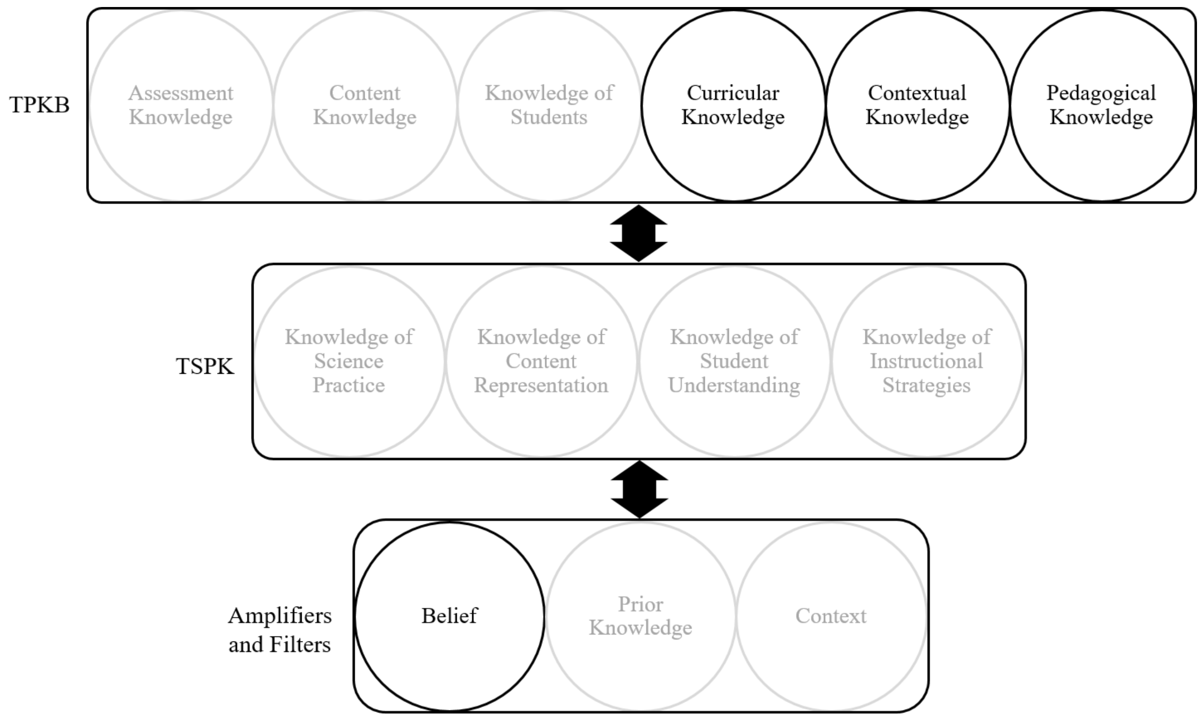
> No, No, I will do exactly the same again but as I said as I should concentrate on one or two things a bit more, such as the pH scale, but I still like to tell stories and still like to do practical, I still want them to take notes, so not much change. (F-I)

It exhibits his persistence to continue with the same teaching strategies. He also not ready to bring much change in his teaching strategy for future teaching that indicated his Belief about an orientation toward preferred teaching style. This Belief filtered the content from the topic. There is filtration because he eliminated some practical works and added some irrelevant content in the topic due to his Belief in his teaching style 'I still like to tell stories and still like to do practical, I still want them to take notes, so not much change'.

The pieces of evidence suggest that he knew teaching strategies well enough such that he engaged the students and crafted the classroom instruction according to the classroom situation (i.e. Pedagogical Knowledge). His Curricular Knowledge combined with his Pedagogical Knowledge for coherence with the NZC recommendations. His Contextual Knowledge combined with Pedagogical Knowledge for taking guidance in the safety issues described by the New Zealand government while his belief about teaching orientation filtered the topic content. The combined knowledge for these teaching practices is framed in Figure 5.30.

Figure 5.30

Philip's combination of knowledge components for activities



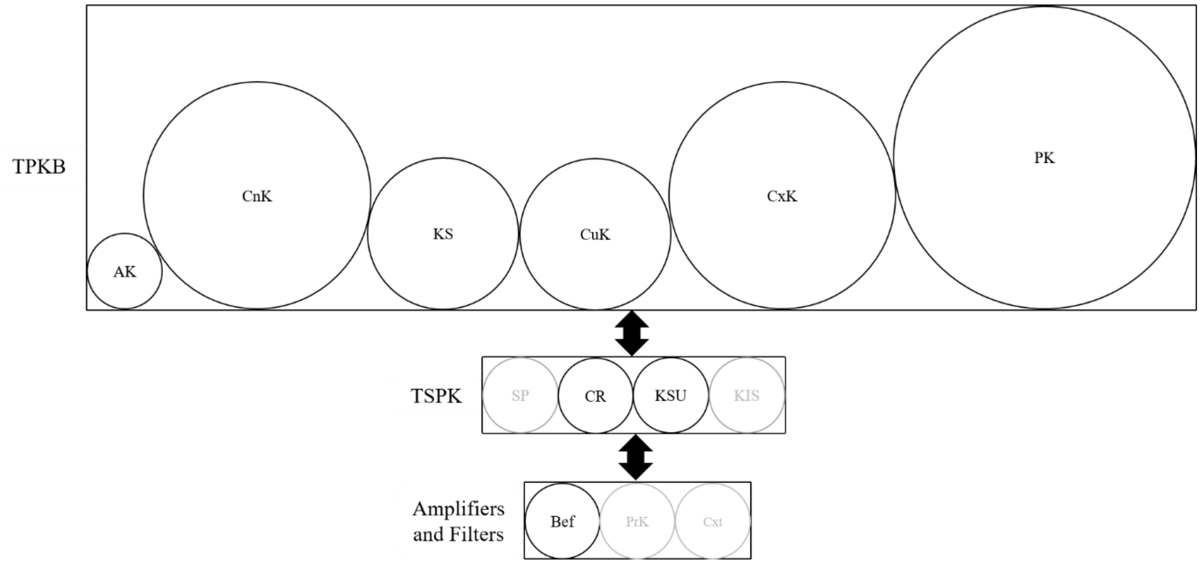
Note: The figure represents Philip's combination of TPKB knowledge components (Curricular Knowledge, Contextual Knowledge, and Pedagogical Knowledge) in his classroom practice for particular students. His Belief filtered practical works in the topic of teaching.

5.8.5 *Summary of Pedagogical Knowledge focus*

The four figures above (5.27, 5.28, 5.29, and 5.30) represent Philip's PCK in the selected pieces of evidence when his Pedagogical Knowledge was identified as prominent in his teaching. In these figures, Pedagogical Knowledge naturally appeared four times in this data (4/4). His Content Knowledge and Contextual Knowledge appeared both appeared three times (3/4). His Knowledge of Students and Curricular Knowledge both appeared twice (2/4) while his Assessment Knowledge appeared once (1/4). Of the TSPK: Knowledge of Content Representation and Knowledge of Student Understanding appeared once (1/4). In amplifiers and filters, only Belief appeared once (1/4).

Figure 5.31

Philip's Knowledge Combination when his Pedagogical Knowledge Identified as Prominent Knowledge



Note: In this figure, the following abbreviations are used: Assessment Knowledge (AK), Content Knowledge (CnK), Knowledge of Students (KS), Curricular Knowledge (CuK), Contextual Knowledge (CxK), Pedagogical Knowledge (PK), and Knowledge of Science Practice (SP), Knowledge of Content Representation (CR), Knowledge of Students Understanding (KSU), Knowledge of Instructional Strategies (KIS), and Belief (Bef), Prior Knowledge (PrK), Context (Cxt).

5.9 Chapter Summary

Philip's responses in the pre-topic questionnaire, classroom observations, and follow-up interview data represented his thinking and teaching. I focused on specific instances of teaching to identify knowledge components during my analysis. The analysis indicates that these teaching instances represented combinations of Teacher Professional Knowledge Base (TPKB), Topic Specific Professional Knowledge (TSPK), and Amplifiers and Filters.

Philip graduated with Chemistry and a Bachelor degree in Education and Chemistry from New Zealand. He has more than 20 years of national and international teaching experience in secondary schools. The observed class of Year 10 class included 24 students (age 14-15) they are generally a low ability class whom according to Philip were low ability.

The close examination of evidence from classroom observations and interviews with Philip indicated that it was possible to identify knowledge components that are part of the conceptual framework. By focussing on each component within TPKB, it was possible to interpret Philip's combinations in his classroom practice, and how and why these TPKB components combined with TSPK and Amplifiers and Filters at a time of his teaching.

His knowledge components worked in a variety of ways in a combination to practice. Different ways of combinations reflected different types of combinations in his teaching rather than a fixed combination. Some knowledge components were identified more often in his combinations as compared to others. For particular teaching instances, his combined knowledge components of TPKB also combined with TSPK, so, the combination between these sets of knowledge components did not identify in every combination. There are different types of combinations observed in both cases but they used different knowledge components in similar situations that reflected their uniqueness.

The knowledge components combined differently to facilitate his specific teaching. The purpose of teaching at specific times helped me to determine the types of the combination. It also revealed in his combinations that all knowledge components did not combine equally in specific teaching. His Amplifiers and Filters identified that amplifying or filtering his teaching practices, particularly, his Context and Prior Knowledge amplified and filtered his teaching.

Chapter 6

Discussion, Conclusion, and Implications of the Study

6.1 Overview

This chapter presents the findings of this research and discusses them in relation to the literature. It addresses a research question:

> RQ: How do science teachers combine the knowledge components within their Pedagogical Content Knowledge (PCK) in their classroom practice?

After discussing this question, this chapter presents the conclusion of this study and its limitations. Finally, it presents the implications with some suggestions for future studies.

6.2 RQ: How do science teachers combine the knowledge components within their Pedagogical Content Knowledge (PCK) in their classroom practice?

This research question addresses teachers' use of Teacher Professional Knowledge Base (see Figure 6.1), Topic Specific Professional Knowledge (see Figure 6.2), and Amplifiers and Filters (see Figure 6.3) in their classroom practices as theorized by the PCK Consensus Model-2015. Science teachers' professional knowledges are an important source of their actions in the classroom (Kulgemeyer et al., 2020).

Figure 6.1

Teachers' Professional Knowledge Base (TPKB)

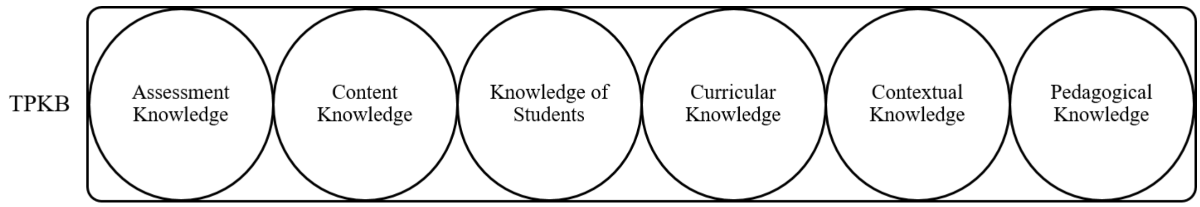


Figure 6.2

Teachers' Topic Specific Professional Knowledge (TSPK)

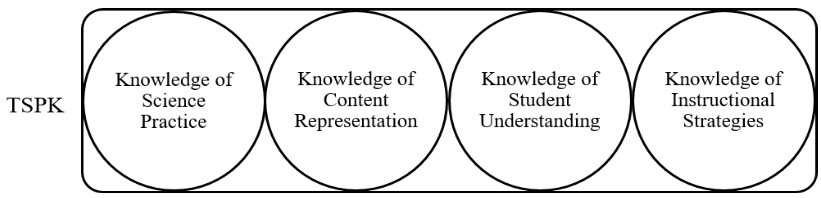
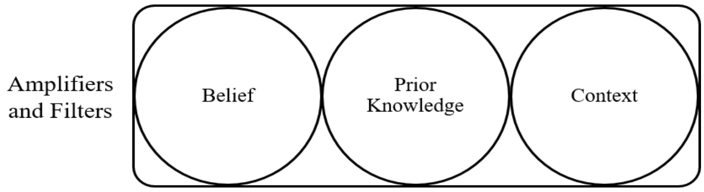


Figure 6.3

Teachers' Amplifiers and Filters

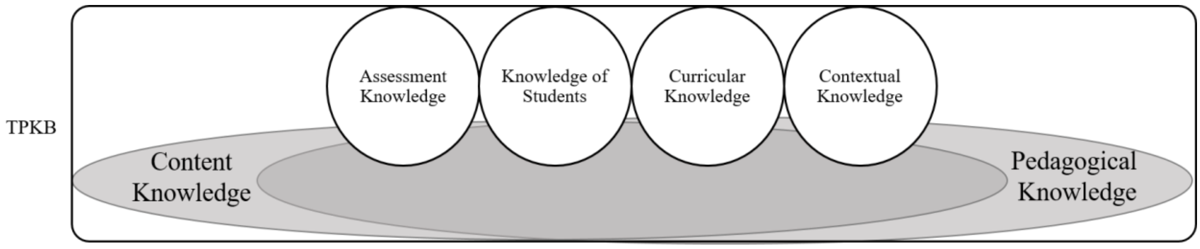


The data interpretation shows that each science teacher used a variety of combinations of knowledge components in their classrooms for a particular topic, for particular students in a particular context. The key finding related to both (Philip and George) teachers' professional knowledges in classroom practice shows that knowledge components identified as contributing to a teacher's PCK do not work individually in practice. In other words, these knowledge components always work in specific combinations (PCK) with other components in TPKB and TSPK. This pattern of results echoed the finding of Chan and Yung (2018) who found the integration of teaching knowledges [Knowledge of Students, Knowledge of Instructional Strategies, Assessment Knowledge, and Curriculum Knowledge] in chemistry teaching. Many other studies also reported integrations and interactions of knowledges in teaching (e.g. Barendsen and Henze, 2017; Bayram-Jacobs et al., 2019; Ekiz-Kiran and Boz, 2020; Hashweh, 2005; Lankford, 2010; Mavhunga, 2018; Mavhunga, 2020; Neumann et al., 2019; Owusu, 2014; Park and Chen, 2012; Park and Suh, 2019; Suh and Park, 2017). For instance, Park and Chen (2012) mapped teachers' PCK in their classroom and found numbers of interactions among PCK knowledge components, which shows that varieties of interactions existed among knowledge components during their practices. Aydin and Boz (2013) also verified the interactions of knowledge components in chemistry teachers' teaching by mapping their PCK. Mavhunga (2018) represented interactions among topic-specific PCK components in the set of knowledges noted in teachers' teaching episodes that also reflected varieties of combinations of knowledge within teachers' PCK in their classroom. The previous studies reported simply that there were interactions/integrations of knowledge components, while the data of this study suggest that knowledge components act in various combinations for teaching. The following paragraphs discuss the main assertions based on the data analysis.

The first assertion: the teachers used combinations of knowledge components in different ways during their teaching practice. PCK studies (e.g. Barendsen & Henze, 2019; Mavhunga, 2018, Park & Chen, 2012) also found varieties of interactions among PCK components in classroom practices. Park and Chen (2012) pictorially mapped those interactions and visualized those teachers used different components in their practices. I found these interactions in the form of varieties of combinations that demonstrate the dynamic behaviour of PCK components in teaching practice. The data reinforce that teachers' PCK is a product of combinations of their knowledge components. I found different types of combinations in their teaching. The review of these combinations indicated that Content Knowledge and Pedagogical Knowledge were always present in these combinations. These knowledge components may be regarded as foundational components of PCK for teaching (see Figure 6.4). The observation was consistent with the concept of PCK where 'pedagogical' and 'content' were the key descriptors of teacher knowledge (Shulman, 198). Other Teacher Professional Knowledge Base (TPKB) components were also present from time to time. Thus, a foundational combination refers to the combination of Content Knowledge and Pedagogical Knowledge with one or more of these other components.

Figure 6.4

Foundational components



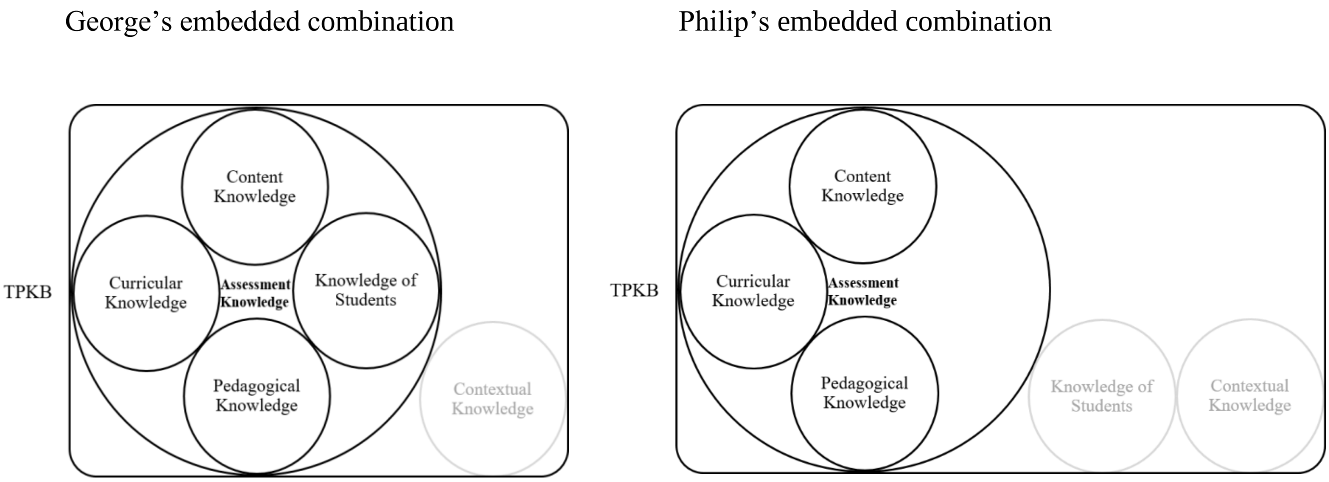
Note: This figure illustrates Content Knowledge and Pedagogical Knowledge working as a foundation in the teachers' PCK, and with other TPKB knowledge components to facilitate particular teaching.

The data suggested that there were at least four types of combinations:

- Embedded Combination: In the embedded situation, teachers' one TPKB knowledge component was identified as the main focus for practice, and other TPKB knowledge components were embedded in that particular teaching episode. The data illustrates that the both teachers used embedded combinations with a focus on assessment (see section 4.3.1, 5.3.1) when they used other TPKB knowledge components embedded in the Assessment Knowledge component to diagnose their students' prior knowledge (see Figure 6.4). The side-view of General Taxonomy of PCK (Veal & MaKinster, 1999) illustrated the authors' theoretical ideas about the embeddedness of knowledge components. This study showed that teachers embedded different knowledge components into their Assessment Knowledge in their classroom practice.

Figure 6.5

An example of George's and Philip's embedded combination during an assessment

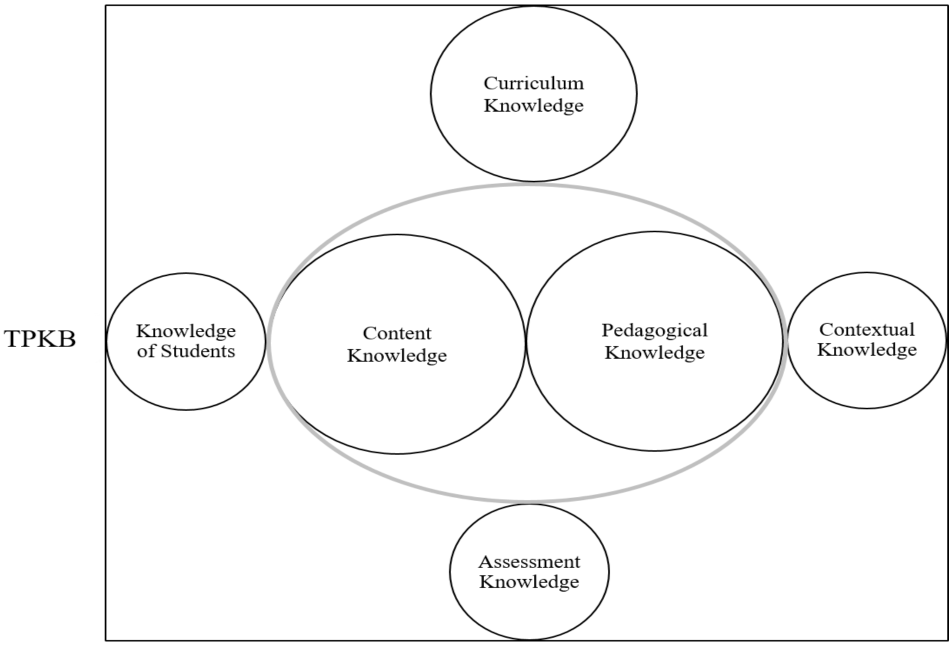


Note: This figure represents embedded combinations when both teachers diagnosed their students' prior knowledge. While they are similar, George appeared to embed Knowledge of Students in his assessment focus while Philip did not appear to do so.

- Collaborative Combination: Collaborative Combination refers the combination of all TPKB knowledge components in a teaching episode. The importance of knowledge components in Collaboration Combinations varied: some components were more evident than others in each combination. Unlike embedded combinations, there was not a single dominating knowledge component in collaborative combinations. Examples of these combinations were identified when the teachers presented content in their classroom practices (see sections 4.5.2 and 5.5.2), where their Pedagogical Knowledge combined with Content Knowledge, and all other TPKB knowledge components collaborated with that foundational combination. One of George's collaborative combinations is shown in Figure 6.6.

Figure 6.6

An example of George's collaborative combination



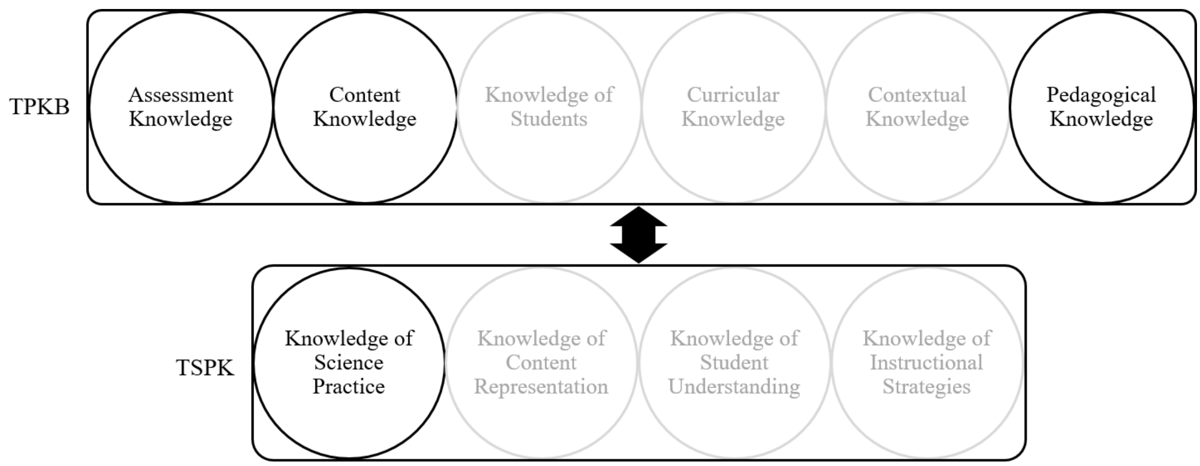
Note: This figure represents an example of a collaborative combination in George's case. All knowledge components collaborate here but his Pedagogical Knowledge and Content Knowledge component appeared more prominently. Of the other TPKB components, his Curriculum Knowledge seemed to engage more than his Assessment Knowledge, Knowledge of Students, and Contextual Knowledge. The grey line shows that all knowledge components collaborate with the foundational combination. This combination aligned to some extent with the finding of Barendsen and Henze's (2019) study, where they found some elements of PCK have strong interconnections while some have weak interconnection because of the teachers' incomplete pedagogical reasoning. These researchers examined interactions among knowledge components as discussed by Magnusson's (1999) model, while this study focused on the compoents as described by the Consensus Model. Moreover, these researchers captured data by using the Content Representation (CoRe) by Loughran, Mulhall, and Berry (2004); they developed an observation table to investigate classroom interactions in specific way that the observations could be related to specific elements of PCK. Along with observations, they recorded all lesson and interviewed the participants by using a semi-structured interview prior to their teaching. I used the questionnaire to gather teachers' amplifiers and filters, teachers' background and main ideas about topic. I recorded and observed all lessons to examine the teachers' PCK in the classrooms by using the CM as the conceptual framework. I interviewed the teachers immediately after each teaching lesson to ask their view about their own teaching in that lesson, and actions in the teaching. I noted that knowledge components were not equally collaborative with foundational components in the combinations, while Barendsen and Henze (2019) suggested weak and strong connections among components.

- Topic Specific Combination: The knowledge components of Teacher Professional Knowledge Base (TPKB) combine with at least one knowledge component of Topic-Specific Professional Knowledge (TSPK) to facilitate topic-specific classroom practice. These combinations were identified in their classroom practice (see sections 4.4.3 and 5.3.3) where both teachers' combined knowledge components of TPKB with their TSPK component Knowledge of Science Practice to conduct experiments in their classrooms. This Topic Specific Combination between TPKB and TSPK (Figure 6.7) indicates that the combined knowledge components of TPKB might have informed the component of TSPK for the most appropriate stance in a specific topic, and the TSPK component afforded the teacher to take appropriate action (e.g. selection of pedagogy) to develop students' understanding in the topic that was needed (See Section 5.5.1). This finding illuminates the finding of another study conducted by Aydin et al. (2014) on chemistry teachers when they taught chemistry topics (electrochemical cells and redox reactions) in their respective classes. These researchers identified the knowledge components of PCK that selectively revealed the topic-specific nature of PCK, for instance, representations is content specific, rather than a discipline specific component such as assessment. Another study was conducted by Mavhunga (2018) to examine the emerging complexity of content-specific components of PCK interaction when 15 pre-service teachers planned a chemistry topic (chemical equilibrium), and data were collected through Content Representations (CoRes). She found the components of PCK in a topic interacted in different forms among each other (linear, interwoven, or a combination) by drawing topic specific PCK (TSPCK) Maps. The data of my study informed that the teachers' sets of knowledges (TPKB) combine with sets of TSPK in the form of varieties of combinations that reflect the topic specific nature of PCK. These combinations provide a view of teachers' combining of a general set of knowledge (TPKB) with a specific set of knowledge (TSPK) in topic teaching. This finding is not surprising as a similar finding with versions of topic specific PCK have been reported in the literature (Aydin et al. 2014; Park and Chen 2012; Lankford 2010; Mavhunga

2018). However, this finding has a significant importance as it represents specifically topic specific PCK, one of the realms in the continuum of PCK reflected in the Revised Consensus Model of PCK (Carlson & Daehler, 2019). The data from both teachers indicated that components of TPKB were not always combined with components of TSPK in the topic teaching, which reflects these combinations formed only for the teaching of particular content. This study explicates the combination (TPKB and TSPK) of experienced science teachers and shows how components of TPKB combine with TSPK to facilitate their teaching. This elucidation of the knowledge combinations for a specific topic in science is significant because it provides examples with evidence of topic-specific case knowledge which can be used as teaching material in science teacher preparation programs. The following Figure 6.7 shows Philip's topic-specific combination.

Figure 6.7

An example of Philip's Topic Specific combination

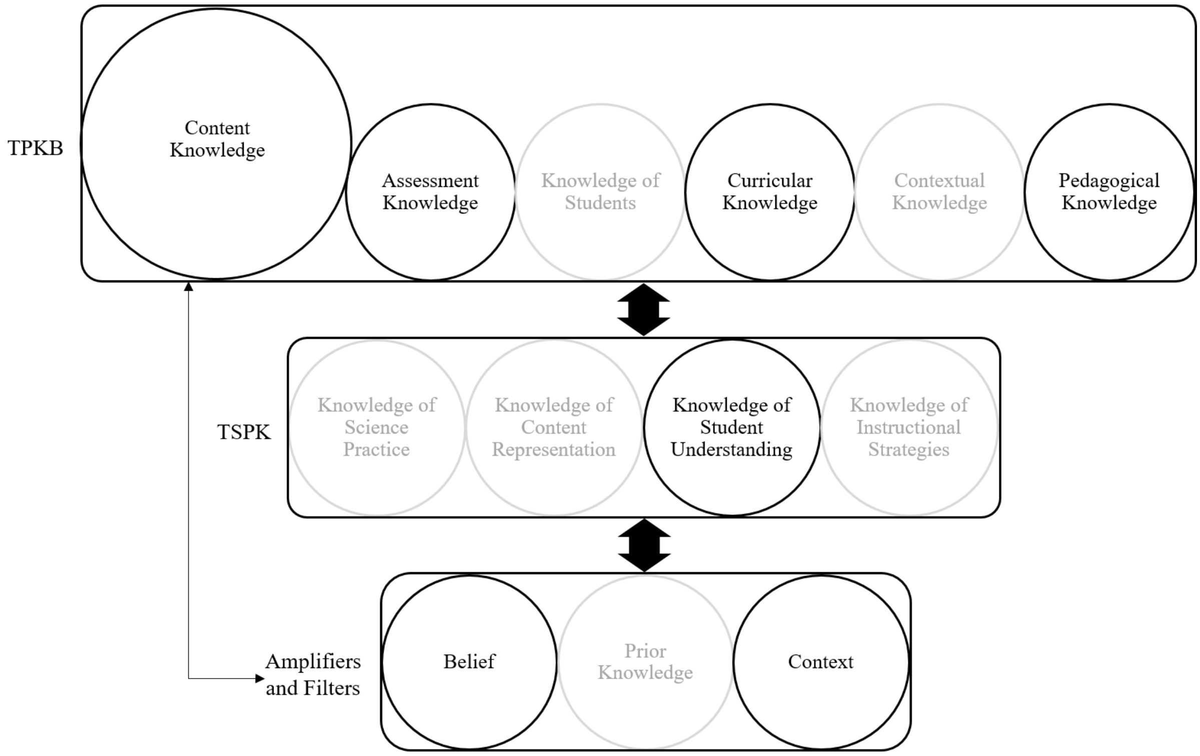


Note: This figure represents an example of a topic-specific combination in Philip's case. His TPKB knowledge components (Assessment Knowledge, Content Knowledge, and Pedagogical Knowledge) combine with Knowledge of Science Practice to conduct an experiment in the classroom.

- Amplified and Filtered Combination: In this situation, teachers' amplifiers and filters (Belief, Prior Knowledge, and Context) amplified or filtered one or more knowledge components in the combination in their classroom practice. This type of combination can be noticed (see sections 4.6.1 and 5.4.2) when the teacher's Prior Knowledge amplified or filtered their combination to complete a task. For example, Philip discussed in his class how to write chemical formulae of acids but he drew structural formulae of water and carbon dioxide which amplified classroom practice. There was amplification because he drew the structural formulae of water and carbon dioxide (these are not part of the school curriculum) and their structural comparison seemed to deliver more chemistry content in teaching at this school level. Philip had a belief that students need to learn more chemical formulae rather than just rely on the formulae specified in the curriculum, so he gave a list of formulae to the students which amplified the content in the topic. His use of Context and Belief were identified as the amplifiers, amplified classroom practice (Figure 6.8). This example shows how a teacher's belief and context can influence the inclusion of content in their teaching. Similarly, the Lankford (2010) study has shown that the teachers exceeded the mandates of curriculum set by the (USA) state and their schools by adding random content of 'molecular motion' as the driving force for concepts (diffusion and osmosis) and he also confirmed that the teachers' beliefs about student learning informed their actions and played a role to shape their teaching instructions in the classroom. In my view, Lankford's observations indicated the amplification in participants' teaching but he discussed this teaching event through another perspective that teacher beliefs shape their teaching. Lankford and I found the same phenomenon (teachers' added extra content) in the science teachers' classroom but we discussed it in different ways because of our different conceptual frameworks of study. Other previous studies also illuminated that teachers' beliefs, prior knowledge and context play a role in teachers' classroom practice (e.g. Huling, 2014; Fang, 1996; Wallace and Kang 2004) but they did not discuss these agencies as amplifiers and filters in the classroom practice as described in the consensus models. The CM introduced for the first time particular aspects (Belief, Prior Knowledge, and Context) as Amplifiers and Filters in PCK, so this study provided an early opportunity to examine amplifiers and filters with teachers' combinations of knowledge or PCK. The CM depicted that these Amplifiers and Filters might amplify or filter teaching practice. Beside, the Refined Consensus Model-2019 also theorized that learning context amplifies and filters teachers' knowledge and skills that would mediate teachers' actions in the classroom (Carlson & Daehler, 2019). The CM indicates the interactions of components of TPKB and TSPK with a set of Amplifiers and Filters. I found that teachers' Amplifiers and Filters amplify or filter at least one component in the combination during teaching practice. This finding provides credibility of insertions of these agencies as amplifiers and filters in the consensus models.

Figure 6.8

An example of amplified knowledge components combination



Note: This figure represents an example of an amplified combination in Philip's case. His Belief and Context particularly amplified the Content Knowledge component that shows with amplification in the combination.

The second assertion: Different teachers used different combinations of knowledge components in their teaching even in similar situations. The ways that George and Philip handled laboratory safety issues illustrated this (see section 4.7.1 and see section 5.7.2). George's Prior Knowledge in Amplifiers and Filters appeared with a combination of TPKB knowledge components (Content Knowledge, Curriculum Knowledge, Contextual Knowledge, and Pedagogical Knowledge), while Philip's Context appeared with a slightly different combination of TPKB knowledge components (Content Knowledge, Knowledge of Students, Curriculum Knowledge, Contextual Knowledge, and Pedagogical Knowledge). It seemed that those different knowledge components in their combinations were due to their Amplifiers and Filters.

A comparison of the use of knowledge components in their combinations revealed that Philip combined the Curriculum Knowledge component (12 out of 20 examples of practice) regularly with the Foundational Combination (i.e. the combination of Content Knowledge and Pedagogical Knowledge) within his PCK. This might be linked to his additional duty in the school which was related to the curriculum (see section 5.2.2). George combined Curriculum Knowledge (9 out of 16) and Knowledge of Students (9 out of 16) frequently with the Foundational Combination, which was also evident in his pre-topic questionnaire responses (see section 4.3.1). The different combinations indicated their unique attributes as teachers, as Shulman (2015) professed that, for teachers, "…different factors will come to the forefront, and others will have to take a backseat" (p. 13). This finding echoed the claim of Park and Chen (2012) that even under circumstances like teaching a similar topic, the resulting PCK may differ between teachers and between their classes. These researchers found that differences in PCK may be due to different integration among components of the teachers' PCK to facilitate the teaching episode. Further, Park and Chen (2012) mapped teachers' PCK by showing the link among five components (Orientations toward Teaching Science, Knowledge of Student Understanding, Knowledge of Instructional Strategies and Representations, Knowledge of Science Curriculum, and Knowledge of Assessment of Science Learning) of their PCK for teaching. Those mapped PCK show different components involved in different episodes in their teaching. Aydin and Boz (2013) also mapped two chemistry teachers' PCK in chemistry topics and confirmed that all knowledge components were not involved in teaching episodes. In my view, these different mappings of PCK indicate varieties of knowledge combinations in teachers' PCK. The data in this study show each teacher used different knowledge components in combinations for teaching, which reflect their personal uniqueness. This uniqueness was referred to as teachers' personal PCK in previous reported studies (Aydin et al. 2014; Mavhunga, 2018; Park and Chen 2012). This uniqueness can be seen bringing life into the idea of teachers' personal PCK at the grainsize of topic-specific level in the RCM (Mavhunga, 2018).

Ideas about combinations of knowledge components within PCK seem to connect well with what other researchers said about situation-specific PCK and contextual-specific PCK (e.g. Abell, 2008; Hashweh, 2005; Kind, 2009; Van Driel & Berry, 2012). However, this study is distinct from these other studies because it presents systematically framed PCK in the form of combinations that are identified in particular situations. The framing of PCK has made a visual comparison between their combinations of knowledge components in a similar situation. In this regard, it contributes to portray teachers' PCK in their teaching. This finding helps to understand experienced science teachers' PCK in their classrooms as "uniquely the province of teachers" (Shulman, 1987, p. 9), and as personal PCK (Carlson & Daehler, 2019; Gess-Newsome, 2015; Mavhunga, 2018). This finding also helps to identify teachers' areas of strength and weakness, which subsequently helps to identify teachers' areas of improvement in teaching.

The third assertion: The close examination of their teaching practices indicated that knowledge components in any combination do not lose their identity. Using classroom observations and follow-up interviews, it was possible to discern the individual knowledge components in a combination. I am aware that it is not so simple to put finger on what knowledge components are being involved within PCK in classroom teaching. The observed teachers' PCK is dynamic (e.g. various types of combinations) in nature that reflects its complexity. My representation of PCK in the form of combination does take the risk of oversimplifying the construction of PCK. However, the potential benefits of simplification make it more accessible to theoretical and empirical analysis and the opportunity to capture teachers' PCK in the form of combinations. I represented this complex nature of PCK in a simple form that will help teachers and researchers to visualise various knowledge components involved in particular teaching. Using an appropriate analytical framework based on the Consensus Model-2015 helped to point to how the knowledge components combine as illustrations of part of a teacher's PCK. George's data shows that his Knowledge of Students always identified with his Contextual Knowledge and often identified with his Content Knowledge and Pedagogical Knowledge (see section 4.5). Philip's data illustrates his Knowledge of Students always identified with his Pedagogical Knowledge and often combined with Content Knowledge and Curriculum Knowledge (see section 5.5). Herein, the Knowledge of Students identified with other knowledge components, and each knowledge did not lose identity but they were combined for a particular purpose (i.e, student learning). This finding provides an alternative view to that sometimes found in the PCK literature. The previously-reported studies indicate that when knowledge components integrate to form PCK they may lose their identities, resulting in a unique form of knowledge for teaching specific concepts in science (van Driel et al., 1998) and teachers find it difficult to separate these components (Archambault and Crippen, 2009; Owusu, 2014). This finding raised a question: how had the previous PCK studies been able to discuss the PCK components clearly if the components lose their identities in PCK? These previous PCK studies had identified and discussed the components of PCK which indicates that they were potentially identifiable. These identities then could be defined in a framework that would help to show the components of PCK during classroom practice. This study took that idea as a starting point to define each knowledge component in a framework before data collection. This process helped to locate the use of PCK components in a classroom by using this developed framework. This finding also helps to understand the knowledge components within PCK that are used by science teachers in their classrooms.

The fourth assertion: At least one knowledge component from Teacher Specific Professional Knowledge (TSPK) in a combination indicates Topic Specific PCK. The data suggest that the knowledge components of Teacher Professional Knowledge Base (TPKB) and TSPK combined to facilitate specific teaching tasks. When Assessment Knowledge was noted as prominent knowledge in both cases (see section 4.3 and 5.3), George's combined this with Knowledge of Student Understanding and Knowledge of Content Representation, while Philip's combined this with his Knowledge of Content Representation and Knowledge of Science Practice. These combinations show the knowledge components combine according to topic and students. There is a similarity between this finding and a theorized idea by de Sá Ibraim and Justi (2019), that during the PCK development process, a teacher's knowledge components combine with each other allied to teaching a particular content to a particular audience. This finding illuminates the aspect of Topic Specific PCK which is discussed by other experts (e.g. Magnusson et al., 1999; Mavhunga & Rollnick, 2013; Park & Chen, 2012; van Driel et al., 1998; Veal & MaKinster, 1999). It appears that the presence of at least one component from TSPK in the combination can develop Topic-Specific PCK in the classroom to achieve a particular task. The Consensus Model of PCK-2015 theoretically shows a relationship between the types of knowledge components (i.e. TPKB and TSPK) but did not explain how they work together. This finding provides evidence to understand this relationship in the science classroom that leads to understanding the construction of Topic Specific PCK.

6.3 Combinations of knowledge components contribute to understanding PCK

The central aim of this study was to examine PCK that was exhibited by experienced secondary science teachers in their chemistry classrooms. A variety of expressed PCK was found in this study. As I engaged in this research, four significant points emerged to understand PCK as combinations of their knowledge components in their classroom practices.

Firstly, the combination of knowledge components has been examined in this study in a specific manner that helps to understand the connectivity of components in PCK which ultimately helps to understand teachers' PCK. Examining these knowledge combinations provides detail on what, why, and how knowledge components were combined in PCK for teaching in a particular context (see section 4.5.2), a particular situation (see section 5.5.3), and for a particular concept (see section 4.4.2). These combinations showed where a knowledge component identified prominent in particular teaching and other knowledge components combined with it to form a combination to achieve a particular purpose. For example, both teachers implemented diagnostic assessments to diagnose their students' prior knowledge (see sections 4.3.1 and 5.3.1). To do this, their knowledge components were embedded in the assessment and formed a combination to assess their students. This examination and framing of teachers' PCK contribute to understanding the PCK concept and models. Magnusson's original model indicates that the PCK components shape each other but there is no explanation for what "shaping" means (Friedrichsen et al., 2011, p. 366). The early ideas suggest PCK is an amalgam of knowledge for teaching (Grossman, 1990; Shulman, 1986) but there was no specific discussion of how knowledges amalgamated in PCK. This study has presented a technique for discussing and framing knowledge combinations by teachers that provides a direction to develop an understanding of what is the meaning of 'shaping', and how? and why the components amalgamated in teachers' PCK. The analytical framework guided the analysis to find out and describe what knowledge is involved with other knowledge(s) in a combination in the teaching episode. For instance, when Philip was assessing his students (see section 5.5.2) I identified his Assessment Knowledge (diagnostic assessment) as the framework guided me. His Pedagogical Knowledge appeared in the form of question-answer teaching method and discussed Content Knowledge in the form of questions. In this embedded combination, his Assessment Knowledge appeared to shape the use of his Pedagogical Knowledge and Content Knowledge in that teaching episode.

Secondly, the framing of expressed PCK in the classroom presented here can help to understand the knowledge components in practice. Different combinations of components were observed in each teacher's selected data: 16 different knowledge combinations were noted in George's case and 20 knowledge combinations were identified in Philip's case. I found a variety of expressed combinations in both cases. Lee and Luft (2008) had suggested that the knowledge components may exist in different orientations in PCK and that teachers hold various forms of PCK that evolve throughout a professional career, and it has also been claimed that PCK development is a complex process that is highly specific to the individual teacher, situation, and context (van Driel & Berry, 2012). This study adds to previous studies through its classroom observations allowing a framing of a variety of teachers' expressed PCK in the form of diagrams. This framing represents teachers' PCK for teaching practice. It was not possible to represent teachers' whole classroom practice because it does not include other elements of classroom practice like student-teacher relationship, students' background, curriculum, class values etc. This framing affords evaluation of a teachers' PCK which does not represent an assessment of teacher effectiveness because teaching has a relationship with the class and situation. For instance, one teacher may teach a concept to a class with good prior knowledge and other teacher teach the same concept to a class with poor academic achievements previously. In these situations, teaching would be different due to the class background and likely student outcomes may also differ. It is possible that a teacher may amend their teaching for particular students for their better learning, as Shulman (2015) said, so different factors come to the forefront in teaching, and others take a backseat. Simply, framing of PCK does not help identify best practice, it only captures teachers' selection of knowledge for teaching in particular situation for particular students. This framing of selection could be improved or evaluated by comparing with a set standards or rubrics (see section 6.6.1). This framing of PCK can be used to evaluate the use of knowlwdge combinations in teachers' PCK according to the situation and context. The literature has highlighted that preservice teachers have weak PCK (e.g. Friedrichsen et al., 2007; Kind & Chan, 2019; Lankford, 2010; Loughran et al., 2004). The framing of PCK could help a teacher in self-evaluation and compare the use of combinations of knowledge components within PCK of one teacher with another teacher, or the PCK of a novice teacher with an experienced teacher. By framing PCK, teachers could note knowledge components in their teaching practice, and with the help of this framing, teachers could evaluate themselves for what knowledge components they use repeatedly or not at all in their ongoing teaching; for detail see section 6.6)

Thirdly, previous PCK studies suggest teachers' knowledge components interact and amalgamate in PCK but do not specify any relative importance of knowledge components in PCK expressions. According to my knowledge, to this date, no specific research study has sought to illustrate the possible relative importance of knowledge components in PCK. The Refined Consensus Model-2019 outer rim hypothetically hinted at this idea: this rim consists of five knowledge components, and of this content knowledge is the prominent knowledge that covers half of the rim, and the remaining half contains the other four knowledge components (Carlson & Daehler, 2019). The writers of this model did not explain what they meant by this partition.

Chapters 4 and 5 of this thesis consist of sections based on the prominent knowledge component that appeared in specific teaching events and each section is divided into subsections. Each subsection portrayed the knowledge combinations with this prominent knowledge component, and at the end of each section, the expressed PCK for those combinations is framed with the quantity of their appearance in the subsections. I am aware that this does not represent an exact quantitative relationship among the knowledge components, but it is an attempt to frame the teachers' overall PCK when specific knowledge was prominent in their teaching. The quantified PCK account suggests that the teachers' TPKB knowledge components do not combine equally in teaching. The evidence illustrates that there is not a fixed equal ratio among knowledge components in the teachers' practices, as sometimes Assessment Knowledge appeared prominent, and sometimes Pedagogical Knowledge or other knowledge components. The idea of quantified components of PCK helps to understand the partition of the outer rim in the Refined Consensus Model and provides evidence that this rim is dynamic in nature. It also helps to show that the knowledge components do not contribute equally at all times within PCK. This finding exposes a possible difference between theoretical conceptualized PCK as theorized by the Refined Consensus Model and PCK in the classroom. This finding also helps to identify and understand the relative quantity ratio of knowledge components in the combinations of experienced or expert teachers in a particular situation to facilitate teaching at that moment, which could be used as a guide for a novice teacher, as was pointed out by Loughran et al. (2004) "[Preservice teachers] need … to break down the traditional view of learning to teach science as a search for the right 'recipe'" (p. 383). It could help to show novice teachers how to improve their classroom practice by knowing what knowledge components in PCK are more effective in a particular situation by making explicit what their counterparts or an expert teacher were using in their teaching. For example, a novice teacher may come into a school with updated content knowledge, fresh training, new pedagogies, and good knowledge of curriculum, but they have limited knowledge about how to use these knowledges in teaching to enhance students learning. By framing experienced teachers' PCK in that school the novice teachers can get an image of the role of particular knowledges in teaching. From this image, the novice teachers can get an idea about how their experienced colleagues select knowledges in combinations from their repertoire of knowledge in their classroom teaching for particular students. Similarly, McDowall and Hipkins (2019) emphasized that teachers can develop their PCK by observing more experienced teachers in their teaching. Fourthly, this study highlights that the class situation, context, and teachers' amplifiers and filters influence their PCK in their classrooms to some extent. Both consensus models discussed the role of amplifiers and filters in implementing PCK in the classroom (Carlson & Daehler, 2019; Gess-Newsome, 2015). In my study, these aspects do not appear regularly but they could not be ignored. In George's case, mostly his Prior Knowledge amplified his knowledge especially when his Knowledge of Students identified as prominent in data (see section 4.5.1). On the other hand, Philip's personal and professional beliefs mostly amplified his teaching combinations. This indicates that teachers' personal attributes contribute to their PCK in particular contexts. This finding supports the claims of other researchers (e.g. Anderson, 2012; Carlson & Daehler, 2019; Garritz, 2015; Gess-Newsome, 2015). The observational data of this study illustrate the other factors that also influenced teachers' PCK. These factors are mainly associated with students' prior knowledge, students' questioning, students' behaviors, learning ability, and classroom context. For example, when both teachers faced some disturbance in their classes, they reacted accordingly to facilitate the students' learning (see sections 5.5.3, 5.8.3, and 4.5.1). This finding indicates that what a teacher does in the classroom is influenced by what students do, and this has been discussed by other researchers (e.g. Alvarado et al., 2015; Park & Oliver, 2008; Sadker et al., 2010). A detailed review of the observational data indicates that the teachers planned their teaching according to their students and combined their knowledge accordingly (see section 5.5.1). In this regard, this view contributes to the influence of the classroom contextual aspect of PCK. The other factor that influenced their PCK is context beyond the classroom. In their classrooms, both teachers preferred to trigger their students' prior knowledge, appreciated students asking questions, and tried to connect their prior learning with the current topic, which indicates their PCK expression was based on constructivism. Different factors may have contributed to this: the national curriculum, students learning needs for later assessment qualifications, teachers' own schooling experiences, and personal interest. This finding agrees with the work of other researchers that focused on New Zealand teachers and found that *The New Zealand Curriculum* and other factors influenced their teaching (e.g. Bell, 2005; Garbett, 2011; Hume & Coll, 2010; McDowall & Hipkins, 2019; Moeed & Anderson, 2018). These observations provide a sense that the educational context beyond the school also influences teachers' PCK. The evidence emphasises the idea highlighted in the first PCK summit by Lee Shulman that teaching must be practiced in the subject, cultural, personal, and social contexts in which it occurs (de Sá Ibraim & Justi, 2019).

These findings suggested that components of the CM in the classroom are dynamic in nature. It is noticed that different combinations of components of Teacher Professional Knowledge

Base (TPKB) were involved in teaching. Sometimes these combinations were combined with one or more components of TSPK or Amplifiers and Filters. These combinations varied according to situations, content, and context. These varieties of combinations of knowledge components and combinations with other levels of the CM (e.g. TSPK) or influenced by Amplifiers and Filters (e.g. Belief) reflected the dynamic nature of PCK. This dynamic nature makes it difficult to show all the combinations in one diagrammatic form of the CM. Two additional findings have suggested possible modifications to the CM. Firstly, the teachers' Contextual Knowledge was added at the stage of development of the conceptual famework because it was noted during the piloting phase of the study. The data suggest that teachers' Contextual Knowledge was a part of their combinations for teaching. Secondly, a decision was made about taking out teaching orientation from Amplifiers and Filters in the conceptual framework as reviewing literature suggested it is a compound term. This decision helped me to make clear identification of Amplifiers and Filters in teaching in the classrooms.

Summing it up, PCK is dynamic in nature. While the CM that was used as a basis for this study appears to represent PCK as static, but the more recent RCM-2019 represents dynamic nature of PCK by adding a continuum of grainsizes of PCK and knowledge exchanges between them. However, it is difficult to show all combinations in one two-dimensional diagrammatic form Contextual Knowledge is a part of TPKB, and teachers' orientation within Amplifiers and Filters is not suitable due to its varied appearance in literature.

6.4 Conclusion

The purpose of the current study was to examine science teachers' PCK in their classroom practices. The main findings of this study have been discussed in the sense of each research question in the above sections. The purpose of this section is to draw conclusions from these findings. In the light of the main findings of this study, it concludes that:

- The teachers' PCK can be conceptualised as combinations of knowledge components within their Teacher Professional Knowledge Base (TPKB) and Topic Specific Professional Knowledge (TSPK).
- Teachers use different types of combinations of knowledge components in their teaching practice.
- Different teachers used different knowledge combinations in a similar situation.

- The expression of particular PCK in particular teaching episodes demonstrated their ability to utilize their knowledge components simultaneously.

- The identity of knowledge components in the combinations in classroom practice can be identified through careful analysis of PCK.

- Teachers' knowledge components are not combined equally in their teaching at all times. Teachers appear to make the deliberate selection of knowledge components, some prominent and some less so, to fit a teaching situation.

- Teachers' amplifiers and filters influence their PCK to some extent which highlights the contextual aspect of PCK.

6.5 Limitation of this Study

I noted the following major limitations of my study:

Firstly, the sample size of this study is small. With this sample size, the findings of the study cannot be generalized. On the other hand, the findings or ideas of this study may be used to think about any case or to transfer to other situations. A qualitative analysis of two experienced science teachers' topic teaching was used to examine their PCK in their classrooms. Through intense data collection through multiple methods (pre-topic questionnaire, observational notes, lesson videos, post-lesson follow-up interviews, and post topic follow-up interviews), it was not possible to include a higher sample size with such amounts of data generated. This study contributes to some understanding of PCK, and further development of these ideas, the study should be repeated with a different, and if possible larger sample.

Secondly, the data of this study focused only on the teachers in the classrooms. For this study, the classroom practice is limited to teachers' teaching and did not directly consider students' participation. So, this study could not examine the impact of teachers' PCK on students and vice versa. The study should be repeated by collecting data from teachers and respective students to examine the real purpose of PCK (i.e. students' learning).

Thirdly, the data of this study were limited to the teaching of a single topic. With the limited lessons within one topic, it is unlikely that this study was able to capture these teachers' complete PCK that they have developed in their professional careers.

Fourthly, the teaching episodes from which the data were derived were specifically selected from their observed lessons and interviews rather than consider the holistic complexity of the teaching. This approach meant that teaching episodes were selected mainly when one knowledge component was more prominent. The selected teaching episodes cannot reflect a whole picture of the teachers' PCK in their teaching practice. I made the analysis of the identification of knowledges within teaching episodes based on the literature-derived analytical framework of the study but remains a possible limitation of the study.

6.6 Implications

The findings of this study can help in teacher evaluation, teacher education, and understanding of teachers' PCK. This section discusses how these findings could be implemented in education.

6.6.1 *Teachers' self-evaluation and comparison*

This study deals with what, why, and how a teacher uses combinations of knowledge components. As part of their practice, teachers could note the knowledge components they use in their classroom practice, and with the help of this, teachers could evaluate themselves for what knowledge components they use repeatedly or not at all in their teaching. This evaluation would allow them to judge their areas of strength and weakness which could ultimately improve their classroom practice. This self-evaluation also allows a teacher to compare with other teachers' evaluations for the improvement of teaching. The self-evaluation record of one academic year can be used to compare with the self-evaluation record of another academic year to improve classroom practice. For self-evaluation or observing other teachers by using the framework will not be a simple task. They will need training to use the framework to note knowledge components. In addition, it will be necessary to set rubrics or define knowledge components for observations because most of the schools have their own values, ethics, achievement objectives, available resources that may influence teachers' contextual knowledge. Similarly, a school-based curriculum may influence teachers' curriculum knowledge. So, to make it more practical, it would need to define its components according to the context that should enhance its adaptability and applicability.

6.6.2 *Teacher education*

This study allows beginning teachers to understand teachers use a variety of knowledge combinations in the classroom. These combinations are specific to teaching content and context.

This study could help the teacher educators to examine the beginning teachers' knowledge combinations during their practicum. These combinations will indicate their area of strengths and weaknesses in particular teaching. The teacher educators can then help to guide beginning teachers about what type of knowledge combinations are more effective in particular teaching or particular situations.

The analytical framework of this study could allow beginner teachers to observe their senior teachers' knowledge combinations according to context, content, and situation. This may help them to 'see' the implicit acts using PCK and improve their classroom practice in a particular context. For using the analytical framework, beginner teachers need to understand the sense of components of PCK in the classroom. By seeing the implicit nature of PCK they can use their own knowledge components in similar situations (e.g. engaging Year 10 students when they create disturbance in class) in a different context (e.g. engaging Year 9 students when they create disturbance in class).

The idea of knowledge combinations in PCK could be introduced in pre-service teacher education that would emphasize how and why experienced teachers combined their knowledge components in the right way to respond to students in the classroom according to content and context. McDowall & Hipkins (2019) highlighted such a challenge in teaching, as throwing "… a spotlight on the demand placed on teachers' own knowledge—both content knowledge and pedagogical content knowledge (PCK) (e.g. recognizing the "teachable moment" and making on-the-spot decisions about how best to respond)." (p. 32). This study could be used as a case in pre-service or in-service teacher education programs to discuss how experienced science teachers make 'teachable moments' and 'make on-the-spot decisions' in their classrooms through knowledge combinations.

6.6.3 ***Future PCK research***

This study focused on examining the science teachers' PCK in their chemistry classroom practices by using the Consensus Model-2015 as a foundation. This model also underpins the impact of PCK on students' learning. Further studies could allow researchers to collect data from teachers and students to check the impact of teachers' PCK on students' learning.

This study collected data from only two experienced science teachers. It identified five different knowledge combinations within PCK in their teaching practices. The same method can be used for examining science teachers and teachers of other subjects on a larger scale sample to verify these combinations. Furthermore, it also needs to explore further what types of PCK use by teachers more repeatedly in their practices and why.

It is well documented that teachers have different experiences and levels of expertise related to particular topics that they teach (Campbell et al., 2017). In this study, two experienced teachers were selected and their PCK was explored in one topic. But when they teach another science topic then they may express different PCK through knowledge combinations. Future research needs to elaborate on one teachers' PCK in different topics of science teaching in different classrooms, to examine what is stable in a teacher's PCK across contexts, topics, and groups of students.

I am not sure that this study has been able to identify all aspects of experienced science teachers' PCK. There is a possibility to explain more variance of teachers' knowledge combinations. Future studies could explore whether teachers use different combination types in their classrooms and why they might do so.

Overall, this study found teachers' PCK to be a combination of knowledge components. I have given names of combinations according to the appearance of knowledge components (e.g. Foundational combination, Amplified combinations) and behaviour of knowledge components (e.g. Embedded combinations and collaborative). It is also possible there might be various combinations of knowledge within PCK which are not identified yet. I acknowledge that to represent PCK as combinations is a simple version of the complex construct of PCK. However, this simple version has potential benefits, for example, it becomes more accessible to theoretical and empirical analysis, it is opening a door for researchers to verify and identify combinations within PCK, and it serves to understand 'amalgam' and 'shaping' of knowledge for teaching. This effort contributes to enhance science teaching that will have an ultimate impact on producing citizens. Teacher educators can support pre-service science teachers' learning to teach because teaching comprises combinations of knowledge rather stimulating individual knowledge. In future, I believe the idea of PCK as combinations of knowledge components and the framing of PCK as combinations in practice will have useful implications for science teaching practice.

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Appendices

Appendix A - Questionnaire

Teacher Name……………….

Q1: What tertiary qualifications do you have (including teacher qualification) or any professional course related to teaching? (Tick all that apply)

Qualification	Teaching Qualification
☐ Bachelor in…………………	☐ Bachelor of teaching (BTchg)
☐ Master in…………………...	☐ Bachelor of Education
☐ Ph.D. in ……………………	☐ Graduate Diploma in teaching
☐ Other………………………	☐ Master of Teaching (Secondary)

Q2: How many years have you been teaching in secondary schools?

☐ 1-2 years ☐ 3-4 years ☐ 5-6 years ☐ 7-8 years ☐ 9-10 years

☐ 11-12 years ☐ 13-14 years ☐ 15-20 years ☐ More than 20 years

Q3: What subjects have you taught and at what levels in this school?

	Year 9	Year 10	Year 11	Year 12	Year 13
Biology	☐	☐	☐	☐	☐
Physics	☐	☐	☐	☐	☐
Chemistry	☐	☐	☐	☐	☐
Mathematics	☐	☐	☐	☐	☐
Other……….	☐	☐	☐	☐	☐
Other……….	☐	☐	☐	☐	☐

Q4: How many class periods do you currently teach in a week.

☐ 10-15 ☐ 16-20 ☐ 20-25

5: What work experience, if any, have you had in addition to teaching?

☐ Industrial work related to science ☐ Research work not related to science

☐ Research work related to science ☐ Other work not related to science

Q6: Do you currently have other responsibilities (Non-teaching) within the school?

Q6 (b): Do you currently have other work-related responsibilities outside the school?

Q7: In general, how do you determine what to teach and what not to teach to your students?

Q7 (b): Why do you think it is important for students to learn the aspects you identified in the above question?

Q 8: How important do you believe it is for students to ask questions in your class?

Q 9: If a student asks a question in your class, what approach do you take to responding?

Q10: What is your philosophy of science teaching?

Q11: What do you believe effective Chemistry teaching at this level or especially for this topic looks like?

Q12: How do you know the prior knowledge of students about this topic?

Q12 (b): Is it important for you to know this or not? Why?

Q13: As you begin this topic, what do you already know about the students in your class?

Q14: Do you think this topic will be difficult or easy for your students? Why do you think this?

Q15: How will you know your students are learning the chemistry ideas and skills you are aiming for?

Q16: How would you define chemistry?

Q17: How important do you think it is that students make connections between their Chemistry learning and the real world?

Q17 (b): Please describe two examples of applications of chemistry or (topic) in New Zealand?

Appendix B - Observational Protocol

Sheet 1

Lesson content: From____________________________ to ________________________________

Class time : Date: D /M /Y Teacher Name:

Knowledge components	How teacher use knowledge components
Assessment Knowledge	
Content Knowledge	
Knowledge of Student	

Curriculum Knowledge	
Contextual Knowledge	
Pedagogical Knowledge	

Sheet 2

Topic Specific Professional Knowledge (TSPK)

Knowledge Components	How teacher use knowledge components
Science Practices	
Knowledge of Content Representation	
Knowledge of Student Understanding	
Knowledge of Instructional Strategies	

Sheet3

Amplifiers and Filters

Amplifiers and Filters	How Explicit
Teachers' Belief	
Teachers' Prior Knowledge	
Teachers' Context	

Sheet 4

Classroom Context

Biotic Context	How teacher use context
Number of students	
Supporting colleague	• Who • What type of support
Any Change in context	• What • How • Why
Unexpected	
General comments	

Abiotic Context	How teacher use context
Curriculum materials	
Av aids	
Scientific Apparatus	
Any Change in context	• What • How • Why
Unexpected	
General comments	

Appendix C - Follow-up Lesson Interview

Teacher Name………………..

Time ………………………… Interview Date / /

The focus of lesson ……………………………. Lesson Date / /

Q 1: Did the lesson go according to your plan**?** (Why/why not?)

Q 2: Do you think your students learned well in the lesson? How do you know that?

Q 3: Would you do anything differently in your next chemistry lesson with the same students? Why?

Q 4: Would you teach this lesson, in the same way, the next time you teach this topic? Why or Why not? If no, how would you modify your teaching next time?

Q 5: What is your plan for the next lesson?

Appendix D - Follow-up Topic Interview

Teacher Name………………..

Time ………………………… Interview Date / /

Topic …………………………

Q1: How do you feel that the topic went?

Q2: Did anything surprise you during the teaching of this topic?

Q3: Did you feel your learning intentions were achieved?

Q4: Did you try anything new and if so, how did it go?

Q5: Did classroom/school context play a role in your teaching during this topic?