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Stories of Teaching Force and Motion: A Narrative Inquiry into Pedagogical Content Knowledge of Science Teachers

by

Saiqa Azam

A THESIS

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Abstract

Since the concept of pedagogical content knowledge (PCK) was introduced in the 1980s, many researchers have tried to elaborate this concept. This project establishes that understanding topic-specific science PCK diverges from understanding the broader PCK construct. It provides a conceptual framework that can be used to represent both general PCK and topic-specific science PCK. The research demonstrates how this framework can serve as a heuristic to consider science teachers' PCK. The research explored how four experienced secondary school science teachers describe their experiences of conceptualizing and teaching the topics, force and motion. The aim was to access teachers' thinking about using content knowledge and pedagogical knowledge to teach science content. Two narrative methodologies suggested by Polkinghorne were employed: *narrative analysis* and *analysis of narratives*. Science teachers' descriptions were developed into (a) narrative configurations that portray their PCK—stories of teaching force and motion, and (b) PCK tools—teaching, learning and assessment tools that can be used to engage pre-service science teachers to help them develop their science PCK. Participant teachers' PCK was organized using ten teacher knowledge components: (i) knowledge of content, (ii) knowledge of student learning, (iii) knowledge of instructional strategies, (iv) knowledge of teaching resources, (v) knowledge of technology, (vi) knowledge of science curriculum, (vii) knowledge of goals, (viii) knowledge of teaching contexts, (ix) knowledge of assessment, and (x) knowledge of student diversity. Each PCK component further contains knowledge elements, which are narrative fragments—events and incidents described by participants about teaching a specific science topic, pointing to the narrative nature of PCK. Each teachers' PCK represents their professional and practical knowledge of teaching science. Participants' knowledge can be further considered using a four-level continuum from general to topic-specific science PCK. This shows that content knowledge understanding is integrated with the other teacher knowledge categories.

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Finally, I offer my sincere gratitude to my family, especially to my mother for her unconditional love and support. Her prayers were a source of reassurance that I could do it. Thank you for all the sacrifices you made so that we could have a better life and future.

I dedicate this work to my mother, and to every woman on this earth whose potential is ignored and whose dreams are cut short only because they are female.

The completion of my doctoral studies and fulfilling my dream represent hope for every woman.

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Chapter One: INTRODUCTION

> *Narrative Inquiry is a way of understanding experience. It is a collaboration between researcher and participants, over time, in a place or series of places and social interaction with milieus. An inquirer enters this matrix in the midst and progresses in this same spirit, concluding the inquiry still in the midst of living and telling, reliving and retelling, the stories of the experiences that make up people's lives, both individual and social. Simply stated, . . . narrative inquiry is stories lived and told. (Clandinin & Connelly, 2000, p. 20)*

1.1 The Research Study: An Overview

Since Shulman (1986) introduced the idea of pedagogical content knowledge (PCK) more than two decades ago, there has been a continuous effort to understand this construct and to elaborate it. Shulman viewed PCK as the professional knowledge that teachers need to teach a specific content to make it understandable for their students. He considered PCK as the teacher knowledge that distinguishes a pedagogue (someone who can teach the content) from a content specialist (someone who knows the content). Shulman also noted that PCK develops as a result of the experience gained through teaching. Research in science education has focused on studying and assessing science teachers' pedagogical content knowledge of teaching various curriculum areas and topics, which gave rise to the new idea of topic-specific science PCK. However, there have been few efforts to understand the PCK construct through studying science teachers' topic-specific pedagogical content knowledge. This research study accessed the knowledge that science teachers articulated about teaching force and motion topics, and contributes to the existing literature on teachers' pedagogical content knowledge (PCK) of science teachers.

I studied secondary school science teachers' personal experiences of engaging with the science curriculum in terms of planning and teaching it—which I think of as "living the science curriculum"—since they bring life experience to their planning and enacting of it in their classrooms. Using guiding questions and practical examples for discussion, I listened carefully to the secondary school science teachers' descriptions of their experiences and collected narrative data about their experiences of living the science curriculum. I interpreted their experiences by analyzing the narrative data, and developed a narrative configuration for each participant's teaching, which I prefer to call a "story of teaching," to portray their topic-specific science PCK.

This study portrays the topic-specific PCK of participant secondary school science teachers. I also explored ways to transform the PCK of individual science teachers into a practical form—teaching, learning and assessment tools—that can be used to help pre-service science teachers to develop their science PCK. The study initiates a discussion about a possible connection between topic-specific science PCK and the PCK construct that is missing in the existing literature.

In this chapter, I will introduce the research study. This begins with my background and personal connection to the study—my story—which describes my experience of engagement with this study and my learning about pedagogical content knowledge and its assessment during this project. I describe the "beginning" of my story, which is the point in time when I planned to enter into this research project and the lives of the research participants. In this chapter, I also outline the research questions that guided this research study, and discuss the worthiness of the research by highlighting the contributions the study makes to the science teacher education research community. As a conclusion to Chapter One, I present the organizational structure of the thesis.

1.2 The Beginning of My Story: Coming to the Study of PCK

As suggested by Clandinin and Connelly (1995), my story is temporal in nature and has a beginning and an end. I describe in this section how my story—an inquiry into the PCK of secondary science teachers—began. The story reaches its conclusion in Chapter Five, where I discuss the findings of this inquiry to answer the research questions.

My curiosity about pedagogical content knowledge (PCK) as a research topic originated at Monash University, Australia, where I earned an MEd degree in 2005. I had the opportunity to attend a talk by Dr. John Loughran, a professor in the Faculty of Education at Monash University, and a renowned researcher of science PCK. His research program on the PCK of science teachers has greatly influenced the discussion about science PCK around the world. This talk led me to think that PCK is a very useful type of knowledge for pre-service science teachers. When I first encountered it, I established my first broad question about PCK: how can we help pre-service science teachers develop their science PCK?

This question perhaps emerged from my experiences as a science teacher educator in Pakistan, where I participated in science teacher education curriculum reforms at the University of the Punjab before starting my MEd program at Monash University. The biggest challenges we confronted at that time were to understand what the knowledge base of science teaching was and how we could help pre-science teachers become effective teachers. It was during this curriculum reform process that I read Shulman's (1986, 1987) work and came across the notion of pedagogical content knowledge (PCK). This is what came to my mind when I heard Dr. Loughran's talk. The idea of PCK appealed to me because of its roots in subject matter knowledge and its potential focus on students' difficulties in understanding the nature of specific

science content—the aspect of science education I found critical during the science education program I took in 2000 in Pakistan.

At that time, during my science education program, I had a very powerful experience—I took a course entitled Concept Learning in Science. Although named vaguely, this course was based on research on students' preconceptions. I studied the alternative ideas students bring to the science classroom about various science concepts, and how these preconceptions pose difficulties in their understanding of the relevant science content. This course not only provided me with a constructive framework from which to operate as a science teacher, but it also highlighted the importance of understanding science in depth. Consequently, I could figure out, for example, why certain students in my science class believed so strongly that in a series circuit, the first bulb after the battery would be brighter than the next one.

From this, I could develop activities to help students understand that in an ideal situation (to conform to the prescribed science curriculum), all the bulbs in a series circuit are equally bright and that therefore they all offer the same resistance. Later, I mixed bulbs of various resistances for some groups to create "discrepant events" (Liam, 1987). This intentional conflict helped many of these students to confront and modify their alternative idea that the first bulb "uses up" most of the energy, which led to their thinking that the first bulb is brighter than the second one.

I also collected some computer simulations to strengthen the concepts of current, voltage, and resistance. I think this type of conceptual understanding is fundamental (Gunstone, 2004) for understanding science in high school and can lead towards success in advanced physics and engineering courses. This course interested me so much that I decided to do my Master's research in the same area, and conducted a research study on pre-service science teachers' ideas

about electric current. I found that many pre-service science teachers held the same alternative ideas about current as those held by high school students.

I realized that it was important for pre-service science teachers to develop a deep understanding of the science content, which I prefer to call a conceptual understanding of science. This includes awareness of students' possible preconceptions, how these preconceptions can affect science learning, and what strategies can help students confront as well as modify their preconceptions in various science topic areas.

After completing my MEd (Science) in 2001, I became a science teacher educator, and my focus shifted from students to student teachers. I wanted to help student teachers develop a conceptual understanding of science content so that they could teach science effectively in their future classrooms. Initially, it was easy to maintain this focus because the teacher education program I taught at the beginning of my career had a greater focus on science content and less of a focus on pedagogy. This teacher education program for elementary science teachers was designed by consultants from Teachers College, Columbia University, USA as a project for the United States Agency for International Development (USAID) to improve teacher education in Pakistan. This teacher education program had a heavy focus on science content because most of the student teachers enrolled in the program did not have a science background, since elementary teachers in Pakistan have generalist backgrounds. While teaching in this program, I observed that these pre-service science teachers were able to explain the science content fairly effectively, but their repertoire of instructional strategies was quite limited.

Later, in 2002, I accepted a position at a public university in Pakistan as a science teacher educator, and taught courses in science education. This program was theory-driven, and pre-service science teachers had to complete many courses in general pedagogy. The content

courses were part of the program but were usually taught by content specialists and treated more or less as standard university science content courses. Many of these courses were considered by pre-service science teachers to be a repeat of their undergraduate science courses and therefore not that useful. I observed during field supervision of pre-service practicums that these student teachers were able to introduce a wide variety of instructional strategies, but the content was often weak. That is when I began struggling with this question: What kind of preparation is required by pre-service science teachers in their major content areas so they can help their students better understand science?

I received a scholarship to take a Master's degree in Australia, and subsequently attended Monash University in 2004-2005, where I gained a wider perspective on science teacher education. I worked with Dr. Richard Gunstone, who was involved in the Learning in Science Project (LISP) in the UK, New Zealand, and Australia. We shared common interests in science education, including the role of students' preconceptions in science learning, constructivism as a conceptual framework for science learning and teaching, and effective pre-service science education. My Master's research project at Monash University focused on the role of physics content and education courses in pre-service high school physics teachers' learning. I was struggling with the right balance between content and pedagogy in pre-service science teacher education and how integration between the two happens. I found the idea of pedagogical content knowledge appealing for the design of pre-service science teacher education courses.

After completing an MEd in Australia, I returned to Pakistan and resumed my duties as a science teacher educator at the University of the Punjab. The science teacher education program there was structured in a way that allowed little possibility to introduce changes. Despite this, I designed courses with PCK as a focus, instead of only content knowledge or pedagogical

knowledge. That is when I was confronted with questions about development and assessment of PCK in pre-service science teacher education programs. To make sure that the student teachers in my courses were developing science PCK, I also felt the need to have learning tools that could be used to assess it.

I had the opportunity to be involved in the Pakistan National Educational Assessment System (NEAS), as the University of the Punjab was a partner institute providing academic and technical support in the then-new national large-scale assessment system. Many consultants from the UK and Australia were involved in the NEAS Pakistan and provided various workshops and courses in large-scale assessment. The workshops that most interested me focused on item development and review, especially in science.

I also completed a course from the Australian Council of Educational Research (ACER) on theoretical and practical aspects of measurement. During this course, we had in-depth discussions on assessment in education, test development, psychometric analysis, and so on. I also received training on how to use item-analysis software.

The training in quantitative analysis helped in many commissioned research studies at the University of the Punjab, where I worked as a team member. For my Master's research project, I relied on qualitative research methods, since they were clearly the most suitable for my research questions. My personal belief in the usefulness of qualitative research to explore educational issues was gaining strength, but the usefulness of quantitative research was also at the back of my mind.

I had always wanted to pursue a PhD, and in 2007 I decided to attend the University of Calgary to achieve that goal. The shape of this research project developed through my work with my research supervisor, Dr. Bonnie Shapiro, who works in the area of students' alternative ideas

of science. She also has participated in the Learning in Science Project (LISP) in the UK, sponsored by Dr. Rosalind Driver, which is a common thread among my mentors and myself in the area of science education. My research questions and proposal were further refined due to my exposure to the wider world of qualitative research at the University of Calgary.

I shaped my initial research proposal differently from what it is now, and received early guidance from a professor who has since left the university. I started a project with the intention of developing assessment tools to evaluate PCK of science teachers, which took me in the direction of item and test development within quantitative and mixed-method research paradigms. It was during the initial literature review of PCK research that I found that the literature on topic-specific science PCK was not sufficiently wide to help me develop items on science PCK in specific topics. Moreover, I also found that there was a gap between PCK as a construct and topic-specific science PCK research and that it was widening rather than closing. This review of the literature shifted my interest towards the need to better understand topic-specific science PCK before developing assessment resources for it. I discussed these concerns with my current research advisor, and this led to a completely different research project.

When I started reviewing the literature on studying teaching and teacher knowledge, I found narrative inquiry to be one of the most suitable research methodologies to study those topics. I extended the scope of the literature review to provide not only a deeper understanding of pedagogical content knowledge and teacher knowledge, but also to develop more diverse ways to research teaching and teacher knowledge. I reviewed the literature on various conceptions of teacher knowledge to highlight the similarities and differences between them and pedagogical content knowledge. One influential source was Fenstermacher (1994), who discussed in depth the epistemological issues attached to pedagogical content knowledge and distinguished between

the formal knowledge of teacher education and the knowledge of the practice. He questioned whether PCK is formal knowledge or whether it results from practice.

The research on science PCK (reviewed in Chapter Two) is generally in agreement that teachers develop pedagogical content knowledge during practice, but there is no clear explanation as to whether PCK lies purely in practice or in formal knowledge. I have sought to understand what the relationship is between these two types of knowledge and how we can transform the knowledge gained from practice into formal knowledge to inform and improve pre-service science teacher education.

These experiences have led to the development of the present dissertation—an inquiry into the PCK of secondary school science teachers, and the potential use of PCK in the design and critique of teacher education curriculum in science education.

1.3 The Intent and Purpose of the Study

Since Shulman (1986) introduced the idea of pedagogical content knowledge (PCK), there has been ample research on science teachers' PCK. The literature on the pedagogical content knowledge of science teachers is divided into two main areas: (a) research on the PCK construct, and (b) research on topic-specific PCK in a variety of curriculum areas.

Research on the PCK construct covers several constituent parts included in PCK, referred to as teacher knowledge categories, such as content knowledge, knowledge of the curriculum, and knowledge of goals. It also covers the connections between these teacher knowledge categories representing the PCK construct as a conceptual framework or model. Moreover, in the body of research on the PCK construct, researchers have focused on varied curriculum topic areas and teachers' backgrounds, but they have not made a sufficient distinction between them. Conversely, the research on topic-specific science PCK has mainly focused on selected teacher

knowledge categories of PCK to understand how science teachers develop or use these categories, without placing topic-specific PCK within the broader PCK construct. This has resulted in a widening of the gap between the two research areas. The present research is an effort to narrow this gap. It focuses on a specific science topic to study all constituent parts of PCK and to develop connections between topic-specific science PCK and the PCK construct.

The current literature on science PCK diverges from the wider literature on teacher knowledge—it involves the personal knowledge, the practical knowledge, and the personal practical knowledge—which views teachers as curriculum planners. The research on science PCK has used various methodological designs that are predominantly qualitative, but narrative inquiry is a methodology missing in the current research literature on science PCK. The present research adopts a narrative inquiry methodology because it is the most appropriate approach to address the research questions, and attempts to introduce new ideas about teacher knowledge, specifically pedagogical content knowledge, in science education. The key contribution is using *narrative analysis* and *analysis of narr*ative techniques suggested by (Polkinghorne, 1995). I used the narrative analysis technique— that is also referred to as the process of narrative configuration—to analyze the data that I gathered, which is not currently found in the research literature on pedagogical content knowledge. This approach assisted in portraying topic-specific PCK of the participant teachers.

The present research is an effort to study participant science teachers' experiences of teaching specific science topics using knowledge that they are able to articulate, and to develop the stories of these teachers' teaching using narrative analysis (Polkinghorne, 1995) to illustrate their topic-specific science PCK. I have used reflexive and recursive processes to develop my own story to present my understanding of topic-specific PCK and the PCK construct. I also

present the analysis of science teachers' stories using the analysis of narrative technique described by Polkinghorne (1995) to develop scenario-based formative assessment tools. These tools will be presented in Chapter Five and can be used in engaging pre-service science teachers in discussions about topic-specific PCK as a procedure to help them articulate their stories of learning and teaching these topics. The tools can also be used to assess teachers' topic-specific PCK if desired.

1.4 The Research Questions

The following research questions guide the procedures and design of the research study:

1. How do secondary school science teachers describe their experiences of conceptualizing and teaching topics related to force and motion?
2. How might science teachers' descriptions be organized as stories to reveal aspects of their pedagogical content knowledge (PCK) of science teaching?
3. How might science teachers' descriptions provide a connection between topic-specific science PCK and general science PCK?
4. How might science teachers' descriptions inform the development of teaching, learning, and assessment tools to help pre-service science teachers develop their PCK, and to assess it?

1.5 The Worthiness of the Research

The worthiness of this research study lies in the consideration of the value of adopting narrative inquiry as a research methodology and using teachers' own voices and stories to understand their experiences of living the science curriculum. The stories shared by the teachers about their experiences of teaching science (force and motion) provide insight into their pedagogical content knowledge of teaching this content. I hope that this research study will

contribute in a significant way to the literature on PCK of science teachers by providing possible connections between topic-specific science PCK and the PCK construct. This will facilitate a consistent framework for science PCK that can be used to study topic-specific PCK. From a methodological standpoint, this framework can then be used in future research to develop assessment tools in other science areas. Moreover, the triangulation design used in this research study is content-specific and might guide future research on science teachers' knowledge in specific topic areas.

The practical worth of the research study lies in its value to develop teaching, learning, and assessment tools that have the potential to be used in science teacher education. These assessment tools can serve the purpose of learning about science teaching and the formative assessment of pre-service science teachers. The tools have the potential to evaluate any interventions introduced during science methods courses for the development of pre-service science teachers' PCK in a specific concept.

1.6 Organization of the Thesis

The thesis is organized into six chapters and seven appendices. Chapter One(Introduction) provides an overview of the research study, establishes the background for the research, describes the reasons for choosing the topic for this research, outlines the research questions, and discusses the worthiness and value of this research study.

Chapter Two (Literature Review) presents a synthesis of the relevant literature that supports the rationale and significance of the current study. This chapter reviews the literature on teacher knowledge and looks at pedagogical content knowledge as the professional knowledge of teaching science, which lies at the heart of the teaching experience and can be accessed through the personal stories of science teachers. The chapter also reviews approaches that have been used

for studying and assessing science teachers' PCK and identifies narrative inquiry as a methodology missing in the study of those teachers' PCK. This in turn provides reasons to use narrative inquiry as a way to provide a fresh new look at the topic. Chapter Two also delineates the conceptual framework that was employed as a lens to interpret experiences of the participant science teachers and organize their pedagogical content knowledge.

Chapter Three (The Research Process) describes the research process, presenting the design of the research study and the narrative inquiry methodology as a research approach. It describes the research participants, data sources, interview tools used to encourage teachers to tell their stories to gather information, and the process of data analysis.

Chapter Four (Stories of Teaching Force and Motion) is organized into four parts where each part presents the story of one participant's experiences of teaching force and motion topics. Part I presents the story of Kevin's teaching as an example to represent the process of data analysis for narrative configuration. This is because it contains topic-stories that are then used to develop the story of his teaching that embodies his topic-specific pedagogical content knowledge. For the other three participants, I present only their stories of teaching, as a means to describe their pedagogical content knowledge. Part II presents the story of Jason's teaching, which exemplifies his in-depth understanding of the concepts related to force and motion and his unique approaches to teach these topics. Part III presents the story of Monica's teaching to reveal her unique knowledge of teaching these topics, and Part IV presents the story of Dave's teaching as an illustration of his distinctive knowledge of teaching these topics.

Chapter Five (The Story of Learning about PCK) discusses the findings, four stories of teaching force and motion, to answer the research questions. The chapter is organized in four sections, and each section addresses one of the four research questions. It takes the form of the

story of learning alongside this research process, where I look at the process of meaning-making in this study and describe my experience of living with this research while conducting it. Here, I discuss the conversations and stories of the participant science teachers to portray my new learning about the pedagogical content knowledge of science teachers that followed from the questions for the study. I also present the teaching, learning, and assessment tools and the process involved in developing these tools. Furthermore, I suggest how to use the formative assessment tools for pre-service and in-service science teacher education, and offer possibilities for assessing comprehensive topic-specific PCK with regard to teaching force and motion.

Chapter Six (Reflections, Implications, and Future Research) presents theoretical, methodological, and practical implications of this research. The chapter also describes the hurdles I faced during this study and the limitation they caused. I also offer recommendations for future lines of inquiry.

In the upcoming chapter, a review of the relevant literature is presented to situate the current research within the literature on teacher knowledge, specifically on pedagogical content knowledge. I also review the literature on narrative inquiry as a methodology to study the experiences of science teachers, in order to access their topic-specific science PCK.

Chapter Two: LITERATURE REVIEW

In Chapter Two, I present a review of several interconnected streams of thinking on teaching and teacher knowledge to develop a wider understanding about pedagogical content knowledge (PCK), a type of knowledge possessed and used by teachers, which distinguishes them from content specialists (Shulman, 1986) and other professionals (Lee, 2005). This literature review is organized into four parts, with each part focusing on one of the streams of thinking.

In Part I, I present an overview of the research on teacher knowledge, highlighting various conceptions of teacher knowledge and the impact it has on teacher education. In Part II, I present a synopsis of the literature on pedagogical content knowledge, which I have organized using various existing PCK theoretical frameworks. The aim is to review the limitations of these frameworks to guide research on topic-specific science PCK and propose a new framework. In Part III, I offer a conceptual framework, Comprehensive Topic-Specific Science PCK, which I developed to conceptualize topic-specific PCK of science teachers. I used several available theoretical frameworks—popularly called PCK models—to depict the PCK of teachers in science education. These theoretical frameworks could not assist in the present research because most of the frameworks are based on general science PCK. This research, however, is oriented to the organization of *topic-specific* science PCK. This literature review pointed towards the need for a conceptual framework, one that can provide a consistent framework for representing topic-specific science PCK and developing an assessment of this knowledge. Here, I describe how these frameworks contributed to developing a heuristic that may provide a conceptual framework for topic-specific science PCK. In Part IV, I briefly discuss the literature on the assessment of teaching, highlighting the methods of assessing teacher knowledge and their PCK. I also review

the literature on developing formative assessment probes, based on the research on student ideas in science. I particularly focused on conceptual understanding of the science topic, basic mechanics at the high school level, which guided the value of formative assessment probes to help students learning in this science area. This literature review assisted in conceptualizing and developing formative assessment tools that can be used to develop and assess the topic-specific pedagogical content knowledge of science teachers. In Part V, I present literature on narrative inquiry as a research methodology. I have highlighted various approaches to narrative inquiry and describe the approach that I have adopted for the present research.

PART I: RESEARCH ON TEACHER KNOWLEDGE

I reviewed the relevant research to identify various conceptions of teacher knowledge and the impact it had on teacher education. In this section, I present a synthesis of that research.

2.1 Teacher Knowledge: Two Parallel Concepts

> *A conceptual framework for the knowledge base of teaching enables us to say what we are teaching and assessing and what we are not. (Reynolds, 1992, p. 42)*

Shulman (1987) first sparked others' interest in the idea of a knowledge base for teaching when he presented the concept as an answer to define professional knowledge base for teachers. The phrase *knowledge base for teaching* has also been used as an alternative to describe the knowledge base of teaching. These two parallel and related concepts are described below.

2.1.1 Knowledge base *for* teaching (profession)

The American Association of Colleges for Teachers Education (AACTE) perhaps presented the first formal view of a knowledge base for teaching, referring to it as "The Knowledge Base for Beginning Teachers" (Reynolds, 1989). Later, many new frameworks for teacher knowledge were introduced, and "knowledge base for teaching" became a common

phrase in the teacher education community (Reynolds, 1992), encompassing the various types of teacher knowledge required for teachers to actually teach. Shulman's (1987) view of the knowledge base for teaching comprises seven knowledge categories: content knowledge, knowledge of learners and learning, curricular knowledge, knowledge of contexts, general pedagogical knowledge, knowledge of goals, and pedagogical content knowledge.

Shulman's (1987) formulation of the knowledge base for teaching has been criticized for being simplistic, presenting an objectivist view of teacher knowledge, and leaving out the complexities of teaching (Barnett & Hodson, 2001; Carlsen, 1999; Sockett, 1987; Valli & Tom, 1988). Despite the criticism, Shulman's view stimulated a re-examination of teacher education and opened a debate in teacher education communities about teacher knowledge and thinking. Abell (2008) asserted that the knowledge base introduced by Shulman was different from previous conceptualizations, first presented in the 1960s and 70s, which contained only a set of rules for effective teaching. She emphasized that in general, Shulman's idea of teacher knowledge was different because it was derived from working with actual teachers and what they know about the particular subject areas.

The idea of a knowledge base for teaching has been used to design teacher education based on the existing frameworks. That is why it is a dynamic concept and requires constant evaluation to respond to the latest developments in the field. Strom (1991) indicated the need to (re)define the knowledge base for teaching for four reasons: (a) to decide the content and structure of teacher education, (b) to evaluate the quality of teacher education programs, (c) to evaluate teachers and teaching, and (iv) to assess teacher for professional certification. Beyond having teaching recognized as a professional status, there is a need to deliberate on teacher knowledge by contemplating "(a) the type of knowledge required and relationships among

[knowledge] categories identified, (b) conceptual frameworks for organizing and using knowledge, and (c) the modes of inquiry used in creating and validating knowledge claims in the field" (Strom, 1991, p. 1). Darling-Hammond (2006) suggested that to develop a professional knowledge base for teaching, teacher education should concentrate on the "close connection between theory and practice, coursework and clinical work" (p. 321). Hiebert, Gallimore, and Stigler (2002) suggested a new phrase encompassing the idea of a knowledge base for teaching, and that is "knowledge base for the teaching profession" (p. 3), which clarifies the underlying meaning.

2.1.2 Knowledge base *of* teaching (personal)

Hiebert et al. (2002) noted that each teacher possesses a "personal knowledge base" of teaching which informs his or her practice (p. 3), and this knowledge base is different from the knowledge base *for* teaching (that is, the professional). The personal knowledge base guides and influences a teacher's actions in explicit pedagogical situations (Brown & McIntyre, 1993). The personal knowledge of a teacher can also be called the *knowledge base of teaching*, as it emerges from actual teaching, in contrast to the term *knowledge base for teaching*, which commonly defines the knowledge required for teaching.

The personal knowledge base of a teacher is also described using terms such as practical knowledge (Elbaz, 1981; 1983), personal knowledge (Lampert, 1985), experiential knowledge (Clandinin, 1985; 1988), and personal practical knowledge (Clandinin & Connelly, 1995; 1996). This suggests that the personal knowledge base of a teacher is transient, subject to change, and situated in personal experiences inside and outside the classroom (Barnett & Hodson, 2001).

The personal knowledge base of teaching has also been referred to as "teacher knowledge." Verloop, van Driel, and Meijer (2001) argued that "teacher knowledge should be included in this

knowledge base [for the teaching profession] along with formal propositional knowledge" (p. 441).

In summary, the knowledge base *for* teaching is a broader view that involves different knowledge aspects required for teaching in general, while knowledge base *of* teaching is the knowledge that individual teachers possess and use for teaching. Clearly, it is worthwhile to distinguish that knowledge base for teaching (the professional or academic knowledge) from the personal knowledge base of a teacher (Verloop et al., 2001, p. 443).

2.2 The Development of Terminologies and Approaches to the Study of Teacher Knowledge

Ideas about teacher knowledge have changed over time, along with changes in the approaches to studying teaching. Similarly, many terminologies have been developed to describe various teacher knowledge. The following section provides a chronological review of ideas about teacher knowledge and the introduction of new terminologies representing that knowledge.

2.2.1 Teacher knowledge as a referent of student achievement

During the 1960s and 70s, process-product research dominated the study of teaching, and the terms associated with this era were "teacher behaviour" and "teacher characteristics." At that time, efforts were made to try to link classroom factors and students' achievement. In a meta-analysis of teacher effectiveness over the past few decades, Siedal and Shavelson (2007) observed that "early teaching effectiveness research hypothesized that certain teaching acts and conditions would affect student outcomes" (p. 454). They asserted that the product-process approach considered variables related to "product [student], process [teaching], presage [traits], and context" (p. 456). Product variables usually included students' achievements and their attitudes towards learning, and product variables included achievement or attitudes toward learning. Process variables considered were mainly teacher characteristics—that is, their

personality traits and behaviour in the classroom that potentially affected students' achievements and attitudes towards learning. Presage variables considered students' characteristics such as age, gender, socioeconomic status, ability, and context variables considered were parental involvement and the use of technology and media.

The predominant approaches used in product-process research are large-scale surveys, correlational models, or quasi-experimental designs to control extraneous variables and study the impact of those variables on student achievement (Siedel & Shavelson, 2007). Some of these research studies reported that neither schools nor teachers have significant impact on students' achievements, and that is the reason that "scholars and policymakers, concerned about the equity and improvement of education, did not see much need for research on teaching or upgrading the quality of the teaching profession" (Porter & Brophy, 1988, p. 74), implying that the terms representing teacher knowledge in that era—teacher characteristics, teachers' personality traits, and teacher behaviour—were misleading.

2.2.2 Teacher knowledge as a referent of student learning

In the late 70s and early 80s, the research expanded to study various instructional strategies and their impact on students' cognitive development. This led to a view of teaching that incorporated student learning, in contrast to the previous view of student achievement as an outcome of effective teaching (Darling-Hammond, 2000). From a cognitive perspective, teachers were facilitators and responsible for creating an effective learning environment by taking into consideration cognitive and meta-cognitive activities (Brophy & Good, 1986), since this is what results in the cognitive development of students. The research on teaching associated with that era focused on the learning theories and learning environment that help students learn, and teachers' ability to facilitate and create constructivist learning environments. The predominant

approaches used in the research on student learning and constructivist classrooms included both positivist research using surveys, correlational models, or quasi-experimental designs, and qualitative research using interviews and/or case studies about the role of the teacher, student thinking, and the effect of various teaching strategies on student thinking.

2.2.3 Teacher knowledge as a referent of teacher cognition and practice

Research on the cognition and knowledge development of teachers flourished during the 1980s (Clark, 1988). Within that research, Elbaz (1981; 1983) posited that teachers develop their knowledge through the act of teaching—something she called "practical knowledge" (p. 5)—which she suggested had five dimensions of knowledge: (i) subject matter, (ii) instruction, (iii) curriculum, (iv) self, and (v) teaching milieu. Elbaz used a case study approach for this research and later followed up with a narrative inquiry to study teaching and teachers' practical knowledge. Lampert (1985) proposed that teachers develop "personal theories" to solve pedagogical problems, and called these theories "personal knowledge." She used self-study approach to research her own classroom to study her own practice and develop stories of that practice.

According to Clandinin (1986), teacher knowledge is "experiential, value-laden and orientated to practice," which she called "experiential knowledge" (p. 19). Connelly and Clandinin (1986) used a longitudinal study to look at the knowledge teachers hold and the way they use it. They termed this knowledge "personal practical knowledge." (p. 25). They asserted that such knowledge is subject to change and is situated in one's personal experience both in and out of the classroom. Other terminologies used to describe teacher knowledge are *wisdom of practice* (Schwab, 1971), *professional knowledge* (Tom & Valli, 1999), and *professional craft knowledge* (Brown & McIntyre, 1986).

In addition, Shulman (1986, 1987) introduced the term "pedagogical content knowledge" (PCK). He initiated and contributed to the debate on teacher knowledge by providing a new vision to study teaching that has a focus on the subject matter to be taught. He presented his view of the knowledge base for teaching and of the seven categories included in this knowledge base. PCK was viewed as the most important, and the one that distinguishes a pedagogue from a content specialist (Shulman, 1987a).

The term "professional knowledge" is used to describe knowledge across all professions. According to Dickenson (2007), it is "dynamic, intellectual, personal, developmental, and research-informed, and is achieved in synthesis" (p. 14). In the context of the teaching profession, Cochran-Smith and Lytle (1999) introduced three terms: knowledge for [teaching] practice, knowledge of [teaching] practice, and knowledge in [teaching] practice. These terms made clear the meanings attached to teacher knowledge, and provided links between teacher knowledge and practice. The term "knowledge in practice" is close to the term "knowledge in action" introduced by Clandinin and Connelly (1986), which is the knowledge studied, used, or applied in practice, and for them, epistemologically, knowledge in practice is the *only* teacher knowledge because it provides evidence that the knower and the known are one. Knowledge *of* practice is the knowledge that teachers have about their teaching experience, and knowledge *for* practice is the knowledge required by teachers to teach. Researchers have used a variety of terms to describe teacher knowledge, but they all agree that teachers have theories that can contribute to the professional knowledge base *of* teaching (Zeichner, 1994). These theories of teachers, developed over time as a result of continuous engagement with the curriculum, students, and certain settings (classroom, school, and so on), have immense value.

2.2.4 Teacher knowledge: A dualism

Along with new conceptions of teacher knowledge, there has been a discussion about the nature of the "knower and the known" (Fenstermacher, 1994, p. 1). Fenstermacher noted various conceptions about teacher knowledge in his extensive review of the literature on teaching, which was aimed at "reconsider[ing] the epistemological character of what is and can be known by and about teachers" (p. 3). He categorized the research literature on teacher knowledge into two areas of study: (a) the knowledge that teachers generate as a result of their experience of classroom teaching – in other words *practical knowledge*, and (b) the knowledge about teaching that is generated by those who specialize in research on teaching, which he referred to as *formal knowledge* and that can be generalized across various contexts. Fenstermacher (1994) also noted that practical knowledge and formal knowledge are epistemologically different. He proposed that practical knowledge is developed by reflecting on action and experience and is "related to how to do things, the right place and time to do them, or how to see and interpret events related to one's action" (p. 12). Furthermore, Fenstermacher suggested that formal knowledge develops through research on teaching using various methods and is a "modification of what is known as the standards, or justified true belief, or account of human knowledge" (p. 8).

Cochran-Smith and Lytle (1998) affirmed that teacher knowledge can be organized into two categories, "knowledge for teaching" and "knowledge about teaching." (p. 19), and said that:

> There is a formal, theoretical or scientific form of knowledge distinguishable from some other kinds of knowledge variously referred as practical knowledge, craft knowledge, lore, received wisdom, the wisdom of practice, accrued wisdom, or knowledge that is experiential, personal-practical, situated, relational, embodied, popular, and /or tacit. (p. 23)

However, they stated that this is not a useful criterion to critique research on teacher knowledge. Drawing on the literature review conducted by Wideen et al. (1998), Loughran and Berry (2011) have recently re-addressed the concept of utilization (prevalent in research on teacher knowledge) which draws a distinction between the producers and users of knowledge: "From a producer-user perspective, formal knowledge is developed by researchers." (p. 66). They assert that the producer-user concept of knowledge is contradictory to the interpretive worldview, which holds knowledge to be "problematic, actively developed by the knower, idiosyncratic and contextually bound" (p. 66). Loughran and Berry used the term "teachers' professional knowledge" to describe teacher knowledge, which "in and of itself creates an expectation that the knower and the known are inextricably linked and that such thinking is embedded in their experience of practice" (p. 66).

Cochran-Smith and Lytle (1998) also supported the deconstruction of the dualism of practical-formal knowledge by merging their two categories: knowledge for teaching and the knowledge about teaching. Dissolving the dichotomy between practical and formal knowledge is also possible by using new terms to represent teacher knowledge, for example, theories in practice (Edelsky et al., 1991), practical theories (Sanders & McCutcheon, 1986), and praxis (Lather, 1986).

2.2.5 Teacher knowledge: Informing teacher education

The primary source of professional knowledge *for* teachers, which influences teacher education, is research on teaching to expose teacher knowledge (Tom & Valli, 1999). So, one of the purposes of research on teacher knowledge is to study teachers' theories to inform the knowledge base *for* teaching (teacher education curriculum), but the validity of this knowledge base is in question, especially for teacher educators. The two challenges faced are: (a) the

epistemological traditions followed for the generation of professional knowledge (research on teaching), and (b) the relationship between knowledge and practice. As Tom and Valli (1999) stated, "the epistemological orientations of educational knowledge do help clarify the knowledge-practice relationship" (p. 378).

Cochran-Smith and Lytle (1998) argued for the value of practical knowledge, which he called *local knowledge*, to inform the formal knowledge that he called *public knowledge*. He further suggested that *local knowledge* can serve the purpose of *public knowledge*. Nevertheless, "few interpretivists take time to question how the results of interpretive scholarship are useful to teaching" and teacher education (Tom & Valli, 1999, p. 385). Erickson (1986) also discussed the utility of educational scholarship in interpretive scholarship (as cited in Tom & Valli, p. 385).

The National Council for Accreditation of Teacher Education (NCATE) requires teacher education programs to include "essential knowledge of sound professional practice" (NCATE, 1985). Thus, it is the responsibility of the researcher to think of innovative ways to deconstruct the epistemological dualism by transforming local knowledge (personal theories) of teachers into public knowledge (formal knowledge) of teaching in order to inform teacher education curricula.

The above review identifies the problem of teacher knowledge dualism, a widening gap between the *knowledge of teaching* and *knowledge for teaching*. The present dissertation takes this issue seriously by researching knowledge of teaching a specific science topic area and then proposing formative assessment tools for pre-service science teacher education, with the aim of contributing to the development of science teacher education curricula that support the development of topic-specific pedagogical content knowledge.

The many types of teacher knowledge described in the research literature, i.e., practical knowledge, personal knowledge, personal practical knowledge, professional knowledge, wisdom

of practice, teachers' professional knowledge and so forth, are important aspects that teachers have developed through practice (Clandinin, 1986; Connelly & Clandinin, 1986; Elbaz, 1981, 1983). Pedagogical content knowledge is considered essential for teaching (Shulman, 1987; Fenstermacher, 1994), since it focuses on "teaching a specific content" included in school curriculum topics. The following sections present a review of the relevant literature on pedagogical content knowledge to place this construct within a broad view of teacher knowledge.

PART II: RESEARCH ON PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

Pedagogical content knowledge (PCK) is the professional knowledge that teachers need to teach specific content, the primary responsibility of a teacher. According to Shulman (1987), PCK "includes the most useful forms of representation of these ideas [the content to teach], 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" (p. 9).

The following sections aim at understanding the development, use, and especially the nature of PCK.

2.3 PCK: Lack of Clarity

After almost two decades, even after substantial research into science teacher knowledge, the notion of PCK introduced by Shulman (1986, 1987) has still not reached a clear, agreed-upon definition among researchers (Abell, 2007; Berry, Loughran, & van Driel, 2008). The PCK construct has been used inconsistently, and many of its aspects have been overlooked (Abell, 2007, 2008). According to Berry, Loughran, and van Driel (2008), the construct has become so seductive for its potential usefulness in teacher education programs that research on PCK has mostly ignored careful clarification of the construct of PCK; therefore, "the construct [PCK] did

not impact the valuing of science teachers' professional knowledge and practice positively which is a major concern for such an important profession" (p. 1272). Any research on PCK done without a full understanding of the PCK construct may introduce diverse interpretations that could lead to limited or misleading implications. It is critical to understand PCK in its wholeness to assess it. Additionally, understanding PCK in its entirety can also assist researchers to interpret their research accurately.

The construct of PCK lacks clarity both structurally and philosophically. The literature reveals an ongoing debate on the structural clarification that mainly surrounds which knowledge components are included in PCK and how they interconnect. The nature of the pedagogical content knowledge itself is less delineated. The following sections provide a synthesis of the existing literature on PCK aimed at identifying its intrinsic nature, suitable ways to study it, and a conceptual framework to access, organize, and assess the topic-specific PCK of science teachers.

2.4 The Nature of PCK

PCK is important teacher knowledge. However, the nature of this knowledge is still in flux. "Knowledge" can be conceived as disciplinary, practical, and experiential (Deng & Luke, 2008): Disciplinary conceptions of knowledge describe the knowledge of various established disciplines, practical knowledge conceptions represent procedural knowledge derived from the wisdom of practice, and experiential knowledge is conceived as being located in human experience and practice. The following sections present the conceptions about PCK as identified in the literature.

2.4.1 The practical and experiential nature of PCK

The teacher knowledge types previously described—practical knowledge, personal knowledge, personal practical knowledge, professional knowledge, wisdom of practice, and others—are important knowledge types that teachers develop through practice. Researchers such as Elbaz (1981, 1983), Clandinin (1986), and Connelly and Clandinin (1988) have used innovative approaches to study teachers and teaching. Pedagogical content knowledge is considered as essential for teaching (Shulman, 1987; Fenstermacher, 1994), but "what is difficult to ascertain in this work is whether it is distinctly formal or practical in type, or a blend of the two" (Fenstermacher, 1994, p. 14).

Research on PCK in science education has reported on the knowledge of experienced and novice science teachers in various topic areas, to assess or evaluate their professional expertise. This line of research has also documented the PCK of expert science teachers (Loughran et al., 2001, 2002, 2004). These researchers have studied experienced science teachers to portray their topic-specific science PCK to show the teachers' knowledge in relation to specific science content. PCK has been accessed while working with actual teachers and comprises what they know about the subject matter and their understanding about how to teach it (Abell, 2008). According to Shulman (1987), teachers' knowledge is practical, develops over years of experience, and is about how they have accumulated "wisdom of practice" (Shulman, 1987). In Gudmundsdottir's (1991) view:

> Pedagogical content knowledge is mostly "homemade" developed on the job, but working with texts, subject matter and students in different contexts year after year, and in the case of some experienced teachers, for decades. . . . Pedagogical content

> knowledge is a practical way of knowing. . . . It is learned mostly on the job from trying things out and observing, talking and working with other teachers" (p. 35)

PCK is the "knowledge possessed by expert teachers" (Veal & Makinster, 1999). Fenstermacher asserts that PCK is no different from the personal and personal practical knowledge (1994, p. 6). This argument points to the experiential and practical nature of PCK. The twofold issue shows what is often seen as a disconnect between what teachers know as a result of their practice (practical knowledge) and what student teachers need to know to become competent teachers (formal knowledge).

2.4.2 The narrative and value-laden nature of PCK

Besides the practical and experiential nature of PCK, Gudmundsdottir (1991) also noted the narrative nature of this type of knowledge. Gudmundsdottir worked with Shulman (1987) as a graduate student on his project *Knowledge Growth in Teaching*. She has written extensively about the narrative nature of PCK (Gudmundsdottir, 1991, 1995, 1998, 2013). Hashweh (2005), another of Shulman's graduate students, who conducted his research on PCK of teachers in the same Shulman's project, also highlighted the value-laden and narrative nature of PCK. He stated:

> This conception of pedagogical content knowledge as having a component related to the teacher's beliefs about content or subject matter was not unique to Gudmundsdottir. Shulman and his colleagues were already pointing out this component (see Grossman et al., 1989). However, the distinctive contribution of Gudmundsdottir was her insistence on both the value-laden and narrative nature of PCK. (p. 274)

Hashweh (2005) reconceptualized PCK as a collection of topic-specific pedagogical constructions (TPCs) which are smaller knowledge entities or units. According to him, "a group or collection of [these] smaller knowledge entities" is called PCK (p. 27). Hashweh also believed

that PCK is better understood as a collection of TPCs instead of a whole. Since each teacher develops topic-specific TPCs as a result of experience of teaching that topic over a long time, these small units of knowledge, TPCs, are situated in personal experience and values of the teachers and are context-dependent. Highlighting the context-dependent nature of the construct PCK, Barnett and Hodson (2001) argued that PCK could be developed or understood only in a particular context. He also offered the new term "pedagogical context knowledge (PCxK)."

According to Gudmundsdottir (1991), "the study of teachers' narratives brings educators to the heart of pedagogical content knowledge" (p. 34), and narratives are "packages of situated knowledge" (Jorden, 1989, as cited in Gudmundsdottir, 1991). A teacher's narrative is studied by interpreting his or her teaching experience. The present research aims to study science teachers' experiences of engagement with a specific science curriculum through their narratives—the topic-specific pedagogical constructions (TPCs) of science teachers—to access their PCK.

2.5 PCK: Implicit or Explicit Knowledge

Many teachers find it difficult to express their personal and practical knowledge. There is a common belief that teachers' knowledge is tacit, thus it is problematic to make it explicit. Loughran et al. (2006) argue that PCK is tacit knowledge and science teachers cannot articulate it. Contrary to this view, Kennedy (1998) argued that PCK "must be explicit rather than tacit" (p. 257). He used the example of knowing the way to the grocery store and being able to give directions to it, which is not possible without having explicit knowledge. Similarly, if a teacher has a strong conceptual grasp of a subject and can solve problems and can reason abstractly about issues in that field, that teacher might still not be able to help students understand these issues unless his or her own knowledge is explicit (Wilson, Shulman, & Richert, 1987, as cited in Kennedy, 1998, p. 257). Kennedy further argued:

> Having explicit knowledge is important in part because it enables better explanations, but also enables teachers to decide what is important to teach, what should be taught now rather than late, and what kind of problems could be posed to students that would most likely facilitate their understanding of some particular ideas. (p. 257)

In agreement with Kennedy (1998), this research assumed that science teachers should be able to articulate their knowledge of teaching a specific science curriculum if they have developed science PCK. Therefore, the present research studies the articulated knowledge of science teachers to access their science PCK.

2.6 PCK: Transformation of Practical Knowledge into Formal Knowledge

As discussed previously, there have been few efforts to use the results of the interpretive scholarship of teaching to inform teacher education. However, the value of such efforts has been extensively discussed. Loughran and Berry (2011) suggested that "paying careful attention to how knowledge is created and used offers interesting possibilities for developing approaches to teacher learning . . . as well as how others interpret and use that knowledge in their own practice" (p. 66).

Cochran-Smith and Lytle (1998) suggested that pedagogical content knowledge is a term that has the potential to dismantle the practical-formal knowledge dualism. They also proposed using terms like "theories in practice" and "practical theories." However, what is not clear is how this deconstruction process can be achieved. Using the above-recommended terms can also help overcome the consumer-producer dichotomy about teacher knowledge and support collaborative efforts to transform practical knowledge into formal knowledge. Cochran-Smith and Lytle (1999) argued that the value of practical knowledge lies in informing the formal knowledge. It is

the responsibility of the researcher to find ways to transform practical knowledge into formal knowledge.

Perhaps the first successful effort to transform the PCK of experienced science teachers into formal knowledge was done by Loughran et al. (2001, 2004, 2006). These researchers developed Content Representation (Co-Re), a way to portray the PCK of experienced science teachers, and PaP-eRs (Pedagogical and Professional Experience Repertoires) to provide explanations for teachers' thinking involved in the process of teaching specific content. A Co-Re is a matrix containing "Big Ideas" on the horizontal side and related teacher's conceptual understanding necessary to teach these concepts on the vertical side. Similarly, Pap-eRs are the collective narratives and stories of the teachers about their successes and the issues involved in implementing individual instructional strategies to teach particular science topics. Loughran et al. (2004) developed a framework to document the topic-specific PCK of science teachers in the form of these Co-Res and Pap-eRs.

Loughran et al. (2006), in their book *Understanding and Developing Science Teachers' Pedagogical Content Knowledge*, presented units on the PCK of experienced science teachers for teaching certain science topics at junior and senior high school levels in the form of Co-Res and Pap-eRs. These units are examples of the transformed science PCK, a type of professional knowledge. Loughran et al. recommended using Co-Res and Pap-eRs for pre-service science teachers to help them develop their topic-specific science PCK. There is some evidence of blank Co-Res being used to develop the PCK of science teachers and science teacher educators (Hume & Berry, 2011). However, how these already developed Co-Res could be useful in pre-service science teachers' learning is not clear. Moreover, there is no evidence of using Pap-eRs in

science teacher education, but they could undoubtedly be used as case studies for the development of science teachers' PCK.

The present research builds the view that using developed Co-Res in pre-service science teacher education involves the philosophical risk of considering knowledge as a single and objective reality and objective, which can hinder the construction of knowledge within prospective science teachers. On the other hand, using Pap-eRs without a relevant Co-Re may not develop useful PCK. There is a need to expand this line of work by using the results of interpretive research to transform teacher knowledge into forms that carry multiple realities of teacher knowledge and that support construction of new knowledge among science teachers. Researchers in the area of science PCK need to consider the possibilities of using constructed Co-Res and Pap-eRs in science teacher education. Also needed are other innovative ideas that can be used in pre-service science teacher education to develop topic-specific science PCK.

In conclusion, the literature shows that within contemporary conceptions of teacher knowledge, pedagogical content knowledge is practical knowledge that lies in the practice of science teachers, and is best considered as teachers' professional knowledge. As suggested by Cochran-Smith and Lytle (1998), PCK should be transformed to help pre-service science teachers learn how to teach science effectively.

In the following section, I further discuss the ways to study the PCK of science teachers, as well as the evolving structural changes of the PCK construct.

2.7 PCK: Evolution of Ideas about the Construct

The PCK construct has evolved since Shulman first introduced the idea in 1986 in his project, *Learning to Teach*, where he pointed to the importance of subject matter knowledge for understanding, studying, and developing teacher knowledge. When Shulman (1986) introduced

the term "pedagogical content knowledge" he considered it as the integration of content knowledge and pedagogical knowledge. He argued that PCK is an amalgam of various teacher knowledge categories, which includes "the most useful forms of content representation, . . . the most powerful analogies, illustrations, examples, explanations, and demonstrations, . . . the ways of representing and formulating the subject matter that makes it comprehensible for others" (Shulman, 1987, p. 6). Shulman (1986) presented PCK as the professional knowledge that distinguishes the true teacher from a content specialist and hence captures knowledge required to teach effectively. He also asserted that teachers' knowledge of teaching centers on individual topics, referring to PCK as a topic-specific knowledge.

When Shulman first introduced PCK in 1986, he referred only to the knowledge of students' understanding and instructional strategies (which he initially called representations) as the fundamental components of PCK. In his *Learning to Teach* project, he considered PCK as a subcategory of content knowledge, but soon after, in his 1987 paper "Knowledge and Teaching: Foundation of the New Reform," Shulman (1987) redefined PCK as a distinct teacher knowledge category and defined it as "a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of understanding" (p. 8). He considered PCK as a "distinctive body of knowledge for teaching which represents blending of content and pedagogy into an understanding of how particular topics, problems, and issues are organized, represented, and adapted to the diverse population of learners and presented for instruction" (p. 8).

Subsequent research and discussion on PCK explored the teacher knowledge categories that shape the PCK of teachers in various curriculum areas, which led to including other teacher knowledge categories (components) in the definition of PCK (Grossman, 1989; Loughran et al., 2001; Magnusson et al., 1999; Tamir, 1988). However, it is noteworthy that some of the research

on PCK persists in using Shulman's initial view and definition of PCK as a type of content knowledge.

Many researchers have raised questions about the conception and structure of PCK, and their critical contributions have introduced various expansions to the construct of PCK. A study by Grossman (1989) on understanding the development of English teachers' PCK provides an extended model that portrays the development of PCK. She included within PCK:

(a) Knowledge of goals

(b) Knowledge of students' understanding

(c) Knowledge of instructional strategies

(d) Curricular knowledge

Grossman also tried to develop links between PCK and other types of teacher knowledge, including subject matter knowledge, general pedagogical knowledge, and knowledge of contexts. Grossman developed this model by reviewing the literature on PCK and using it to organize the PCK of her participant English teachers.

Similarly, a research study by Marks (1990) on mathematics teachers' PCK resulted in another model of PCK that included new categories of teacher knowledge. According to Marks, PCK is composed of four knowledge categories: (a) subject matter knowledge, (b) knowledge of students' understanding, (c) media for instruction in the subject area, and (d) instructional processes for the subject matter. He identified a need to clarify the PCK construct, and strongly recommended expanding it to develop a clear and complete picture of PCK in different disciplinary areas.

Cochran et al. (1993) attempted to view teacher knowledge in the light of constructivism. They suggested a new title for the construct, *Pedagogical content knowing* (PCKg), and offered a

model to depict it. According to their model, PCK is the result of the integration of four other types of knowledge: (a) knowledge of subject matter, (b) knowledge of pedagogy, (c) knowledge of students, and (d) knowledge of contexts. As a result of the development of the PCK concept, all four of these knowledge aspects are also transformed.

2.8 PCK: Conceptualization in Science Education

Specific to science education, Carlsen (1999) proposed the very first theoretical conceptualization of science teachers' PCK. He presented it in the form of a visual model in a landmark edited book on science education and pedagogical content knowledge, *Examining Pedagogical Content Knowledge: The Construct and its Implications* (Gess-Newsome & Lederman, eds., 1999). He used and modified Grossman's (1989) model of PCK to devise a model that represents PCK for science teaching.

Magnusson et al. (1999) conducted an extensive analysis of the literature on PCK and proposed another theoretical conceptualization of it for science teaching. Their visual model of science PCK provided an expanded view of the pedagogical content knowledge of science teachers, including five knowledge components connected in a specific hierarchical way:

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

Magnusson et al. (1999) also described the connections between these five knowledge aspects and provided a further description about each of them.

Recently, Park and Oliver (2006) and Lee and Luft (2008) provided some empirical evidence for their respective expansions of ideas about science teachers' PCK. Park and Oliver (2006) identified five knowledge components of PCK from the literature and developed a pentagon-shaped theoretical model of PCK. The five knowledge components included in their pentagon model are the same as those identified by Magnusson et al. (1999), but are not hierarchically ranked.

In Park and Oliver's (2006) model, PCK lies at the center of the pentagon while the five knowledge aspects are at the five corners. Their in-depth research on three chemistry teachers helped them to further evolve their theoretical PCK model, adding a new component, teacher efficacy. Based on their research, they converted their pentagon model into a hexagonal model with PCK at the centre and six components at the six corners. They also explored new dimensions of PCK by including the roles of teachers' qualifications, their idiosyncrasies, and their reflections: especially, reflection in action, and reflection on action.

Lee and Luft (2008) studied PCK from the perspective of four experienced science teachers, using a case study approach. They identified seven knowledge components contributing to the science PCK of these science teachers:

- Knowledge of science
- Knowledge of goals
- Knowledge of students
- Knowledge of curriculum organization
- Knowledge of instructional strategies
- Knowledge of assessment
- Knowledge of resources

They further identified specific elements within these seven knowledge aspects. Their efforts to represent the PCK of individual science teachers resulted in graphic representations of the unique PCK of each science teacher (Lee & Luft, 2008).

In addition to including new knowledge components in PCK, researchers have also tried to make the relationships explicit between these knowledge components, and found that the "boundaries of PCK are blurry" (Loughran et al., 2000). Earlier, in 1998, Gess-Newsome and Lederman referred to similar blurred boundaries, using the analogy of an ideal gas to help argue that it is difficult to understand explicitly the role of individual knowledge components within PCK. They asserted, however, that studying individual knowledge components of PCK can help in understanding the PCK construct. This argument led towards the importance of understanding *all* the knowledge components of science teachers' PCK to explore how these individual knowledge components are organized in science teachers' overall PCK, which can help in understanding the PCK construct.

An important point to note here is that Lee and Luft (2008) were studying the PCK of science teachers who were teaching topics in various subject areas. This may provide a possible explanation for their different representations of science teachers' PCK. On the other hand, Park and Oliver (2006) studied the PCK of chemistry teachers teaching various chemistry topics and found a more consistent representation of their PCK. This representation of science PCK of chemistry teachers may represent their domain-specific science PCK.

Most of the research on topic-specific science PCK studied selected knowledge components of the science teachers' PCK, which has not added much to understanding and elaborating the PCK construct. van Driel et al. (1998) believed that PCK is basically topic-

specific knowledge, and developed a research program to create examples of topic-specific science PCK in various curriculum topics. Their research contributed to the discussion of PCK but did not offer a new model, relying instead on various existing definitions in the research literature. Loughran and his associates also considered that PCK is essentially topic-specific knowledge. Their research has documented the topic-specific science PCK of science teachers in various curriculum areas (Loughran et al., 2001, 2004, 2006). While they made important contributions towards the understanding of the topic-specific PCK of science teachers and the knowledge base of science teacher education, they did not elaborate on the existing PCK models at the time, and they preferred to employ their own unique approach of studying and documenting topic-specific science PCK. Thus, they ignored newer developments in understanding this construct. Part of the reason might be the appropriateness or sufficiency of the existing PCK models for their research goals.

In Table 2.1 (Appendix A), I present a summary of the research studies that I reviewed about pedagogical content knowledge in different discipline areas (published from 1993 to 2009). I was particularly interested in the nature of the research and the approaches and theoretical frameworks that the researchers used. Most of the research on science teachers' PCK is topic-specific and predominantly qualitative in nature. These studies have focused on the limited knowledge aspects of PCK, mainly relying on the initial descriptions of PCK by Shulman (1986, 1987). Researchers have, however, shown efforts to devise new methodologies to study science teachers' PCK, which include the lesson study method (Van der Valk & Broekman, 1999), Co-eRs (Content Representations), and PaP-eRs (Pedagogical and Professional experience Repertoires) (Loughran et al., 2001).

This review also reveals that the researchers studying one or more aspects of science PCK preferred particular aspects, and considered those aspects' important. These aspects of PCK include: (a) subject matter knowledge, (b) knowledge of students' understanding and their preconceptions, and (c) knowledge of teaching strategies. There is a need to study each knowledge category within science PCK by isolating it from the other knowledge categories. However, this approach can be problematic, since limiting the study to specific PCK components runs the risk of presenting a skewed or incomplete picture of the teachers' science PCK. Further, this complication makes it hard to develop a full understanding of PCK as a construct.

In summary, the research on understanding the PCK construct has not taken into consideration the topic-specificity of the construct. On the other hand, the research on topic-specific science PCK has not considered it important to use science PCK models to frame their research, or develop their own models of topic-specific PCK. This has created a gap, and I suggest that there is a need to bridge this gap between research on science PCK and topic-specific science PCK. To minimize this gap, I propose a new conceptual framework based on the existing science PCK models—Comprehensive Topic-specific Science PCK

PART III: TOWARDS A NEW CONCEPTUAL FRAMEWORK – COMPREHENSIVE TOPIC-SPECIFIC SCIENCE PCK

Based on the review of the literature on PCK, particularly science PCK, I propose a new conceptual framework, *Comprehensive Topic-Specific Science PCK*, to address the questions of the current research project. The following sections describe how the current theories and research on science PCK have contributed to conceptualizing this framework, and how it is a useful lens to explore and analyze the data in this study.

As described above, developmental studies of PCK—research studies with a focus on understanding and developing the PCK construct (Lee & Luft, 2008; Park & Oliver, 2008)—have reported it as an interaction of many different categories of teacher knowledge, as opposed to only the two categories that Shulman (1986) proposed. Although Abell (2008) corroborated the conceptualizations of many other researchers, and affirmed that PCK is an amalgam of *many* knowledge categories at the intersection of content knowledge and general pedagogical knowledge, these *many* knowledge categories are not yet consistently reported in the existing literature. Following Abell (2008), I see topic-specific science PCK as an amalgam of multiple teacher knowledge categories. However, I elaborate by identifying and describing the knowledge categories using ten specific teacher knowledge components. Eight teacher knowledge categories are identified in the existing literature as contributing to the PCK in various combinations: (i) subject matter knowledge, (ii) knowledge of student learning, (iii) knowledge of instructional strategies, (iv) knowledge of resources, (v) knowledge of curriculum, (vi) knowledge of goals, (vii) knowledge of assessment, and (viii) knowledge of teaching contexts. I propose to include a ninth category in science PCK, (ix) knowledge of technology, which has been discussed in other literature as part of technological pedagogical content knowledge. I also propose a tenth teacher knowledge category within science PCK, (x) knowledge of student diversity.

I further describe the ten knowledge components within these teacher knowledge categories, with each of the ten knowledge components being informed by a relevant teacher knowledge category. For example, the category *knowledge of curriculum* infroms the PCK component *knowledge of a specific science curriculum*, which further includes knowledge elements such as the mandated goals, horizontal and vertical connections to other topics, and curriculum emphasis. I argue that these ten knowledge components, and not the ten teacher

knowledge categories, amalgamate into a form of teacher knowledge that is referred as *topic-specific science PCK*.

This concept of topic-specific science PCK is used to represent a new conceptual framework, *comprehensive topic-specific science PCK*. I call this framework *comprehensive* because it includes all possible teacher knowledge categories introduced to date, as opposed to considering only a few of them.

I also argue that this framework represents a transformative model. Gess-Newsome (1999) suggested two parallel models to distinguish the quality of pedagogical content knowledge: (a) an integrative model and (b) a transformative model. The integrative model presents individual teacher knowledge categories coming together as PCK. In an integrative model, teacher knowledge categories exist separately, and the teacher draws upon them to make pedagogical decisions. In contrast to this, in the transformative model the previously disparate knowledge categories are consolidated to generate a new knowledge category, PCK. This consolidated form of PCK is framed as "transformed" PCK, which is ready to use in new pedagogical situations. So, *transformative* PCK exists as a distinct knowledge category that is more unified in nature, in contrast to *integrative* PCK, which exists as individual knowledge categories and hence is less unified. Gess-Newsome (1999) used this distinction to assign quality rankings to the PCK of science teachers, and considered that transformative PCK represents high-quality PCK while integrative science PCK represents poor-quality PCK. I followed the transformative PCK model in the design of the conceptual framework, and asserted that topic-specific PCK is more transformative in nature and hence rich in quality and ready to use. Moreover, each knowledge category is transformed to become a specific aspect that

amalgamates with other specific knowledge aspects to develop topic-specific science PCK as a whole.

To teach a specific science topic, science teachers may draw upon the above ten knowledge components to develop integrative PCK in an immediate pedagogical situation, whether conceptual (planning) or practical (teaching), depending on the science topic and pedagogical situation (including students and context). Teaching the same science topic over a period, integrative PCK, which exists as isolated bits of knowledge, is converted into *transformed* PCK, which represents a unified knowledge and is stored in the teacher's memory as a holistic bundle of knowledge and skills.

As suggested by Gudmundsdottir (1990, 1991, 1995), transformed PCK is value-laden and narrative in nature, and "narrative knowledge is obtained from a narration of experience" which is saved in the brain in the form of a narrative schema. Shank (1990) developed an understanding of the relationship between stories and memories; he stated that teachers' remembered-stories are recreated from the recalled "gist of the stories." Gudmondsdottir (1991) called these stories of teachers' thinking about teaching "curriculum stories", which according to her can be either long (e.g., year-long) or short (a single event). She argued that: "The shorter stories are related to, or generated by, the curriculum stories teachers use" (p. 209) and are about a single example or event related to teaching. Clandinin (1988) referred to these as narrative fragments. Using Hashweh's (2005) term "teachers' pedagogical constructions" (TPCs), these short stories represents pieces of knowledge about teaching a specific science topic. While trying to unpack the PCK amalgam, Hashweh (2005) argued that a teacher's PCK is a collection of TPCs, and thus likely takes the form of events and incidents, i.e., short stories about teaching a science curriculum.

Researchers can access science teachers' short curriculum stories— or their pedagogical knowledge constructions (TPCs) as suggested by Hashweh—by engaging them in meaningful conversations and listening to the remembered gist of their stories about planning and teaching a specific topic.

As identified by Park and Oliver (2008), when teachers' reflect on planning their teaching, may help them to develop their PCK. Therefore, when teachers engage in activities like reflection and professional discussions, they enhance their PCK through telling and retelling their curriculum stories. The researcher can take an added role to guide the science teachers through questions and examples to assist them in recalling and retelling the stories of their teaching of a specific science topic, and hence reveal their topic-specific science PCK.

An experienced science teacher will likely have more well-developed topic-specific science PCK since they have had more chances to teach a particular science topic as well as opportunities to reflect on their teaching, as compared to a novice science teacher who has had fewer teaching opportunities and therefore fewer opportunities for reflection. The opportunity to teach the same topic numerous times, which involves integrating teacher knowledge categories, and then reflecting on the experience can help a teacher develop transformed PCK. Gess-Newsome (1999) suggested that in this circumstance, the PCK of the science teacher becomes a distinct aspect of their teacher knowledge. This is then considered as transformative topic-specific PCK, even while some PCK may still be in the process of being integrated to become transformative PCK.

Shulman (1987) called PCK a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8). As discussed previously, with the evolution of the concept, researchers have expanded their view of

PCK and included more knowledge components into the amalgam. The literature review identified nine teacher knowledge aspects, while I added the tenth, knowledge of student diversity, comprising PCK. I argue that topic-specific science PCK can be an amalgam of all or any of these ten aspects, depending on the pedagogical situation. This argument also asserts that topic-specific science PCK is a fluid form of knowledge and may vary from situation to situation, depending on the topic to be taught and the context of teaching. Thus, it is important to clarify which components of teacher knowledge in each new pedagogical situation will constitute this amalgam, why these knowledge components are becoming part of the particular PCK, and why the other knowledge components do not contribute towards PCK in the particular situation under study. In the literature, these questions have rarely been addressed, and merely choosing a few of the knowledge components in the name of assisting the in-depth study of PCK is not helpful in developing a systematic understanding of science teachers' PCK.

Figure 2.1 illustrates how I conceptualize topic-specific science PCK as being influenced by almost all possible teacher knowledge categories, and teacher knowledge components that contribute to it. Many kinds of topic-specific PCK component comprise comprehensive topic-specific science PCK. It is these specific components of knowledge *within* teacher knowledge categories, and not the individual teacher knowledge categories themselves, that constitute a science teacher's topic-specific science PCK. Figure 2.1, with the ten circles arranged around the chart, represents the ten teacher knowledge categories. The shaded central circle represents comprehensive topic-specific science PCK, composed of the ten surrounding ovals, each representing the specific knowledge component related to one of the ten knowledge categories. The dotted rectangles between the outer and inner circles represent a science teacher's orientations towards teaching this topic, and highlight that comprehensive topic- specific science

PCK is shaped and filtered by the science teacher's orientation to teaching science (Magnusson et al., 1998).

The Figure also shows that many specific knowledge components represented as ovals, which I call PCK components, comprise science teachers' topic-specific PCK. Each PCK component further contains many knowledge elements. It is these specific components of knowledge *within* the teacher knowledge category, and not the teacher knowledge categories *themselves,* that constitute a science teacher's topic-specific science PCK. This distinction points to the use of consistent terminology when defining PCK. Elaborating on the work of Lee (2005) I have made a clear distinction between three terms: Knowledge category, knowledge component, and knowledge element.

A teacher's thinking involves complex cognitive processes. This proposed conceptual framework does not claim to depict fully all of those cognitive processes, but serves as a heuristic for understanding topic-specific PCK in various pedagogical situations, whether conceptual or practical.

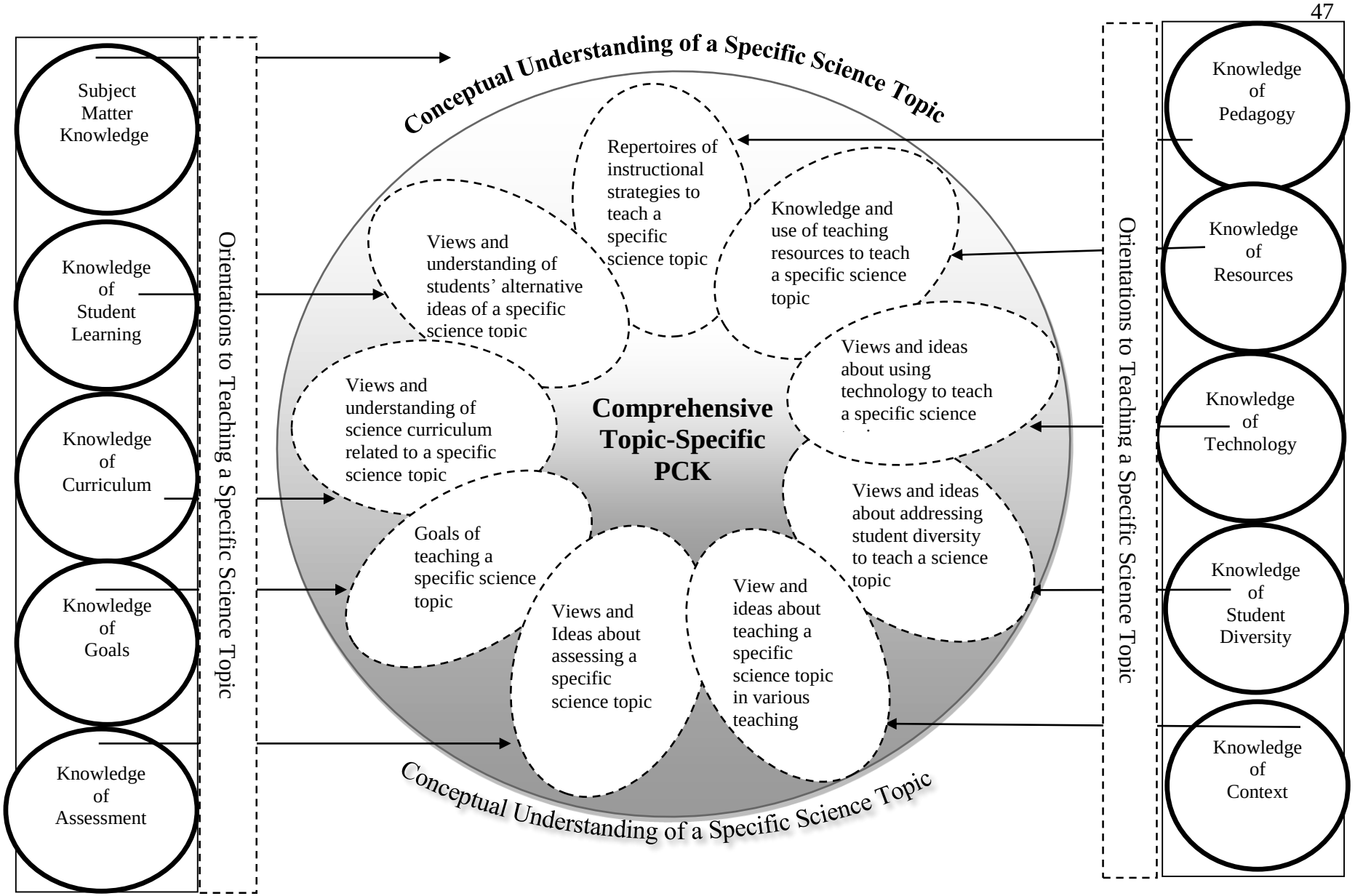

Figure 2.1: An Illustration of Comprehensive Topic-specific PCK

The following section describe "orientation to teaching science" that may shape the pedagogical content knowledge of a science teacher. Then I define the ten teacher knowledge categories along with the related knowledge components in each category that becomes a PCK component of comprehensive topic-specific science PCK.

2.9 Orientation to Teaching Science

Magnusson, Krajcik, and Borko (1998) noted that teachers' orientations to teaching define and shape their PCK. According to them, "An orientation represents a general way of viewing or conceptualization science teaching" (p. 56), which guides a teacher's decision to teach science content in a particular way. Several kinds of orientation to science teaching and learning that science teachers hold have been identified (Blakeslee et al., 1986; Hollon & Anderson, 1986; Smith & Anderson, 1984). Science teachers may emphasize on a specific view of teaching and learning that guides their pedagogical decisions. These emphases include, for example, importance of discovery, science processes, inquiry, science as a body of knowledge, and conceptual change, and are the basis for judgment of the individual science teacher's orientation to teaching. Teachers may hold more than one orientation and usually work from two or three orientations (Miller, 1983) to science teaching. Considering that orientations are important aspect of science teachers' pedagogical content knowledge, a section is included in each "story of teaching" that attempts to interpret and describe individual teacher's orientation to teaching science. This is achieved through an overall analysis of their topic-stories of teaching and their conversations, focusing especially on the instructional strategies they described they used.

2.10 Subject Matter Knowledge or Content Knowledge

Subject matter knowledge (SMK) "refers to the amount and organization of knowledge per se in the mind of the teachers" (Shulman & Sykes, 1986). Shulman (1987) used the term "content knowledge" instead of subject matter knowledge in his proposed knowledge base of teaching, which consisted of seven teacher knowledge categories, stating "content knowledge" as being one of the seven categories and defining it as "knowledge, understanding, skills, and dispositions that are to be learned by school children" (p. 8). He used the terms "subject matter knowledge" and "content knowledge" as equivalent terms. However, his definition of content knowledge refers to the conceptual understanding of disciplinary knowledge as compared to disciplinary declarative knowledge. Gess-Newsome (1999) noted that the definition of subject matter knowledge expanded when Shulman (1986) defined the SMK of teaching, including in it the "nature, form, organization and content of teacher knowledge" (p. 250), which Shulman referred as content knowledge.

Gess-Newsome (1999) reviewed the research on the knowledge and beliefs of secondary school science teachers about their subject matter knowledge, with a focus on how this affected their classroom practice. She noted that in classroom practice, the line between knowledge and beliefs is becoming blurred. She described the SMK that teachers needed to have, and stated: "Teachers need to understand the structure and nature of their discipline, have skill in selecting and translating essential content into meaningful learning activities, maintain fluency in the discourse of the community, and recognize and highlight the field to the lives of the students" (p. 53). Gess-Newsome (1999) also identified five categories of SMK: (a) conceptual knowledge, (b) subject matter structure, (c) nature of the discipline, (d) content-specific orientations to teaching, and (e) contextual influences on curricular implementation.

Teachers' SMK contributes to their topic-specific PCK. While studying the topic-specific PCK of science and mathematics teachers, Hashweh (1987) defined science teachers' understanding of subject matter knowledge by referring to the teachers' knowledge of the discipline, including content knowledge and organization. He explained, "This [knowledge] is both abstract knowledge, such as knowledge of discipline, conceptual schemes, and more specific knowledge, such as knowledge of details of a particular topic" (p. 110). Teachers should be able to define the accepted truths in a domain and explain why this is considered truth and is important to know (Shulman, 1986). These accepted truths in a discipline are the big ideas that students should understand. Kennedy (1998) argued, "If teachers are to focus [their] students' attention on the big ideas in a subject . . . [and] to engage students in reasoning about important ideas in these subjects . . . they must themselves have a grasp of these ideas" (p. 252). This understanding is referred to as their conceptual knowledge. According to Gess-Newsome, (1999), the conceptual knowledge is "the facts, concepts, principles, and procedures that are typically taught in secondary school classrooms" (p. 55), which she believed is "interconnected in nature, impacted by related beliefs, socially constructed, and potentially integrated" (p. 56). She also noted that the "richly integrated conceptual knowledge is most closely the type of student's outcomes advocated in national school reforms" and program of studies (p. 56).

Gess-Newsome (1999) also believed that the conceptual knowledge of teachers has an impact on their students' learning, and is distinguished from disciplinary knowledge that is "strictly declarative in nature" (p. 55). Therefore, the early efforts to find a relationship between teacher knowledge and students achievement failed because they involved declarative disciplinary knowledge (Gess-Newsome, 1999) and not teachers' conceptual knowledge. "The conceptual knowledge is assumed to be organized in long-term memory in a manner that is

structured and integrated, and facilitates the storage and retrieval of information" (Gess-Newsome, 1999, p. 56), creating relationships, which according to Gess-Newsome (1999) are "formally called knowledge structures." She argued that each teacher has their own unique form of the knowledge structure of their subject matter.

Teachers' conceptual knowledge of various science topics and the related knowledge structures are important features of their subject matter knowledge understanding and contribute to their topic-specific PCK, as with, for example force and motion. This aspect of topic-specific PCK is composed of the knowledge of the ideas and topics and how they are organized, that secondary school students need to learn to develop an understanding of these topics.

Magnusson et al. (1999) did not include subject matter knowledge understanding in their PCK model, though they acknowledged its importance. Abell (2008) modified and elaborated the PCK model proposed by Magnusson et al. (2008) by adding subject matter knowledge as a major influence on science teachers' PCK. Loughran et al. (2004, 2006) defined topic-specific pedagogical content knowledge as including the conceptual understanding of the big ideas involved in a science topic area. Loughran et al. (2004, 2006) also included these big ideas and the conceptual understanding involved for learning and teaching these ideas in their description of the topic-specific PCK of a group of science teachers, which they called as I have called Content-Representations.

I consider the conceptual understanding involved in science topics as a pivotal part of the topic-specific PCK of science teachers. This understanding, at a minimum, includes these elements: the big ideas; concepts; and topics that teachers find important to teach in a certain topic area; the conceptual understanding involved that they want to provide to their students; and the rationale for teaching these topics to students at a particular level. Knowledge structures are

important aspects of the conceptual understanding of science teachers. The way science teachers employ these ideas to organize these topics to teach, represents their knowledge structures related to these topics as it is part of their conceptual knowledge (Hashweh, 1989).

2.11 Knowledge of Students Learning

Describing the PCK of science teachers, Magnusson et al. (1999) interpret one of its components, knowledge of students, as teachers' "knowledge of students' understanding of science", and defined it as "the knowledge teachers must have about students in order to help them develop specific scientific knowledge" (p. 104). They considered two aspects of this knowledge:

1. Knowledge of requirements for learning: This includes teachers' knowledge and beliefs "about prerequisite knowledge" for learning specific science topics and their understanding of students' approaches to learning in various topic areas (Magnusson et al. 1999, p. 104).
2. Knowledge of areas of students' difficulty: This means teachers' understanding about students' learning difficulties in various science topics, which may include students' alternative ideas and misconceptions that hinder their learning of science topics.

Shulman (1986) acknowledged the importance of research on students' alternative ideas and declared it as one of the most important aspects of PCK. According to him, this aspect of teachers' pedagogical content knowledge

> include[s] an understanding of what makes the learning of specific topics easy or difficult; the conceptions and preconception that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in

> recognizing the understanding of learners, because those learners are unlikely to appear before them as blank slates. (p. 9)

The two key elements of Shulman's work related to students' knowledge, and adopted by other scholars in the field, are: (1) the way teachers understand content-related difficulties, and (2) their comprehensible representations of subject matter knowledge to address these difficulties (van Driel, Verloop, & de Vos, 1998). Knowledge of students' misconceptions and alternative ideas is an important part of teachers' understanding of their students' content-related learning difficulties in science, and is considered a critical aspect of their topic-specific science PCK (Loughran et al., 2004, 2006; van Driel, de Jong, &Verlopp, 2005).

Loughran et al. (2004, 2006) considered teachers' understanding of students' alternative ideas in various science topics as one of the critical aspects of their topic-specific science PCK, and considered this aspect of science teachers' PCK a part of the Co-Re(s) they developed to represent the collective understanding of a group of science teachers representing their topic-specific science PCK. I followed the trend set by the scholars in the field of science PCK and treated the category of teachers' knowledge of students as a critical aspect of science teachers' topic-specific pedagogical content knowledge, as it affects the strategies they use to overcome these misconceptions and modify them into appropriate scientific ideas. So, in this category, teachers' understanding of the alternative ideas about the specific science topic, and the specific techniques to help their students modify these ideas and develop a conceptual understanding of the science topic, is transformed and becomes a *specific* part of their topic-specific science PCK.

2.12 Knowledge of Instructional Strategies

> Teachers' knowledge of instructional strategies falls into two groups: (b) knowledge of subject-specific instructional strategies, and (b) knowledge of topic-specific instructional

> strategies, and both differ in their scope (Magnusson et al., 1999). The topic-specific strategies are "narrower in scope [and] apply to teaching particular topics within a domain of science" (p. 110), which may take the form of "representations" or "activities" used to facilitate students' learning of these topics (p. 111).

I treated the category "knowledge of instructional strategies" as meaning the use of topic-specific representations and activities by science teachers. The topic-specific representations include "illustrations, examples, models, or analogies", while the topic-specific activities include "problems, demonstrations, simulations, investigations, or experiments" (Magnusson et al., 1999, p. 111). So, when science teachers apply their knowledge of instructional strategies to a specific science topic, it becomes transformed into the knowledge of using topic-specific instructional strategies, which becomes a *specific* part of their topic-specific science PCK.

2.13 Knowledge of Teaching Resources

Shulman (1986) noted that for programs in different subject areas designed for K-12 students, there are a "variety of instructional materials available in relation to these programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular subjects and topics at a given level" (1986, p. 9). He called these "materials for instruction," which may exist in the form of "the alternative texts, software, programs, visual materials, single- concept films, laboratory demonstrations" (p. 10). Hashweh (2005) described teaching resources as "available textbooks, films, equipment, etc." (p. 283), and noted that resources that contribute towards science PCK may include a topic-specific video or handout prepared by a teacher. Lee and Luft (2008) identified "knowledge of resources" as part of science teachers' PCK, and noted that this affects the way science teachers organize their curriculum, select instructional strategies, and assess their students' learning.

The category "knowledge of resources" has not been considered a critical component of many PCK models, but I consider this as one of the important components of science PCK. It becomes a *specific* part of the comprehensive topic-specific science PCK of a science teacher when the teacher applies their knowledge of resources to a specific science topic and uses a specific teaching resource to help students understand that topic. Examples of this include a science teacher's understanding of using a video to teach gravity, or their knowledge of an interactive computer program to teach acceleration.

2.14 Knowledge of Technology

Building on Shulman's (1986, 1987) PCK construct, Koehler and Mishra (2005) included "knowledge of technology" as one of the important knowledge aspects required to teach effectively. They developed a framework for technology integration, and initially called it "technological pedagogical content knowledge" (TPCK). Later they revised this framework, naming it TPACK (technology, pedagogy, and content knowledge), and argued that "the development of TPACK by teachers is critical to effective teaching with technology" (Koehler & Mishra, 2009, p. 60). According to Koehler and Mishra (2005), some assumptions underlying the TPCK or TPACK are that: (a) teaching is a complicated practice and teaching with technology is complicated further, (b) technologies can be both analogue and digital, including new and old, (c) newer technologies present challenges to teachers, and (d) technologies are "neither neutral nor unbiased" (p. 61).

This implies that when teaching a particular science topic, teachers need to choose an appropriate technology, because some technologies are more suitable for certain tasks than others due to inherent potentials and constraints (Bruce, 1993). Social and contextual factors play a role in integrating technology (Koehler & Mishra, 2009) in teaching a specific science topic.

Teachers may not have adequate experience with a particular technology, or are unable to appreciate the value of a particular technology for teaching a certain science topic because they cannot see the relevance between them. Science teachers need adequate training to provide experience with new technologies to be used in teaching various science topics. Moreover, sometimes science teachers are unable to integrate technology when teaching a specific science topic because their pedagogical beliefs are not consistent with the use of that particular technology (Ertmer, 2005). To be able to integrate technology into teaching specific science content, teachers need to have an understanding of their pedagogical beliefs related to selecting and using a particular technology. McCrory (2014, p. 197) described three categories of technology use in science education:

1. Technology unrelated to science but used in the service of science—for example, word processing and spreadsheets
2. Technology designed for the teaching and learning of science—for example, programs like Virtual Frog and BIOkids
3. Technology designed and used to do the science—for example, microscopes and online telescopes

The literature on PCK, especially the research on science PCK, has not considered knowledge of technology or technology integration as part of the PCK construct. However, the research on technological pedagogical content knowledge exposes the role of technology in understanding science topics.

I consider knowledge of using various technologies critical to 21st-century education. Therefore, science teachers need to understand the use of the above technologies for effective science teaching. More precisely, to be part of their topic-specific science PCK, teachers engage

their knowledge of various technologies to select appropriate technologies and use them to make a science topic more comprehensible for their students. For example, Vernier equipment is specially designed learning technology for various science topics, and includes motion sensor probes and related computer software to record and graph data. A science teacher's knowledge and use of these probes for teaching force and motion ideas transforms their knowledge of technology to become a component of their comprehensive topic-specific science PCK.

2.15 Knowledge of Science Curriculum

Knowledge of curriculum is a distinct teacher knowledge category founded in the knowledge base of teaching (Shulman, 1987), and is defined as the "knowledge of what should be taught to a particular group of pupils". It includes the understanding of "national syllabuses, school planning documents and year group plans" (Cogill, 2008, p. 5). Shulman (1987) referred to curriculum as "the full range of programs designed for the teaching of particular subjects and topics at a given level" and curriculum knowledge as a "particular grasp of the materials and programs that serve as 'tools of the trade' for teachers" (p. 8). He explained that: "The variety of instructional materials available in relation to these programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular subjects and topics at a given level" (p. 9).

Grossman (1989, 1991) considered curricular knowledge as one of the components of pedagogical content knowledge, and included "knowledge and beliefs about the selection and organization of content for instruction" in the pedagogical content knowledge of English teachers (Grossman, 1989, p.27). Magnusson et al. (1999) interpreted the category "knowledge of curriculum" for science teachers' pedagogical content knowledge, and called it "knowledge of science curriculum." They identified two components of this type of teacher knowledge:

knowledge of (a) mandated goals and objectives, and (b) specific curricular programs and materials. The authors referred to this aspect of teachers' pedagogical content knowledge as "knowledge of the goals and objectives for students in the subject they are teaching . . . , the knowledge of programs and materials that are relevant to teaching a particular domain of science, and specific topics within that domain" (Magnusson et al., 1999, p. 55).

I consider "knowledge of science curriculum" as an important aspect of teachers' science PCK. As part of their comprehensive topic-specific science PCK, science teachers apply their understanding of the science curriculum to a specific science topic with a conscious effort to improve their students' learning of this topic, which includes understanding the place of a science topic within the specific science curriculum and the materials these teachers are mandated to teach, including the goals and objectives of teaching this topic.

2.16 Knowledge of Goals

As noted above, knowledge of the goals and objectives of teaching science is often included in discussions of knowledge of the science curriculum, and is sometimes even considered as part of the subject matter knowledge of the teachers (Shulman, 1986). I introduce it as a separate knowledge category in my conceptual framework, comprehensive topic-specific science PCK to highlight the importance of this component. The knowledge of goals in topic-specific science PCK focuses on teachers' views and understandings about why a science topic should be taught to a particular group of students at a particular level. This also includes an understanding of the goals and objectives within a specific science curriculum.

2.17 Knowledge of Assessment

During his study of fifth-grade math teachers, Marks (1990) identified knowledge about student assessment as part of teachers' PCK. Tamir (1988) considered that teachers' knowledge

of assessment consists of two parts: (a) what aspects of a science topic should be assessed, and (b) what methods or measures are best used to assess them. Magnusson et al. (1999) also used these two categories to elaborate this aspect of science teachers' pedagogical content knowledge: (1) methods of assessing science learning, and (2) dimensions of science learning to assess.

I incorporated these two aspects of teachers' knowledge of assessing a specific science topic as part of their topic-specific science PCK, including what aspects of a particular science topic are assessed and what methods are used by the teacher to assess the particular science topic.

2.18 Knowledge of Teaching Contexts

To illustrate science teachers' PCK, Carlsen (1999) reviewed and updated the teacher knowledge domains for science education. He emphasized the "importance of context and its unique relationship to the various knowledge domains", and suggested examining the role of context knowledge, in which many factors play a part, for example, urban and rural school settings, type of content, various science curricula, students' backgrounds, and so on. Carlsen advised studying knowledge of context during the first few years of teaching, because this is a "movement from student to student teacher to teacher provides a physical-spatial and sociological 'edge effect' where conceptions of subject matter are manifested in different places in different ways" (p. 141). Another place to examine the role of context may be in the use of innovative technologies in the classroom in the later years of teaching (Carlsen, 1999). Teaching to new groups of students, teaching in different school settings, and teaching in different geographical locations are also occasions to examine the role of teaching contexts in science teachers' PCK. According to Carlsen, changes in context helps develop new PCK by challenging teachers' previously held beliefs and understanding about a certain aspect of teaching (p. 141).

For example, teaching in an urban school setting after teaching in a rural school setting may stimulate teachers' thinking about using more relevant, real-world examples.

I consider that knowledge of contextual factors, such as urban or rural school settings and science curricula, is relevant to a science teacher's life, and that it is responsible for reshaping their science PCK. The way science teachers engage their knowledge of various contexts with specific science topics transforms their knowledge, so that it become part of their topic-specific science PCK.

2.19 Knowledge of Student Diversity

Shulman's (1987) conceptions of PCK implicitly included diversity as an important aspect of pedagogical content knowledge. He defined PCK as "blending of content and pedagogy into an understanding for how particular topics, problems, or issues are organized, represented and adapted to the diverse interest and abilities of the learner, and presented for instruction" (p. 8). However, to date, diversity has not been considered a distinct component of PCK; rather, diversity is generally subsumed under the *knowledge of student* category, and is usually limited to the understanding of student learning. Magnusson et al. (1999) interpreted the knowledge of students as the teachers' knowledge of students' understanding of science, including *knowledge of requirement of learning* and *knowledge of areas of student difficulty*. The current focus on students' *understanding* of science misses many other aspects that affect students' learning.

Loreman, Lupart, and Andrews (2015) noted a wide range of differences within student populations in today's schools. According to them, "Students come to school with a wide range of characteristics. They vary according to race, ethnicity, gender, age, and ability. They can also differ according to culture, ancestry, language, religious beliefs, sexual orientation, and socio-

economic background" (p. 13). Therefore, the idea of student diversity is wider and deeper than PCK researchers usually consider it to be.

Loreman et al. (2015) argued that ignoring these differences may result in failure for the students, especially those who are different from the mainstream, causing eventual failure in their lives as adults. They recommended more personalized approaches to teaching and learning to address students' diversity in the classroom. To address student diversity in the science classroom, Shapiro (2015) took a sociocultural perspective to offer strategies to "effectively address the needs of diverse populations of children learning science in elementary schools" (p. 363). To create inclusive science learning, teachers need to develop an understanding of the following: (a) student differences in terms of their experience of learning science, and (b) creating supportive and interactive communities in science classrooms. She asserted that "to best understand the needs of diverse learners, teachers must build deep understanding of the backgrounds and characteristics of all the children in their care" (p. 386). Shapiro further described the knowledge that teachers need in order to address student diversity in science classrooms: "The knowledge that children hold, as members of a specific group or culture, the ways students have learned through their own culture, or the ways that individual with disabilities have discovered their own special learning needs is knowledge that should be highly valued in planning classroom learning" (p. 386).

I deem Shapiro's (2015) view of teacher knowledge to address diversity in science classrooms important. Thus, I included "knowledge of student diversity" as a new category within my conceptual framework, topic-specific science PCK. This refers to science teachers' views and understandings of students' wide range of backgrounds, their understanding about how these backgrounds affect the learning of a specific science topic, what strategies they are

effective to help students understand the topic, and how their knowledge of student diversity impacts their science teaching. In this category, teachers' broader knowledge of student diversity in their science classroom, and their ways of understanding the backgrounds and characteristics of their students to help them learning a specific science topic such as force and motion, is the specific knowledge that becomes part of their comprehensive topic-specific science PCK.

In summary, *comprehensive topic-specific science PCK* provides a framework to conduct this research on science teacher's pedagogical content knowledge. This framework guided the development of interview questions and an interview protocol to guide and encourage participant science teachers to talk about their experience of teaching a specific science area: force and motion topics. This framework helped in organizing the participant science teachers' stories of teaching force and motion to reveal their PCK. In addition, the framework also directed my analysis of these stories to locate participant teachers' science PCK on a continuum from general science PCK to topic-specific science PCK.

PART IV: ACCESSING, ASSESSING AND INTERPRETING TEACHING

In this section, I present an overview of the literature on methods to study teaching and teacher knowledge to identify approaches used to assess, access, and interpret teacher knowledge, and more specifically their science PCK. This review of literature helped me to identify an appropriate approach to assessing science teacher PCK, and more precisely, the tools that can access teachers' topic-specific science PCK.

2.20 Studying Teaching and Teacher Knowledge: Assessing, Accessing and Interpreting

Assessing teaching has three primary purposes: research, teacher development, and licensure (Tittle, 2006). Assessment of teaching in the context of research—mainly for the purpose of policy-making—aims at explaining, understanding, and assessing teacher knowledge,

with a focus on developing methods to assess teaching and ensure the validity and reliability of these methods. Assessment for licensure aims at making judgments of teacher knowledge for the purpose of recruiting and selecting candidates for teacher education programs or teaching positions. Assessment of teaching for teacher development purposes aims at developing and changing teacher knowledge, beliefs, and practice to adjust the student instruction and learning processes (Tittle, 2006). This last purpose is addressed by making a distinction between assessment *of* learning and assessment *for* learning. Indeed, many new terms have been introduced in the assessment literature to highlight the developmental purpose of assessment. These terms include: formative assessment, authentic assessment, and alternative assessment. This research study focuses in part on the developmental purpose of teaching assessments.

Haertel (1991), identified various ways to assess teaching in his review of the literature. These ways include tests, observations, lesson planning exercises, documenting history exercises, and teaching portfolios. He noted that these assessment techniques can be grouped following bureaucratic or professional models. However, many assessment techniques can be used under both the models. For example, under a bureaucratic model, classroom observation is a popular way to assess teaching, and is widely used to evaluate teachers for decisions about permanent status and promotions. This type of teacher assessment has been criticized because sometimes assessors lack training and expertise in relevant subject matter areas (Haetral, 1991). Classroom observation, as a way of assessing teaching for research purposes, falls under a professional model. However, using that alone may be misleading. The science teacher Bruce in Connelly and Clandinin's (1995) study, for example, was considered as a traditional science teacher based on interpretations of his classroom observations. Later, during conversations, Bruce provided the reasoning and explanation for using these traditional strategies to help a

particular group of students to help them stay in the science class and prepare them for the next grade.

Criticism of teacher assessment methods has been driven by the premise that such methods "trivializ[e] teaching proficiency" (Macmillan & Pendlebury, 1985, as cited in Haertel, 1991). In an effort to improve assessment of teaching, literature reports various efforts to clarify what constitutes effective teaching, and what knowledge a proficient teacher should have. The movement to highlight teacher knowledge and the professionalization of teaching, mainly beginning with Shulman (1986), has offered fundamental changes in the views about the assessment of teaching. Darling-Hammond (1986) noted that teacher assessment, especially under the professional model, should be based on a high standard of professional practice. She showed a concern for using multiple choice questions with previously approved answers for teacher assessment, as this undervalues the complexities of teaching. This makes clear that teacher assessment should incorporate the complexities of teaching a specific science topic in a classroom. The "emergent forms of teacher assessment are expected to be far more specific to different subject matter, age and grade levels" (Darling-Hammond, 1986, p. 13). Moreover, assessing teachers' knowledge and their ability to make sound pedagogical decisions requires formats in which a richer context can be presented for decisions to be taken (Haertel, 1991, p. 13).

Shulman (1987) asserted the importance of the subject matter for teaching and PCK and also initiated a reform in the field of teaching assessments. With his colleagues, Shulman designed prototype assessments for assessing teaching in the Teacher Assessment Project (TAP) at Stanford University (Shulman, 1987b). The prototype assessments designed in the Teacher Assessment Project (TAP) were discipline-specific and topic-specific, for example, fractions in

elementary mathematics and a unit on the American Revolution in social studies. Each prototype was a working model of one section of a teacher assessment, based on what a teacher needed to know and how to do it in order to teach a particular topic (Shulman, 1988b, p. 42).

The TAP was oriented towards reforming the process of professional certification and licensure in the United Sates and developing a National Board of Professional Teaching Standards (NBPTS). Shulman (1888b) provided a vision of "assessment of teaching that faithfully reflects its complexity" (p. 42), and for this purpose he recommended using multiple assessment strategies that he called "a union of insufficiencies" (Shulman, 1988c, p. 38). He included written examination as part of teacher assessment, and he refused to dismiss this method, believing it to be economical and easy to use (Shulman, 1988b). Shulman's work at Stanford challenged assessment efforts by focusing on integrating teacher effectiveness with content taught (Andrews & Barnes, 1990). The force behind the TAP project was the desire to reform the bureaucratic purpose for assessing teaching, mainly so that teaching licences in the USA could be issued. Hence, teacher development was not the prime focus of this project. Some other new forms of teacher assessment did develop under the TAP project, including lesson planning exercises, document history exercises, and developing teaching portfolios, which could be part of a professional model.

Some of these alternative types of assessment have been used to study the PCK of teachers in small groups in research settings. A summary of the research on the PCK of science teachers, attached as Appendix A, presents the type of assessments used to access and assess teaching.

2.21 Studying Science Teachers' PCK: Accessing, Assessing, and Interpreting

A substantive portion of the research on science PCK has been shaped by an interest in accessing and/or assessing the PCK of science teachers—either to study and understand the science PCK of these teachers or to understand and develop the PCK construct—and thus has led to the development of various techniques to achieve these aims. Baxter and Lederman's (1999) summary of research on assessment of PCK identifies several techniques: such card-sorting tasks (Shulman, 1987), concept maps (Morine-Dershimer, 1989), lesson study methods (Van der Valk & Broekman, 1999), and open-ended questions (Gess-Newsome & Lederman, 1993). More recently, multi-method techniques using interviews, classroom observation, and reflection by teachers have been used to understand PCK for teaching science (Lee & Luft, 2008; Loughran et al., 2004).

To provide a rationale for developing their own tools to study science PCK, Taylor and Gess-Newsome (2007) presented a review of research that discussed the available tools for assessing science PCK. Their list includes:

- ESTEEM (Expert Science Teaching Educational Evaluation Model—Science Classroom Observation Rubric, Burry-Stock & Oxford, 1994)
- RTOP (Reform Teaching Observation Protocol, Piburn et al., 2000)
- Science Case Methods Project: Teacher Interview (Heller et al., 2004)
- Content Representations (Co-Res) and Pedagogical and Professional Experience Repertoires (Pap-eRs) (Loughran, Mulhall, & Berry, 2004, 2006)
- PCK Interview Protocol and Corresponding Rubrics (Lee & Luft, 2005)

Most of these techniques are research-based and are, therefore, more suitable for research purposes. However, Taylor and Gess-Newsome (2007) have *not* recommended these techniques as assessment tools for developmental purposes for science teachers.

Notable among the above list are the Co-eRs and Pap-eRs introduced by Loughran et al. (2004; 2006), the documented forms of the topic-specific PCK of a group of science teachers. They recommended these Co-Res and Pap-eRs for using to develop the topic-specific PCK of science teachers. The Co-Res were central to their conceptualization of the PCK of science teachers, and became popular in the professional community. As described above in the sections on science PCK, blank Co-Res have been used in science teacher education courses to enhance the content knowledge understanding of pre-service science teachers. Loughran et al. (2004, 2006) considered Pap-eRs essential to gain a better understanding of the relevant Co-Res, and suggested that both Co-Res and Pap-eRs need to be developed to portray the PCK of science teachers. There is no evidence available in the literature on science PCK about the practical usefulness of Pap-eRs.

The success of using Co-Res as a tool to develop topic-specific PCK of science teachers refers to the need for developing such tools, which can be formative in nature and can help diagnose and develop science teachers' pedagogical content knowledge.

2.22 Research on Learning Force and Motion: Guidelines for Developing Formative Assessment Tools for Developing and Assessing Science PCK

Topics related to force and motion are included in K-12 science curricula around the globe. Pre-service science teachers consider many of these topics as difficult to understand and teach due to their abstract nature (Azam, 2005). In addition, secondary students, university students, and pre-service teachers (Gunstone & Watts, 1985) are reported to have alternative

ideas about these topics, and some of these ideas are similar to the ones held by secondary school students. Appendix B presents a summary of students' alternative ideas about force and motion as reported in the literature on students' ideas in science. Halloun and Hestenes (1985), in addition to identifying students' preconceptions about force and motion, also described the way they influence student learning (Appendix C). The literature on students' ideas identifies that teachers need to have the conceptual understanding of these ideas to be able to help students learn these ideas. Loughran et al. (2006) identified force and motion ideas and the conceptual understanding that science teachers need to understand these ideas in order to teach effectively (Appendix D).

To help science learners develop a better understanding of the topics related to force and motion, research programs have developed techniques to identify and modify the preconceptions of science learners at various levels. Recently, the National Science Teacher Association (NSTA) used the research on students' ideas in science to develop a series of books on uncovering students' ideas in science. They developed formative assessment probes in various topic areas that can be used in science classrooms to diagnose students' alternative conceptions in relevant science topics. Once these misconceptions are identified, strategies can be invoked to overcome them and help the students develop an appropriate conceptual understanding of those topics.

Consistent with this trajectory of developing formative assessment probes for K-12 science education, the current research is designed to enable the development of formative assessment tools that can fulfil diagnostic and developmental purposes in science teacher education, specifically about the topics force and motion. These purposes include:

(i) to diagnose the learning needs of student teachers about teaching force and motion

(ii) to judge whether prospective teachers have developed the knowledge needed to teach force and motion

(iii) to evaluate the effectiveness of teaching interventions used to develop knowledge for teaching force and motion in a science methods course

To help improve instruction in science teacher education, such assessments need to be efficient and economical in terms of time and resources, and I also address this in this study.

PART V: NARRATIVE INQUIRY IN EDUCATIONAL RESEARCH

> *By sharing stories about their classroom [teaching] experience, teachers not only gain insight into their own practice, but they also contribute to the storehouse about teaching. (Mary Renk Jalongo, 1992, p. 68)*

The literature review on science PCK shows that the predominant methodologies used to study science PCK include case studies (Lee & Luft, 2008), interview research (van Driel, Verloop, & de Vos, 1998), multi-methods approaches (Loughran et al., 2004; Loughran et al., 2006; van Driel & DeJong, 2001), and grounded theory approaches (van Driel & de Vos, 1998). Narrative inquiry as a research methodology is missing in the research literature on science PCK. The only mention of the word narrative was found in the work of Loughran et al. (2006), but they did not call their research methodology "narrative inquiry," nor their analysis "narrative analysis." I choose to employ a narrative inquiry approach to studying science teachers' pedagogical content knowledge related to force and motion ideas. In this section, I review the literature about narrative research approaches in educational research and social sciences. I will begin with an exploration of definitions for the term "narrative", as well as the one that I adopted in this research. Then, I scan the approaches that have been used in narrative research. This

section concludes with a description of the particular narrative inquiry approach I adopted in this research.

2.23 Defining "Narrative"

Narrative research has become popular in the last few decades, and researchers have used the term "narrative" to represent different things. According to Leiblich et al. (1998) and Riessman (1993), narrative, as a term, is rarely defined in the narrative research. The following sections provide an overview of various meanings attached to narrative research by those who conduct research in the area of narrative inquiry.

I looked in different dictionaries to find the meaning of the term narrative. According to the Merriam-Webster Dictionary (11th ed.), the Oxford Advanced Learner's Dictionary (8th Ed.), the Webster's New Collegiate World Dictionary (4th), and the American Cambridge Dictionary of English, the word "narrative" is both a noun and adjective. As a noun, narrative means a description of events (especially in a novel), and as an adjective it is used for highlighting the story or the fiction component of it, for example, narrative poetry. An older meaning of narrative that is presented is "discourse" (Webster Dictionary, 1966).

Educational researchers have developed specific meanings for the term "narrative." Smith (1981) provided a succinct definition of narrative as a "verbal act consisting of someone telling someone else that something happened" (p. 232), referring to discourse as a highlighting aspect of narrative. Polkinghorne (1988) argued that narrative can be any verbal or written presentation, and he used the term to describe "an organizational scheme expressed in story form" (p. 13). He used these ideas to suggest a process of creating a story in social science research, which he called "narrative configuration," and used the term narrative especially to the texts that are thematically organized by plot (Polkinghorne, p. 5). Polkinghorne used narrative as

a product, that is, the story itself, *and* as a description of the process, that is for creating that story. He also used narrative as the evaluative criteria of a story, based on the internal logic of the story, which he calls its plot and theme. Polkinghorne's (1988) organizational aspect of the narrative is also shared by Clandinin and Connelly (2000). They identified "plot" as the central theme of the narrative. In addition, they also suggested the sequence of a narrative in educational research—that a story has a beginning, a middle, and an end. Moreover, in their research, they extended the use of the word narrative as a metaphor to represent teachers' lives as curriculum developers (Connelly & Clandinin, 1988). They studied teachers' narratives in a longitudinal ethnographic inquiry in classrooms to understand teachers and teaching. Through this type of narrative inquiry, they sought the teachers' identities.

Another popular notion of narrative in narrative research is using it as autobiography (Butt & Raymond, 1987), which refers to a full or in-depth story used in narrative research with a similar aim of studying teachers' personal and professional realities. This started a debate in narrative educational research about a full story as compared to a short story. A full story is usually considered a long story where teacher's lives are studied for longer periods of time and are understood through interpretation of their experiences. A short story is a segment of a long story related to a particular aspect of practice; such segments are usually called biographic narratives or narrative fragments.

Social science researchers agree that the fundamental aspect of narrative is some form of storytelling to communicate or transfer thoughts, experiences, and sometimes identity, in the form of narrative. Riessman called narratives "storied lives" (Riessman, 1993). She argued that narrative is a basic way that we, as humans, use to make sense of the wor*ld*, and that we convey these meanings through storytelling. Elbaz (1991) noted that the stories can be long or short

depending on the goals of the research. She preferred using the notion of "story" instead of "narrative" because she believed that the focus of the story is the teller and not the one to whom it is told. She also argued that a curriculum story can be either a long story or a short story. In fact, Elbaz (1991) did not find the distinction between long and short stories to be helpful.

2.24 Narrative Inquiry or Narrative Research

In the last few decades, narrative inquiry has emerged as a research mythology, and it is still developing. Researchers advanced the field of narrative inquiry by introducing various methods of collecting and analyzing data. Elbaz (2005) believed that "categorizing the different types of narrative research provides a way of mapping the field and a means of describing one's work." However, this categorization is not helpful for researchers in answering their methodological questions. In the following sections, I describe various understandings of narrative inquiry and identify the one most suitable for this research study.

2.24.1 Various approaches to narrative inquiry

Lieblich, Tuval-Mashiach, and Zilber (1998) called narrative research a revolution—a paradigm shift away from positivist research. Connelly and Clandinin (1990) asserted that narrative research is a new methodology in the social sciences, but that the notions of narrative and narratology are old and have their roots in the humanities and other disciplines. They believed that narrative inquiry is both a phenomenon and a method. Connelly and Clandinin argued that "people by nature lead storied lives, and tell stories of those lives, whereas narrative researchers describe such lives, collect and tell stories of them, and write narratives of experience" (p. 2). In a way, narrative inquiry is about "stories lived and told" (Clandinin & Connelly, 2000, p. 30).

Butt (1984) provided a new look to the narrative inquiry methodology by using biography and autobiography as sources of narrative data to study teachers' knowledge that shape their professional lives. He advanced his particular research methodology over the years while working on many research projects with colleagues (Butt & Raymond, 1989; Butt, Raymond, & Yamagishi, 1988; Butt, Raymond, McCue, & Yamagishi, 1992). He also introduced collaborative autobiography as a tool to share stories of teachers to understand individual teachers' knowledge (Butt & Raymond, 1989). In his words, the purpose of his ongoing research on teacher knowledge was "to discern and represent teachers' voices concerning how they experience their working realities and the nature and formation of their personal professional knowledge" (Butt & Retallick, 2002).

Later, Clandinin and Connelly (2000) also noted that "narrative inquiry is a way of understanding experience," (p. 20) which underpins a particular view of human experience. They conceptualized narrative inquiry as a three-dimensional space where each dimension represents Dewey's criteria of experience: continuity, interaction, and situation. In the first dimension lies the past, present, and future, which represents *continuity*, while in the second dimension we find *interaction*, personal and social. In the third dimension lies *place* or *situation*. Clandinin and Connelly (2000) emphasized the dynamic and dialogical nature of narrative research by saying that narrative inquiry is a "collaboration between researcher and participants, over time, in a place or series of places, and in social interaction with milieus" (p. 20). They further highlighted the temporal nature of narrative inquiry by saying that "an inquirer enters this matrix in the midst and progresses in this same spirit, concluding the inquiry still in the midst of living and telling, reliving and retelling, the stories of the experience that make up people's lives, both individual and social" (Clandinin & Connelly, 2000, p. 20).

Clandinin and Connelly (2000) used this three-dimensional inquiry space in a longitudinal design to study teachers' lives in classrooms and schools with the sole aim of exposing their narrative unity. A focus of their research was to understand teachers' actions in the light of their pasts and the choices they will make in the future.

Cortazzi (1993) made a distinction between narrative, life story, and autobiography; he noted that narrative inquiry is one of the best approaches to create accounts of teacher knowledge because it relies on everyday meaning. According to Cortazzi, the purpose of narrative inquiry is to elucidate the *experiential* understanding of teachers' thinking in terms of everyday meaning and their practices, so as to understand their experience. This stands in contrast to life story and autobiography research, which studies life transitions and turning points. From a teacher knowledge perspective, Cortazzi's distinctions provide support for the argument that narrative is a short story that focuses on a specific experience, while life story and autobiography are both a form of long story, usually oriented to studying a teacher's identity.

Elbaz (1991) also commented on life story, biography, and narrative by making a distinction between whole or *full story* versus a *short story* or *narrative fragment* by considering the work of Connelly and Clandinin (1985) and Butt and Raymond (1987). She believed the idea of narrative unity (Connelly & Clandinin, 1985) considers all that has happened in the past, to define present actions and future options, thus bringing wholeness to the story. On the other hand, biography and life story consider the full length and breadth of the story, tracing everything that a person has experienced to make it a whole story. Elbaz (1991) argued that conceptions of narrative unity and wholeness fail to acknowledge "the fragmented nature of modern social life in which facts and values, ends and means, thoughts and actions are split apart and the individual's life is similarly divided up into spheres and roles" (p.5). She believed that "it

is one thing to share the quest for unity . . . but it is quite another to see unity because one has posited it before one looks" (p. 5).

Elbaz (1991) offered the notion of story as compared to narrative and autobiography, and argued that "story" is a "tale told on one occasion" and only becomes fixed or frozen as a result of publication, otherwise it can be changed. Moreover, it focuses on the teller and the audience:

> The story keeps the teller clearly in focus . . . if the story achieves a unity or wholeness, it is because the teller has done so, not because unity has been found to inhere in the stuff itself . . . [and] what counts as a meaningful story . . . depends on the listener who plays an active role in making sense of the story. (p. 5)

In other words, a story is a creation of coherent meaning, and in the context of research it is the responsibility of the researcher to create such a story. To achieve coherence and meaningfulness in a story, Elbaz suggested joint publication, where at the minimum, the researcher takes the story back to the teacher to review. Butt and Raymond (1998), going a step further, actually collaborated with teachers to develop their stories. From an ethical perspective, Elbaz (1991), in agreement with Grumet (1987), recommended producing multiple accounts, which can be achieved by using narrative fragments—that is, pieces of conversation taken from longer conversations—to draw specific meanings (Clandinin & Connelly, 1986, as cited in Elbaz, 1991). This works because "if they undermine the authority of the teller, they also free her from being captured by the reflection provided in a single narrative" (Grumet, 1987, p. 234, as cited in Elbaz, 1991).

Leiblich et al. (1998) defined narrative research as a "study that uses or analyzes narrative materials" (p. 2). They believed that data for narrative research can be collected as "a story" (a life story provided in an interview or a literary work) or in a different manner (such as

the field notes of an anthropologist who writes up their observations as a narrative or in personal letters). Commenting on the objective of such a research study, Lieblich et al. (1998) said that "it may be used for comparison among groups, to learn about a social phenomenon or historical period, or to explore a personality" (p. 2).

Riessman (1993) noted that narrative research does not have a standard set of procedures, in contrast to other qualitative analysis. She suggested that the narrative method could be divided into three stages: telling, transcribing, and analysis (p. 54). Later, she proposed four analytical methods of narrative analysis: thematic analysis, structural analysis, dialogic/performance analysis, and visual analysis (Riessman, 2008). Thematic analysis focuses on *what* is spoken in the narrative, while structural analysis relies on *how* the story was told. Dialogic/performance analysis examines the interaction of dialogue as narrative, and visual analysis mainly interprets the images of the storyteller. Riessman suggests that it is acceptable for a narrative researcher to choose the type of analysis that best suits their research question.

Smith (1986) noted that story analysis can fall within two perspectives based on Bruner's (1986) two modes of thinking—paradigmatic and narrative. One perspective that falls within the paradigmatic stream involves textual and structural analysis. Textual and structural analysis of stories, according to Smith, are paradigmatic in nature, since these types of analysis place the narratives into categories and uses them to build a hypothesis. The other perspective which falls within the narrative stream involves "understand[ing] the meanings of the stories to those who use them, rather than some truth they tell us . . . [and] we must study them in their contexts of use" (Smith, 1986, p. 68). Smith also noted that this perspective derives mainly from various hermeneutic traditions.

Polkinghorne (1995) classified narrative inquiry research into two categories: narrative analysis and analysis of narrative. According to Polkinghorne, analysis of narrative uses stories as data and analyzes the stories to study a phenomenon that is predictive in nature, while narrative analysis involves developing the story or stories of the participants and is exploratory in nature. He calls the explanatory narrative report "retrodictive" as opposed to "predictive," denoting the narrative researcher's process of building a reasonable and believable account by piecing together past events so that "their parts in the whole story become clear" (Polkinghorne, 1995, p. 171).

Lieblich et al. (1998) proposed a two-dimensional framework to interpret narrative data that provides various possibilities for reading, interpreting, and analyzing life stories and other narrative materials (p. 12). The first dimension represents *holistic* versus *categorical* analysis, while the second dimension represents *content* versus *form* analysis. The holistic versus categorical type of narrative analysis is equivalent to Smith's two perspectives discussed above, structural and hermeneutics. The content and form types of narrative analysis refer to two extremes in reading texts: reading texts to find what the story is about (content) and reading text for the structure, grammar, and styles of the story (form). Lieblich et al. (1998) visualized these two dimensions as intersecting each other, creating four quadrants where each quadrant represents a type of narrative analysis. These four types of narrative analysis, holistic-content, holistic-form, categorical-content, and categorical-form, are available to narrative researchers to choose from to fulfil the purpose of a particular narrative inquiry.

A narrative is a way to transform knowing into telling (Mishler, 1985). Most of the above methods of narrative inquiry focus on analyzing the story or story data; few methods have a focus on developing a story. There are few models available in the literature on developing a

story or a narrative account. One such model is "narrative analysis," one of the two possibilities of narrative inquiry as suggested (and noted above) by Polkinghorne (1988, 1995). This type of analysis is explanatory; it explains through a narrative why something happened. Narrative analysis is an opportunity for researchers to develop a narrative to represent a phenomenon.

Elbaz (1991) and Riessman (1987) did not make a clear distinction between narratives developed by researchers or those of the research participants, but both described some rules to follow to accomplish the goal of developing a meaningful narrative or story. Elbaz (1991) suggested using the notion of story as compared to narrative, which seems close to the idea of "narrative analysis" because both use narrative fragments from the conversations between the researcher and the research participants to develop a meaningful and coherent story about a phenomenon. According to Riessman (1987, p. 19), a "fully formed" narrative includes six elements: an abstract (summary of the substance of the narrative), orientation (time, place, situation, participants), complicating action (sequence of events), evaluation (significance and meaning of the action, attitude of the narrator), resolution (what finally happened), and coda (a return to the present perspective). Riessman believed that these six elements help the "teller construct a story from a primary experience and interpret the significance of events in clauses and embedded evaluation" (1987, p. 19). These six elements also provide guidelines for a researcher to develop a coherent and meaningful story of the experiences of the research participants.

2.24.2 The narrative inquiry approach adopted for this research

For two reasons, I found the ideas of narrative advanced by Smith (1981) and Polkinghorne (1988) helpful in conceiving this research study and planning an analysis of the data. First, the study focuses on teachers' descriptions of their experiences of living a specific

science curriculum. This is a verbal act, in a way, where teachers tell the researcher about their planning and teaching, which is close to the way Smith defined narrative as a "verbal act consisting of someone telling someone else that something happened" (p. 232). Secondly, the study aims at exposing the topic-specific pedagogical content knowledge of the participant science teachers. The assumption is that the participant science teachers have developed their PCK as a result of their experience in planning, teaching, and reflecting, which they articulate as short curriculum stories or stories about teaching specific science content. In other words, this means studying their practice (Elbaz, 2005). To expose their topic-specific science PCK, it is necessary to organize their experiences in story form, using a logical organization scheme. This is the idea on which Polkinghorne (1988) based his view of the two types of analysis—narrative analysis and analysis of narratives. For this research study, following Polkinghorne, narrative means a process (of developing a story) as well as a product (a story).

The purpose of narrative research is to study personal experience and to construct meaning in a systematic way. The purpose of the present narrative inquiry is to study the experiences of science teachers and derive meanings about their topic-specific PCK. The narrative analysis suggested by Polkinghorne (1995) provides a useful framework for this research study. This is because one of the aims of this study was to create stories—narrative configurations—of the participant science teachers' accounts that represent my own transformed "knowing about the topic-specific pedagogical content knowledge of participant teachers," which is to be reflected in my telling of these stories. In the second stage of the research study, analysis of narratives (Polkinghorne, 1995) was used to analyze teachers' stories of teaching to:

1. Look at their general PCK and that of their topic-specific PCK on a four-level PCK continuum, which helped to see a connection between the two

2. Develop formative assessment tools

The notion of story, specifically the short curriculum story as suggested by Elbaz (1991), was helpful since it pointed to using narrative fragments to make a whole story. Moreover, wholeness was achieved through collecting data across a range of interconnected science topics.

2.25 Summary

The present study is located at the intersection of the literatures discussed in Part I, Part II, and Part III on various conceptions of teacher knowledge, PCK, the dichotomy between practical and formal knowledge, and a need to transform teacher' practical knowledge into formal knowledge. The literature on teacher knowledge and their pedagogical content knowledge identified a similarity between teachers' practical knowledge and their PCK. Science teachers experience teaching a particular science topic differently, and the knowledge they accumulate of teaching this topic over time is unique to each teacher. The literature on the conceptions of science PCK, especially efforts to understand the PCK construct, has not taken into consideration the topic-specificity of the construct. This research study introduces a topic-specific model of science PCK, and is an effort to understand PCK through studying science teachers' experiences of teaching a specific science topic.

The body of literature presented in Part V discusses various approaches to narrative inquiry, a useful way to study experience but one that is missing in the literature on studying science PCK. This research has adopted narrative inquiry as a meaningful way to answer the research questions.

The review of the relevant literature in Part V on assessing teaching and teacher knowledge helped in recognizing formative assessment as an appropriate approach to assessing science teachers' pedagogical content knowledge. The literature on students' alternative ideas on

force and motion and the influence they have on students' learning led to the development of formative assessment probes to assess and diagnose students' ideas with the intention of helping them modify these ideas to better understand the topics, helped in conceiving the idea of formative assessment tools that can access teachers' topic-specific science PCK.

This review of the interconnected literature on teacher knowledge provides a foundation to conceptualize the present research as well as providing a basis for future studies based on the findings and recommendations of this study.

Chapter Three: THE RESEARCH PROCESS

This chapter describes the approach to an inquiry into the pedagogical content knowledge of secondary school science teachers. The chapter begins by summarizing the research questions described in Chapter One and presents my worldview assumptions that influenced the design of the research study. Next, the narrative inquiry approach adopted is outlined, and I introduce the research participants. In subsequent sections, I describe the data sources and the application of the long interview (McCracken, 1988) used to develop the interview questions, collect the data, and to analyze it. At the end of the chapter, I consider the ethical issues associated with the research, the trustworthiness of the findings, and the limitations of the research.

The research aimed to understand and represent secondary school science teachers' PCK about teaching force and motion topics, and to develop formative assessment tools that can be used in science teacher education to help pre-service science teachers develop their PCK and to assess it. The following research questions guided the procedures and design of the research study:

1. How do secondary school science teachers describe their experiences of conceptualizing and teaching topics related to force and motion?
2. How might their descriptions be organized as stories to reveal aspects of their pedagogical content knowledge (PCK) of science teaching?
3. How might their descriptions provide a connection between topic-specific science PCK and general science PCK?
4. How might their descriptions inform the development of formative assessment tools to help pre-service science teachers develop their PCK and assess it?

I initiated the research process by exploring my own worldview assumptions, which guided the design of the research study.

3.1 My Worldview Assumptions

Overall, I embraced a qualitative approach to developing the research study. Qualitative research is an umbrella term that covers a range of research ideas and activities. Denzin and Lincoln (2005) preferred to call it a "paradigm" (p. 6) that is based on a set of worldview assumptions and not a set of procedures one must follow. As Creswell (2007) noted:

> these philosophical [worldview] assumptions consist of a stance towards the nature of reality (ontology), how the researcher knows what she or he knows (epistemology), the role of values in the research (axiology), the language of research (rhetoric) and the methods used in the process (methodology)" (p. 16).

To clarify my worldview assumptions, as suggested by Creswell (2007), I reflected on my views about the nature of reality, and how my perspective related to the decisions I made about the design of the research.

I believe that there is no single reality, as we all live in our own unique worlds and experience things differently. The same is true in science teachers' lives—each individual experiences the science curriculum differently. To understand these differences, I consider reality as being subjective and multiple. Both the researcher and the research participants perceive and interpret experiences. I also believe that reality is socially constructed (Krauss, 2005; Lincoln & Guba, 2000).

Taking a constructivist perspective involves the philosophical orientation of interpretivism, which I hold. This is relevant here, as science teachers construct and reconstruct their ideas based on their experiences of engaging with the science curriculum both through teaching and learning.

I tried to understand the development of science teachers' pedagogical content knowledge by interpreting and thus representing their social realities as stories of science teaching. I also interpreted, in Chapter Five, my own evolving experiences and understandings that developed during this research study.

I believe that there is no approach that can be used to see fully the research participants' reality, or assume that the reality presented by the participants is the "actual" reality. In this research, to best represent the participants' experiences, their own words are reported as evidence for my interpretations of their perspectives on science teaching and learning. This also reveals, through language, values about teaching and learning. To further verify their statements and reports of ideas, I took the stories of teaching back to the research participants and invited their input and feedback, which helped validate, preserve, and honour the participants' ideas.

This research study is about science teachers' PCK, so it is important to address the epistemological assumptions that underpin the PCK construct in the research study. Teachers' knowledge lies in the practice of teaching, which is lived through the conceptualization and the acts of teaching. Therefore, teachers' knowledge is practical and experiential in nature. To understand teachers' knowledge, specifically their topic-specific PCK, their personal experiences of engagement with a specific science curriculum become important. The experiential knowledge of the teachers, which they have accumulated through repeated experiences of teaching force and motion topics, is the knowledge that I sought in this research study. I believe that the best way to gain access to this knowledge was to engage participant teachers in conversations about teaching these topics. I listened to their descriptions of events, incidents, and stories and tried to represent them, realizing that I am interpreting the stories as I do so.

As described in Chapter Two, there are differing views about whether PCK is tacit, implicit or explicit knowledge. I agree with Kennedy (1998) that PCK must be explicit, and I believe science teachers should be able to articulate their knowledge of teaching a specific science curriculum if they have developed what is referred to as transformative science PCK, where knowledge in individual teacher knowledge categories mixes and become unified knowledge. I made an attempt to understand participant teachers' transformative science PCK by developing interpretations of their description of experiences of teaching.

Narrative inquiry in education is a way to study experience where researchers listen to the stories of teachers and teaching to make sense of teachers' knowledge. To understand the worldviews of teachers, and their insights and ideas about teaching force and motion topics, I interpreted their stories about events and incidents teaching these topics, and reconstructed their experiences in the form of *stories of teaching force and motion*, presented in Chapter Four.

Some narrative inquiry researchers do not find the stories of their participants adequate for constructing their reality and representing their knowledge, and thus suggest various techniques to overcome these insufficiencies. One such technique in educational research is to observe teachers in the act of teaching to validate their stories. However, Loughran et al. (2004) pointed out that PCK cannot be captured by observing teaching, and others have noted that observations can be misleading (Connelly & Clandinin, 1986, p. 320). Kvale (1996) suggested several strategies to overcome this insufficiency: Using probing, following-up, interpreting, specifying, critical questioning, using direct and indirect questions, and deploying patience and careful silence. I believe that guiding teachers to tell stories using specific details of their experiences of teaching a specific science curriculum exposes their in-depth personalized knowledge of teaching science.

I believe, as did Krauss (2005), that it is through meaning-making that human beings make sense of their world. Meanings are generated and enriched through life experiences and provide an explanation for experiences that are lived (Chen, 2001). Erikson (1963) divided meaning into two categories: (a) common meanings, and (b) unique meanings. At the core of the meaning-making process is individual subjectivity. Individuals use various criteria to determine meaning, which means that they differ from person to person.

I believe that meanings are constructed socially through social interactions. Science teachers continually build and reshape meanings through and from their experiences of teaching and learning. I, therefore, reconstructed my interpretations of science teachers' experience by engaging with teachers in two ways. First, I had conversations with them where I invited them to share their stories (descriptions or interpretations of their experience), and I guided them using prompts and personal examples to encourage them to tell their stories. Secondly, I interpreted our conversations and developed their stories, which were finalized with their consultation. I added to the teachers' ideas by including references that referred to my own story. These processes are part of the way I co-constructed meaning to make sense of the participant teachers' experiences of teaching science.

To reveal the personal biases I brought to this research study, the beliefs that I hold about science learning and teaching and what I value the most as a science teacher educator, I developed my own story, presented in Chapter One and Five. I have consciously attempted to reveal my subjectivity throughout the process by using my story of learning about PCK. I also describe new knowledge that I have gained through the process of engaging in this research study, the knowledge of developing and assessing PCK of secondary science teachers.

By situating my worldview within the broad paradigm called qualitative research, I required a research design that met many needs. It could not be predetermined, and data collection strategies would need to be open and context-dependent, and would allow me to enrich the data. I wanted to maintain options to revise the process for meaning-making so that new ideas generated fresh, possible answers to the research questions. Narrative inquiry fulfilled these methodological needs of the research study.

3.2 Narrative Inquiry: The Research Approach

> *The narrative capability of humans is a unique, fundamental cognitive process, which is crucial to the interpretation and reconstitution of cultural and personal reality.*
> *(Sinclair, 2005, p. 56)*

To study secondary school science teachers' experiences of engaging with a specific science curriculum, I chose a narrative inquiry approach as the methodology for this research study. Narrative Inquiry "is an appropriate way to study experiences (Clandinin & Connelly, 1983) that "allows for [the] systematic study of personal experience and meaning" (Riessman, 2001, p. 45).

Polkinghorne (1995) notes two types of narrative inquiries, based on the type of data and analysis used. According to Polkinghorne, the first type of narrative inquiry "gathers events and happenings as its data" and then "uses narrative analytic processes, called *narrative analysis*, to produce explanatory stories" (p. 1). I used narrative analysis to answer research question two, to expose the PCK of participant science teachers. Use of narrative analysis allowed reconstruction and reorganization of the knowledge of the professional practice of participant teachers to portray their topic-specific science PCK. The second form Polkinghorne (1995) describes uses stories as data sources and analyzes the stories to identify themes and to answer specific research

questions, which, he calls *analysis of narratives.* This type of narrative inquiry was used to answer research question two and four.

The following sections describe the processes undertaken for this inquiry, which include an introduction to the research participants, the data sources used, and the procedures I followed to collect and analyze the data.

3.3 The Research Participants

The research study focused on four secondary science teachers: Kevin, Jason, Monica, and Dave.[1] All four research participants are secondary school science teachers in Alberta. Monica and Kevin are junior high school teachers, while Dave and Jason are senior high school science teachers. Jason has a background and exceptionally diverse experiences in teaching physics. Monica and Dave have backgrounds in biology and have little interest in physics teaching, though they teach physics topics as part of the science curriculum. Kevin has a background in biology and chemistry but is interested in physics teaching. All four participant science teachers hold both BSc and BEd degrees, the required qualification to become a secondary science teacher in Alberta, Canada. Monica and Jason have also both completed their PhD. Monica has a PhD degree in Education, and Jason has a PhD in Physics. Chapter Four, the stories of teaching, presents a detailed profile of each participant.

I limited the number of participants so I could focus on collecting detailed information to create the stories of teaching.

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[1] These are Pseudonyms that my participants selected for themselves.

3.3.1 Selection of the participants

I contacted a number of science teachers, and my doctoral supervisor and colleagues also recommended a few to me. I had initial conversations with seven secondary school science teachers who were at various stages of their teaching careers, from beginning to experienced. After initial conversations, I selected these four secondary school science teachers who had diverse backgrounds and who were available and interested in talking in-depth about their experiences of teaching topics related to force and motion. The selection of the volunteer participants was, therefore, both purposeful and convenient. Before we began, I provided each potential participant with an invitation letter, an explanation of the research study, and a consent form. Once the consent forms were signed, I set up meeting times for our conversations, attempting to make them as convenient as possible by considering the participants' requested times and locations.

3.3.2 Teaching experience of the participants

Each participant, as a secondary school science teacher, has several years of secondary high school science teaching experience. Monica and Dave have approximately 15 years of experience; Kevin has approximately eight years, and Jason two. Table 3.1 shows the formal science teaching experiences of the participant teachers and their accumulated experience of teaching force and motion topics.

Each participant presented a very different perspective on teaching the topics force and motion. This was an ideal topic area as it recurs across several grades in the Province of Alberta Secondary Science Program of Studies. In the junior high science curriculum, these topics are discussed in Grade Seven in the unit Structures and Forces, and again in the Grade Eight unit Mechanical Systems. Grade 10 Science has a discussion on force and motion in the unit Energy

Flow in Technological Systems, and a detailed discussion of force and motion is also found in Physics 20.

Table 3.1: Participant Teachers' Science Teaching Experiences

Name	Teaching Experience Related to				
	No of Years	Grade Levels	Force & Motion Topics	Student Teaching Topics	Other
Kevin	8 years	Grade 7, 8, & 9 science Grade 8 mathematics	5-10 times	Water System (Grade 8 unit) Electrical Principles (Grade 9 unit)	
Jason	2 years	Grade 11, 12 Physics 20, Physics 30	5-6 times in high school, but overall 15-20 times	Physics 20 (Grade 11)	Post-secondary teaching for 3 years & teaching assistantship for 6 years (Introductory Physics), and Tutroing
Monica	14 years	Grade 7, 8, & 9 Science Grade 7 Mathematics	5-10 times	Mathematics Grades 7-12	Tutoring
Dave	15 years	Science 10, Bio 20 & Bio 30	5-10 times		Tutoring

All four participant science teachers taught force and motion topics regularly at certain grade levels, but not necessarily in a wide range of grade levels. Jason taught force and motion topics at the post-secondary level in addition to teaching the same topics in Physics 20. Overall, he has taught force and motion topics approximately 15-20 times. Monica and Kevin both taught force and motions topics at the junior high school (JHS) level approximately 5-10 times. Monica had 14 years of formal teaching science experience in JHS, while Kevin had eight years of formal science teaching experience at the JHS level. Dave has 15 years of experience in teaching

high school science and has taught topics related to force and motion (mainly in Science 10) 10-15 times.

3.3.3 Background knowledge of the participants

All four participant science teachers have very different preparations for the content knowledge required to teach the topics related to force and motion, chosen as the context for this research study. There is an enormous disparity in their levels of interest for these topics. Moreover, the choices for teaching science, particularly these topics, are also varied. Table 3.2 summarizes the content knowledge preparation of the participant teachers and their academic preparation for teaching topics related to force and motion.

Table 3.2: Participant Teachers' Education and Professional Qualifications

Name	Education	Specializations
Kevin	BSc	Biology as Major Outdoor Environmental Education as Minor
	BEd, Two-year after-degree	Secondary science curriculum
Monica	BSc	Mathematics as Majors
	Bed, Four-year concurrent degree	Secondary mathematics curriculum
	PhD	Education
Jason	BSc (Double)	Chemistry majors Physics Majors
	BEd, Two-year after-degree	Secondary science curriculum
	PhD	Computational Physics
	Post-Doctoral	Computational Physics
Dave	BSc	Biology majors
	BA	Sociology majors
	Bed, Two-year after-degree	Secondary science curriculum

3.4 The Data Sources

The data for this research study are the interview transcripts of conversations with the participant teachers in which they describe their work as planners and enactors of the science curriculum. I collected the participants' short curriculum stories about the events and happenings, especially about their experience with force and motion topics. The data were analyzed and organized to produce coherent explanatory stories, as suggested by Polkinghorne (1995). The intention was to produce stories that present information in a logical way that retains the wholeness of each individual's description of experience and generates insights about their topic-specific pedagogical content knowledge.

. To accomplish this, when collecting the data I used Elbaz's (2008) and Grumet's (1987) distinction between "short" and "long" curriculum stories of teachers. Short curriculum stories are teachers' representations of specific incidents—for example, an experience with a specific science curriculum, the learning needs of a specific learner, a teacher's attempts to address a student's learning need, or a specific pedagogical problem. Long curriculum stories are the stories that teachers share or researchers develop that might encompass experiences over a semester or school year. Teachers' curriculum stories provide a view into the complexities of the pedagogical decisions teachers make while enacting a science curriculum, both in their planning and teaching.

I worked primarily to acquire teachers' short curriculum stories about their experiences with planning and teaching force and motion topics. The participant science teachers each discussed five to twelve topics with me. I used a tentative list of topics related to force and motion (Figure 3.1) and an interview protocol (Figure 3.2) in a suitable way to invite the participant science teachers' short curriculum stories related to these topics. The numerous short

stories of teaching collected from each participant science teacher, audiotaped and transcribed, served as data sources across various topics regarding teaching about force and motion. These multiple data sources were used later to triangulate the data. The following sections discuss the data collection tools and procedures I followed to collect and analyze the data—an application of *the long interview* approach (McCracken, 1988).

List of topics related to Force and Motion (Tentative)

- Force
  a. What is force?
  b. What does force do?
- Rest and Motion
  a. What does it mean to be at rest?
  b. What does it mean to be in motion?
- Frictional Force
- Reaction Forces
- Field Reaction Force
- Gravity
- Acceleration
- Newton's 1st Law
- Newton's 2nd Law
- Newton's 3rd Law
- ----------
- ----------
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- ----------
- ----------

Figure 3.1: List of Topics Related to Force and Motion (tentative)

Interview Questions for the Topic, Force

Q: Can you share a memorable event or incident of teaching the concept, force that stands out for you? or
Q: Can you share insight into your experience of teaching the concept force that stands out for you?
Q: Can you discuss the conditions that facilitated or provided obstacles to your teaching about the concept force?
Q: What understanding Force means to you? or
Q: How do you define force? or
Q: If you want your students understand force, what are the underlying ideas or concepts that you think your students need to grasp?
Q: What common misconceptions did your students bring into your classroom about the concept of force?
Q: How did you address, challenge, and try to modify your students' alternative ideas about the concept of force?
Q: What teaching strategies usually helped your students understand the concept force?
Q: How did you relate the concept, force with the real world? Share few specific examples.
Q: What Resources helped you plan your teaching of the concept, to help students understand the concept force?
Q: How did you make use of technology to help your students understand the concept force?
Q: How did you use your knowledge about the Alberta science Program of Study to plan and teach the concept, force?
Q: Why is this important for high school students to understand the concept, force?
Q: How did teaching in various contexts affect your teaching the concept, force?
Q: How did you assess your students' knowledge to make sure that they understand the concept, force?
Q: How did the range of students' background affect your teaching the concept, force?
Q: Do you teach the concept, force the same way you were taught as a high school student?
If yes, what do you like the way you were taught?

If No, what did you change? Why?

Note: The set of questions were repeated for each topic selected by the participant teacher.

Figure 3.2: The set of interview questions used to initiate discussion about each of the topics selected by the participant teacher

3.5 Data Collection and Data Analysis Procedures

I followed the long interview approach recommended by McCracken (1988), a four-step model to design interviews as well as to analyze data (p. 7). These four steps are:

Step 1: Review of analytical categories and interview design

Step 2: Review of cultural categories and interview design

Step 3: Interview procedures and discovery of cultural categories

Step 4: Interview analysis and discovery of analytical categories (McCracken, 1988, p.29)

The first two steps in McCracken's (1988) long interview framework assisted in developing the interview, while the last two steps helped in the analysis of the collected data.

3.5.1 Step 1: Review of analytical categories and interview design

To provide the needed structure for a semi-structured interview, I reviewed the existing literature on PCK, which is consistent with McCracken suggestion to review analytical categories. "The long interview" is a suitable method when some aspects of theory are already known, or there is a need to see the effects of various factors on the existing theory (McCracken, 1988), which is the case for PCK. It is an efficient way to collect meaningful data because "it is a sharply focused, rapid, and highly intensive interview process that seeks to diminish the indeterminacy and redundancy that attends more unstructured research processes" (p. 7).

The present research study aimed to study the pedagogical content knowledge of participant science teacher in the context of teaching force and motion ideas. A review of the literature in Chapter Two shows that there has been ample research on the PCK of science teachers. I conducted a systematic literature review to develop interview questions and identified ten teacher knowledge categories that various researchers have identified as features of PCK. To review, these are: (i) content knowledge, (ii) knowledge of student learning, (iii) knowledge of

instructional strategies, (iv) knowledge of teaching resources, (v) knowledge of technology, (vi) knowledge of curriculum, (vii) knowledge of goals, (viii) knowledge of assessment, (ix) knowledge of teaching context, and (x) knowledge of student diversity. I further noted that it is not the knowledge category itself but specific features of the category that contribute to teachers' pedagogical content knowledge, which I called PCK components, as shown in Figure 2.1 (p. 47). Therefore, I developed questions around each of these ten teacher knowledge categories and used them to invite teachers to share stories, events, and incidents of teaching about force and motion. The following sections provide details on how in each category I formulated the questions, and the interview question.

3.5.2 Step 2: Review of cultural categories and interview design

The second step in McCracken's (1988) four-step model is a "review of cultural categories and interview design" (p. 29), which allows for examination of the values, beliefs, and biases of the researcher. I considered my personal understanding of the research topic and the potential biases I bring to this research study. This helped to avoid my personal bias in the questions I designed. In my own initial story, I brought out my own understanding of the PCK of science teachers and the potential biases that might have shaped my understanding. The purpose was to ask prompt questions to discover if there were alternative answers. For example, I have had extended teaching experiences in which students expressed alternative concepts and demonstrated difficulties in learning science. I believe that these experiences are the most important ingredient in shaping science teachers' PCK. Therefore, I tried to keep a check on my biases in this area and carefully created the prompt questions to focus on the participants' stories.

Employing these two steps resulted in the development of a particular interview design.

3.5.3 Step 3: Interview procedures and discovery of cultural categories

The third step in McCracken's (1988) four-step model is the creation of "interview procedures and discovery of cultural categories" (p. 29), which involves developing interview questions that allow interviewees to tell their stories in an unbiased and reflective manner.

3.5.3.1 Formulating the interview questions

Carefully formulating questions is the key to getting access to the interviewees' *stories of experiences* and not just their *opinions*. Therefore, I phrased questions in sociological terms, as suggested by Chase (1995), to avoid opinion-based responses. I formulated interview questions that I hoped would encourage the participants to talk about how they conceptualized and engaged in teaching about force and motion. To access the details of their experiences in depth, follow-up questions were also developed and used, for example, "What did you do to make your students understand the concept, force?" These type of questions also indicates that a narrative research interview is a less formal talk. Rather than simply asking and answering questions, I conceptualized the narrative interview as a conversation guided by the researcher.

3.5.3.2 The interview questions

In this section I describe the process of developing the interview questions in the ten knowledge categories identified above.

Category one: Content knowledge. To develop interview questions in the category of teachers' content knowledge understanding, I wanted to focus on the big ideas, concepts, and topics related to force and motion that these teachers consider essential to teach these topics. I also aimed to attend to their conceptual understanding of these topics, and to the ways they represent their knowledge structures within these topics. The central questions developed in this category were:

Q: What does it mean to understand force? Alternatively, **Q:** How do you define force?

Q: If you want your students to understand force, what underlying ideas or concepts do you think your students need to grasp?

To help the participant teachers identify the ideas, topics, and concepts that they think are necessary for teaching force and motion, based on their experiences of teaching these topics, a tentative list of topics related to force and motion was prepared (Figure 3.1). Each participant and I considered this list together at the beginning of each interview, and we negotiated and selected topics for our conversations. Each topic was discussed by using one of the above two questions along with some prompting questions when required, in the order the teachers preferred. The use of these questions was effective to help me to gain a glimpse into his or her conceptual understanding of the topic. The way the individual participants chose to sequence the topics and talk about their experiences of teaching, as well as the way they organized the science curriculum, enabled me to see features of the ways they organized what they believed to be the important knowledge structures relative to force and motion. Further probing questions were asked where appropriate to gain additional insight into the reasons participants organized their particular teaching of these topics as they did.

Category two: Knowledge of student learning. The category of teachers' knowledge of students focuses on students' alternative ideas in science. So, to develop interview questions, I focused on gaining access to the teachers' experiences with students' misconceptions and alternative ideas about the force and motion topics. I was also interested in learning about the strategies they used to help students. The questions below were developed for every topic or concept selected by the teachers in the study. Questions for the topic of force were:

Q: What common misconceptions did your students bring into your classroom about the concept. force?

Q: How did you address, challenge, and try to modify your students' alternative ideas about the concept, force?

I would follow with a discussion about the participants' insights of students' difficulties in learning this topic. Since, this was a logical sequence that brought into focus students' conceptual understanding.

Category three: Knowledge of instructional strategies. I treated knowledge of the instructional strategies used by the science teachers to represent specific science concepts within comprehensive topic-specific PCK as: (a) topic-specific representations, which include illustrations, examples, models, or analogies, and (b) topic-specific science activities, which include problems, demonstrations, simulations, investigations, or experiments. In addition, I considered it important that science teachers understand "the conceptual power" of these representations and activities "to clarify the important information about a specific science concept or a relationship" (Magnusson et al., 1999, p. 18).

The following questions were developed and asked to gain access to the teaching strategies the teachers used to teach topics related to force and motion.

Q: What teaching strategies usually helped your students understand the concept, force?

Asking this question was a means to invite talk about the instructional strategies that the participants found effective when teaching about force. Further probing questions were asked to clarify these strategies, add details to them, and challenge the understanding of these teachers about the conceptual power of these instructional strategies and their reasons for selecting them.

In some cases, another question was added to ask specifically about the real world examples used by the participants in their classrooms.

Q: How did you relate the concept of force with the real world? Please share a few specific examples.

Category four: Knowledge of resources. Knowledge of teaching resources has also been identified in the PCK literature as one of the important knowledge categories. To gain an insight into my participants' worlds of planning for teaching a specific topic, I asked:

Q: Which resources help your students understand the concept, force?

Sometimes I needed to rephrase the question as:

Q: What teaching resource do you find helpful for teaching the topic, force?

It was logical to ask this question at the end of a discussion about instructional strategies, but in some cases the conversation itself took a route where the topic was discussed at a different point, for example, after the question about strategies to help students modify their alternative ideas.

Category five: Knowledge of technology. One of the teacher knowledge categories that I found important for science teachers is the use of technology to make a science concept understandable for their students. Therefore, I included this category in my conceptual framework—comprehensive topic-specific science PCK—described in Chapter Two. I developed and asked the following question to gain access to the ways participant teachers use technology to make a specific content understandable to their students:

Q: How did you make use of technology to help your students understand the concept, force?

Category six: Knowledge of science curriculum. I consider "knowledge of science curriculum" a particularly important feature of the topic-specific PCK of science teachers. This includes an

understanding of the place of a science topic within the specific science curriculum, the materials they are mandated to teach, and the mandate, goals, and objectives of teaching this topic. I wanted to develop interview questions in the category of teachers' knowledge of science curriculum—specifically, the Alberta Science Program of Study—that revealed how the participants enacted this science curriculum in their classrooms. The question developed for the topic, force was:

Q: How do you use your knowledge about the Alberta Science Program of Studies to plan and teach the concept, force?

I asked this question when having conversations about teaching the topic of force. The same question was adapted for other topics selected by the participant teachers.

Category seven: ***Knowledge of goal.*** The question developed to gain access to the participants' understanding of the goals of teaching the topics of force and motion was:

Q: Why is it important for high school students to understand the concept of force?

The same question was asked for other topics related to force and motion that were identified by individual participants.

Category eight: Knowledge of assessment. To access the participants' knowledge of assessing the understanding of concepts related to force and motion, I developed question(s) for every topic or concept selected by participant teachers. For example, the following question was developed:

Q: How do you assess your students' knowledge to make sure that they understand the concept, force?

Category nine: Knowledge of teaching context. During the discussion of the ten knowledge categories of comprehensive topic-specific science PCK, I considered it important for science

teachers to consider various teaching contexts for teaching a science topic. So, it was important to gain access to the teachers' experiences in this area. To develop questions in this category, I focused on various contextual factors relevant to the individual participants' lives. One such context was their experiences of *learning* about force and motion ideas, as compared to their experiences of *teaching* these ideas. The intention was to gain access to their various conceptions of the subject matter involved and to their critical stance on using various teaching innovations. Therefore, the following question(s) were developed:

Q: Do you teach the concept of force the same way you were taught?

If yes, what do you like about the way you were taught?

If no, what did you change, and why and how did you change it?

It is interesting to note that this question contributed less to accessing the effect of contextual factors on the participants' topic-specific PCK, and more tn their orientations of teaching science.

I added a further question about context which I repeated for all force and motion-related topics selected by the participants. This question was:

Q: How did the teaching contexts affect your teaching the concept of force?

This question was never enough to gain full access to the teachers' thinking, and so specific probing questions were added, such as:

(For Dave)

Q: How was teaching in Australia different from teaching in Canada?

Q: Did you find any difference in your teaching after coming back to Canada?

(For Monica)

Q: Has teaching in three different schools changed your approach to teaching the topic of force?

In some cases, I provided hypothetical situations to challenge the participants' beliefs. For example:

Q: If you are to teach in a rural classroom, do you think you will teach this topic the same way as in an urban setting?

If yes, why?

If no, what will you change and why?

Category ten: Knowledge of student diversity. I included knowledge of students diversity as a new category of science PCK. To learn about the participants' knowledge of students' diversity as it pertains to teaching force and motion, question(s) were developed and asked for every topic or concept selected by these teachers. For example, the question developed for the topic of force was:

Q: How does the range of students' backgrounds affect your teaching of the concept, force?

Some probing questions were deemed necessary, which included:

Q: How do you help students from various language backgrounds in your class while teaching them about the concept of force?

Q: Do the various cultural backgrounds of students in your classroom affect your planning about how to teach about force? How?

Depending on the individual teachers' experiences, additional questions were asked to gain access to their understanding of addressing diversity for teaching a science topic. For example, I asked Kevin specifically about teaching students with rural backgrounds. I asked Dave talk about force and motion topics to the First Nations students in his science class. I asked Monica and Jason about teaching force and motion topics to students who are new immigrants

and for whom English is their second language. I also asked Jason questions about teaching force and motion topics to students with physical disabilities, such as a hearing impairment.

3.5.3.3 The interview procedure

To access the experiences of research participants I collected narrative data by using the following strategies, which proved effective: considering the interview as a conversation, setting the stage, starting the interview with a general question, and using prompts.

***Interview as conversation*.** I considered the interview process as "a specific form of conversation" that allows meaningful interactions to occur between the researcher and the research participants (Kvale, 1996, p. 19). According to Kvale, conversations are used as: (a) part of everyday interactions, (b) a professional interchange, and (c) a philosophical dialogue. In this research study, the purpose of the interviews was "to understand themes of the lived daily world" of the participants regarding their planning and teaching a specific science curriculum "from the subjects' [participant science teachers'] own perspectives" (p. 7). The conversations that made up these interviews were a type of professional interchange where a conversation about teaching a science topic was initiated and the participant teachers were engaged in discussing how they teach specific science content. This led to the sharing of events and stories from their everyday teaching experiences and interactions with their students. I prefer to call these interviews "collegial conversations."

To ensure active participation, I engaged the participants in meaningful conversation to allow considerable interaction. This enriched the narrative data I gathered in the interviews about the participants' experiences. I followed the notion of an "active interview" emphasized by Holstein and Gubrium (1995), and attempted to investigate both the *whats* (science teachers' experiences of teaching force and motion topics) and the *hows* (the ways that a conversation

generated meanings about science teachers' experiences of teaching these topics) of the interview process. The interviews in this research were considered as sites where the researcher and participants co-constructed data, because "all interviews are reality-constructing, meaning-making occasions, whether recognized or not" (Holstein & Gubrium, 1995, p. 4).

To investigate participant teachers' PCK, I encouraged them to share stories and incidents of their experiences of teaching topics related to force and motion. As well, to deepen the discussions, I reflected on incidents from my own experiences. The process of constructing meanings from these experiences is multi-layered. The research participants independently constructed meanings of their own experiences of teaching force and motion ideas. Then, during conversations about these experiences, these research participants and I together constructed meanings of their experience of teaching topics related to force and motion. Finally, during the process of analyzing the collected data, I further drew meanings of these experiences. Each of these layers in the process of meaning-making was open to personal biases and human subjectivity. Therefore, the interpreted meanings in this research are not claimed to be a full representation of the actual experiences.

***Setting the stage*.** I considered "setting the stage" to be a vital part of the research design to "encourage the interviewees to describe their points of view on their lives and world" and to talk freely (Nielsen & Kvale, 1999, p. 128). Setting the stage for an interview involved several factors: (a) the research participants knowing the researcher, (b) selecting a convenient place for the interview where they would feel comfortable talking, (c) mutually deciding how long each interview would be, and (d) mutually agreeing on how many sittings would be required to complete the conversations. My first meeting with a participant was exclusively devoted to letting the research participant get to know more about me, the researcher and the research

project. Moreover, the interview meetings were flexibly scheduled, and locations were selected based on the participants' preferences. A consequence of this was that the atmosphere for the interviews that followed became relaxed, and the participant science teachers appeared to speak freely.

Using grand tour question. After discussion about which force and motion topics teachers wanted to talk about, I started the conversation by asking a "grand tour" question (McCracken, 1988). For example, I asked, "Can you recall and share an insight into your experience of teaching force that stands out for you?" This question is general in nature and non-directive in manner to allow the participant to specify much of the substance of their perspective. This question took the participant teachers into their world of teaching science, and they started talking about some vivid experiences. In some cases, they dove right into specific aspects of their teaching experiences. The discussions continued with further questions about various aspects of teaching the topic of force. Questions were asked to help them further share experiences of teaching the topic of force, which were based on the ten teacher knowledge categories identified in the conceptual framework, comprehensive topic-specific science PCK.

Using floating and planned prompts. Throughout the interview process, to "encourage fuller narration of the complexities of [the participant's] story", I tried to "listen for gaps, silences or contradictions" (Chase, 1995, p. 289). I used spontaneously generated prompting questions to encourage the participants to reiterate information that clarified or resolved contradictions I observed and to fill the gaps felt as silences (McCracken, 1988). The nature of the prompting questions used varied depending on the content and situation of each interview, usually with the intention of extending the conversation.

3.5.3.4 The collected data

The interview conversations with teachers were audio-recorded with their permission, which I transcribed then verbatim into written texts. My analysis is derived from those interview transcripts.

3.5.4 Step 4: Interview analysis and discovery of analytical categories

The fourth and last step in McCracken's (1988) four-step model is "interview analysis and discovery of analytical categories," which involves analyzing the interview data to answer the research questions, and to define and present new analytical categories to contribute towards existing theory. Analysis of the data involved reviewing the research questions and selecting a suitable method or framework from the variety of techniques available. In this case, I first reviewed the research questions, and then to address them I used the two types of analysis suggested by Polkinghorne (1995): narrative analysis and analysis of narratives.

- I used the *narrative analysis* technique to develop stories of teaching force and motion. These came from the four participant science teachers and were aimed at revealing their topic-specific pedagogical content knowledge of these topics.
- I used *analysis of narratives* to develop formative assessment tools that will be useful for pre-service science teachers.

I strongly favoured the use of the term "story" instead of "narrative" or "narrative account," which I explain below. I will follow this by clarifying the techniques of narrative analysis and analysis of narratives.

Using the Term "Story": I used "narrative configuration," the process by which happenings are drawn together and integrated into a temporally organized whole called a "narrative"

(Polkinghorne, 1995) or "story" (Elbaz, 1991). Taking guidance from Elbaz, I used the term "story" instead of "narrative" in this research study: Story is distinguished from narrative and "autobiography," based on the way unity and wholeness are understood. Elbaz, noted, "If the story achieves a unity or wholeness, it is because the teller has done so, not because unity has been found to be inherent in the stuff itself" (p. 5). In addition, the story is a "tale told on an occasion" that can be changed, and hence is not fixed in time. The only thing fixed is its publication (Elbaz, 1991, p, 6). Thus, the stories of participants' teaching about force and motion topics illustrate their topic-specific PCK, but they are fixed only for this research project. Their actual lives are changing, and hence the stories of their lives to be told and captured in the future will be different.

In addition, a story "most adequately constitutes and presents teachers' knowledge" (Elbaz, 1991), when used as a device to effectively represent "rich and voluminous" data, which "would otherwise be difficult to convey" (p. 3). In this research study, to represent teachers' knowledge, views, and ideas of teaching topics related to force and motion, I configured various stories described in the following section.

- I configured topic-stories, which represent the participants' knowledge, views, and ideas of teaching a single topic. I used data collected through the conversations with the research participants about events, incidents, and stories of teaching a particular topic—For example, force.
- I developed, for each participant teacher, a story of teaching force and motion to represent their topic-specific science PCK. The story of each participant's teaching topics is organized by triangulating a number of topic-stories configured for that participant. This is the story of

the interaction between science content and pedagogy, representing their PCK, as described by the individual teachers.

3.5.4.1 Performing narrative analysis

Narrative inquiry in educational settings is not the mere telling and hearing of stories (Clandinin & Connelly, 2000). (Re)telling stories to professional communities is an important characteristic of narrative inquiry. To *(re)tell* the stories, the narrative data collected needs to be analyzed, and a coherent story of experience ought to be developed.

One of the goals of this research study is to expose topic-specific PCK of the participant science teachers, pulled from the narrative data collected in the accounts of events and incidents of their teaching topics related to force and motion. By using the "narrative analysis" technique suggested by Polkinghorne (1995) I developed the accounts of the participants' teaching. I began by developing stories of teaching individual topics related to force and motion—which I call topic-stories. I then used these participants' topic-stories to develop their stories of teaching that illustrate these teachers' force and motion-specific PCK.

3.5.4.1.1 Developing topic-stories

Using the narrative analysis technique, I developed a number of topic-stories for each participant teacher, depending on the topics they selected and discussed.

Each topic-story:

- Is a narrative configuration (Polkinghorne, 1995) based on interview data that consist of collegial conversations about teaching various topics related to force and motion
- Corresponds to an individual participant's teaching of a particular topic related to force and motion

- Is plotted using the theme of teaching for understanding, and focuses on the participant teacher's views, ideas, and knowledge about teaching the particular science topic in a way that helps students conceptually understand this topic
- Contains aspects of the participant's pedagogical content knowledge

To assist the narrative configuration process for developing a topic-story, I carefully reviewed the transcript of the interview conversation about teaching that particular topic, using the conceptual framework, comprehensive topic-specific science PCK, to identify narrative fragments—small pieces of narrative data that represent an aspect related to one of the ten knowledge components within topic-specific science PCK. I reviewed the transcript at least three times to ensure that all relevant narrative fragments were identified.

I used the process of narrative analysis to weave together these relevant narrative fragments to configure a topic-story—the story of teaching a specific science topic by a science teacher such as *force*. "Teaching for understanding" was the plot that I used to represent the story as a set of intentional efforts described by the participant teachers that they used to make this topic comprehensible for their students.

For each participant teacher, I developed four to twelve topic-stories, depending on the number of topics discussed by the individual participant. Figures 3.3 and 3.4 show examples of developing a topic-story. Figure 3.3 presents the interview transcript of the conversation with Kevin about his teaching the topic, acceleration, where relevant narrative fragments are underlined. Figure 3.4 presents the topic-story developed using the narrative analysis, the process of configuring narrative fragments from the transcript together to develop a whole. This way I have aimed to meaningfully represent Kevin's teaching of the topic, acceleration.

Kevin – Transcript of a Conversation about Teaching Acceleration

R: Do you remember any incident or event about teaching acceleration?
K: [Silence/thinking]
R: If no, can you share any general insight into your experience of teaching about acceleration?
K: Hmm… It is not a huge concept.
R: Or, any conditions that facilitated or provided obstacles, generally to the teaching of acceleration?
K … I think acceleration is fairly a new concepts for kids.
R: Do you teach this topic specifically at grade eight, in Mechanical Systems?
K: No… acceleration, not specifically, maybe when there is a question or a need to explain.
R: In grade seven you teach about structures and forces, but motion is a big part of understanding force, and we have to talk about motion, at some point?
K: Yes.
R: So if we have to talk about motion, we need to talk about acceleration.
K: Yes, absolutely.
R: I mean we cannot understand Newton's 2nd Law without understanding acceleration.
K: Yeah.
R: There is a huge discussion on acceleration in Grade 11.
K: Yes, in Physics.
R: Yes, but usually there is a focus on quantitative stuff, like solving numerical problems, and the conceptual part is missing sometimes. So, do you think the conceptual understanding of acceleration is part of junior high curriculum?
K: Yes, for sure.
R: So, if you want your students understand to acceleration, what underlying ideas or concepts you want them to understand?
K: I think that… forces come into play hugely there…as well as mass. So, if they understand these little pieces, [they can understand acceleration] and then that is huge… ongoing… through examples and doing lots of practice, as for as calculating, and that kind of things.
R: Sometimes, students can do calculations and find answers, but they do not have a conceptual understanding of what acceleration is, or how we can accelerate objects. So, for that type of understanding, do you think they need to know something else?
K: No, I think if they get the idea of objects speeding up, and slowing down… acceleration and deceleration, and… maybe if they can make predictions on what would happen with gravity… no, I mean with friction forces and that kind of stuff. Then I think they are pretty good.
R: Did you experience any misconceptions or alternative ideas that your students bring to your classes?
K: No… I cannot think of any.
R: Actually, I experienced one, when teaching about acceleration. The difference between constant velocity and constant acceleration, I found that some of my students were not able to distinguish between the two. So sometimes if it is constant speed...
K: Oh, yeah, I think if they see graphs of that, like when I show graphs of them [constant velocity, and constant acceleration] they see a straight line versus a curved line trend, and I think they kind of get that. I mean, they all are driven in cars and have experienced when their parents drive with cruise control on the highway, when the car is accelerated on a stop light or something like that.

R: OK, great, so that is how you teach about acceleration?
K: Acceleration seems like a tricky concept, but maybe at this level it is fairly straightforward.
R: And, do you think using graphs is the best way to teach this?
K: Yes, that is one way, to show them the difference between speed, velocity, and acceleration, and that is when I show them different graphs.
R: Other than graphs, what instructional strategies you have used for teaching acceleration?
K We talk about… the idea of driving a car... [an everyday example]
R: Would you describe how do you use this example and what discussion questions guide classroom discussion?
K: Just a discussion about… when you are driving in city versus on the highway, using cruise control and a speed limit. And go on to the constant speed versus when you accelerate from a stop [red light].
R: Did you use any other resources, any technology, or any video clips to show them for this purpose?
K: I do not remember.
R: OK, how do you show them graphs actually?
K: I have graphs in my notes, so I do not have graphs up on the board… although I would make them… because we have Geo Algebra… a program for active board. It is an online program to show quick and easy online graphs.
R: I also have used online computer simulations where you put values for certain variables like speed and time… and you get a quick online graph of the motion, easy to use in class.
K: I think I have used the epxplorelearning.com website and a gizmo for this… but I cannot think of it exactly, how I used it.
R: If you want, I can send you the link to the simulation that I used.
K: OK
K: Cycling, it would be another way that they would understand [objects] accelerating and decelerating.
R: You just mentioned using the example of driving, and let's suppose that your students do not have a background in driving. How will you consider your students' background when planning for teaching acceleration?
K: Oh, yes, there might be students who have never driven… but I think everybody… I would say that everybody in my classroom had been in a car, not maybe driven, but have felt the different acceleration and… if not, you could even talk about aeroplane and… and taking off… accelerating versus cruising speed… and that would… you know, less would have that experience, but I think everybody could take that lead from not actually pushing the gas pedal and feeling the acceleration but actually feeling the acceleration. And the odd chance where I have students who have never experienced sitting in a car… [Thinking]
K: Yes, I am thinking about, for example, in Pakistan, especially, in a rural school there might be half of the students who had never a chance to sit in a car.
K: Yeah, and that would be different if I would be teaching there… versus here.
R: So, what would you change there?

K: Well, any automotive transportation you can look at, you can even show videos… I guess of predatory animals like cheetahs, or a horse or something, where an animal accelerates, and then has more of a continuous speed, so going from a slow speed to that of a burst and that of acceleration and chasing… That would be really rare, but you can do that.
R: How did you assess your students to ensure that they have achieved an understanding of acceleration?
K: That is usually a quiz, and then there will be a unit test, pretty simple.
R: So, do you think you teach acceleration the way you were taught?
K: [Silence/Thinking]
R: Can you share anything special that happened in your class as a student which you also used later as teacher?
K: I do remember in junior high school in science class talking about… I do not remember what it was, if it was velocity or acceleration, something… whatever. I remember my teacher having a Hot Wheels track and have it setting up high and the car coming down, kind of thing, and showing that car is moving...car is speeding up... but I did not know how... maybe we just took his words that the car started slower, and got faster, and as it went out at the flat, it slows down...so it is accelerated and then it is decelerated...because I know that we did not film it, or had a radar gun showing the speed change or anything like that.
R: I guess that might be because he did not have those types of technologies in class.
K: Yes, not in a junior high school classroom.
R: So, you are not sure how many students could see the difference… in that demonstration.
K: Yes, but I know how we did it… on such a track… if you are going down the hill or a slope, you feel the acceleration, but if they are behind the steering wheel they can experience that better.
R: So, did you ever use Hot Wheels tracks in your science class?
K: No, I never used the Hot Wheel tracks… [Laughing], but I am going to. I just never thought of it… I almost forgot. So, this is going to help.
R: Glad that our conversation helped you to recall this. Now you can use Hot Wheels in your class.

Figure 3.3: Interview transcript of conversation with Kevin about teaching acceleration

Topic-Story: Teaching Acceleration

Kevin was unable to recall an incident or event from his teaching of acceleration, as he said that this is not "**a huge concept**" at the junior high school level. After much thought, he eventually said, "**I think acceleration is a fairly new concept for kids,**" which he thought they had not yet been exposed to. He also noted that he does not deliberately teach this concept to grade eight students. He talks about the topic only when a question arises, or a discussion requires that this concept be clarified. Kevin supports the view that motion is an aspect of force, and therefore any discussion about motion is incomplete without at least touching on acceleration. Our conversation led to the connection between acceleration and Newton's second law of motion, where Kevin pointed out that students should understand acceleration qualitatively as well as quantitatively.

I inquired about underlying concepts or ideas Kevin thinks students need to understand to grasp acceleration. After careful consideration, he said, **"I think that... forces come into play hugely there... as well as mass. So, if they understand these little pieces [they can understand acceleration]."** He elaborated, adding that students can understand acceleration **"through examples and doing lots of practice, as far as calculating and that kind of thing."**

I expressed the concern that sometimes students can do calculations and find the right answers but do not have a conceptual understanding of what acceleration is or how we can accelerate things. To ensure that students have this understanding, beyond just how to do acceleration calculations, Kevin said that he wants his students to **"get the idea of objects speeding up and slowing down... acceleration and deceleration."** He also thought that if his students **"are able to make predictions about the role of friction in acceleration, they have a good understanding of acceleration."**

Kevin was initially unable to share alternative ideas about acceleration that his students brought to class. However, when I mentioned my experience of some students not being able to distinguish between a constant velocity and constant acceleration, Kevin quickly responded that showing graphs can help to deal with this problem. He added, **"If they see graphs of [two types of motion] ... [and] they see a straight line versus a curved line trend. . . [and] they get that."** Then, he talked about another strategy to help students distinguish between two types of motion using three examples: a car driven with cruise control on highway; the accelerated car [going] off the highway; and the car [stopped] at traffic lights. Kevin said that he believes that these examples are effective because even if they have no driving experience, **"they have all driven in cars and have the experience of driving with their parents with cruise control on a highway."**

Kevin also uses graphs and the above examples to teach about acceleration, saying, **"Acceleration seems like a tricky concept, but maybe at this level it is fairly straightforward."** He added that he uses different graphs because this "**is one way to show the difference between speed, velocity, and acceleration**."

Goals of Teaching Acceleration

Conceptual Understanding of Acceleration

Effective Instructional Strategies

Whether acceleration is difficult or easy concept

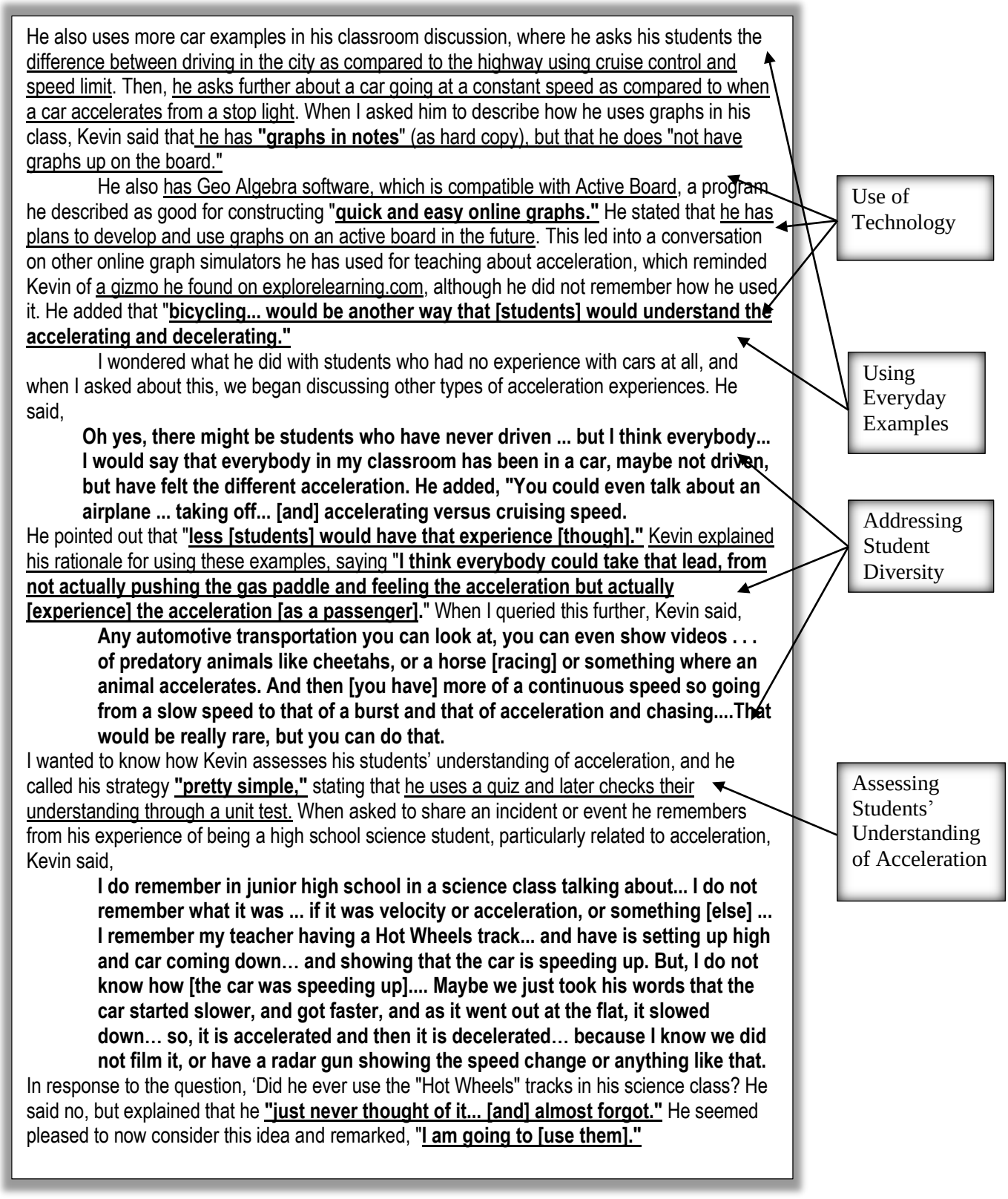


Figure 3.4: Developing Kevin's topic-story of teaching topic, acceleration

3.5.4.1.2 Develop stories of teaching

To illustrate the topic-specific PCK of each participant science teacher, I needed to develop a consolidated story of teaching topics related to force and motion that I call a "story of teaching."

Each story of teaching:

- Is a narrative configuration based on the topic-stories developed for each participant teacher
- Corresponds to an individual participant's teaching of a set of interrelated force and motion topics
- Is plotted using PCK as the theme, and focuses on the participant teacher's views, ideas, and knowledge about teaching a set of force and motion topics in a way that reveals their PCK related to these topics
- Presents the participant's topic-specific science PCK

To assist the process of developing a consolidated story of teaching for each participant, I devised a technique for triangulation of data that I call "inter-story triangulation analysis." Inter-story triangulation analysis allowed me to generate insights into that participant teacher's science teaching and develop their profile of PCK related to force and motion topics.

For each individual participant teacher, I triangulated the data collected about teaching multiple force and motion topics by engaging in an analysis of the topic-stories using the inter-story analysis. Figure 3.5 shows an alternative view of the conceptual framework, comprehensive topic-specific science PCK, which I used to represent a topic-story, since each story has aspects of PCK, as identified in this conceptual framework.

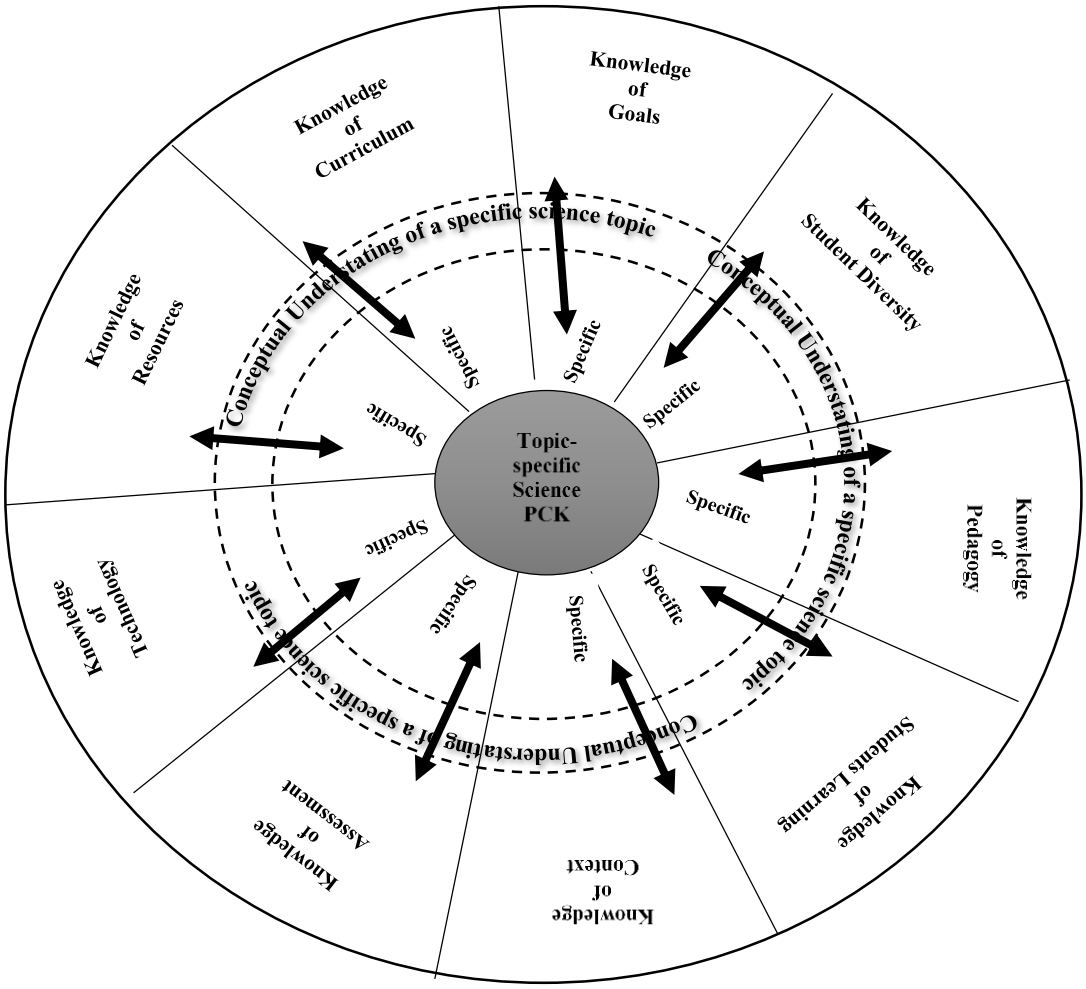


Figure 3.5: Azam's conceptual framework – comprehensive topic-specific science PCK, - An alternative view

I used the narrative fragments highlighted in the topic-stories developed for an individual participant teacher, representing elements of the PCK of the teacher. Weaving the narrative fragments representing a particular PCK component within one of the ten knowledge categories, I configured a section in the story of teaching representing the participant teacher's PCK in that particular category.

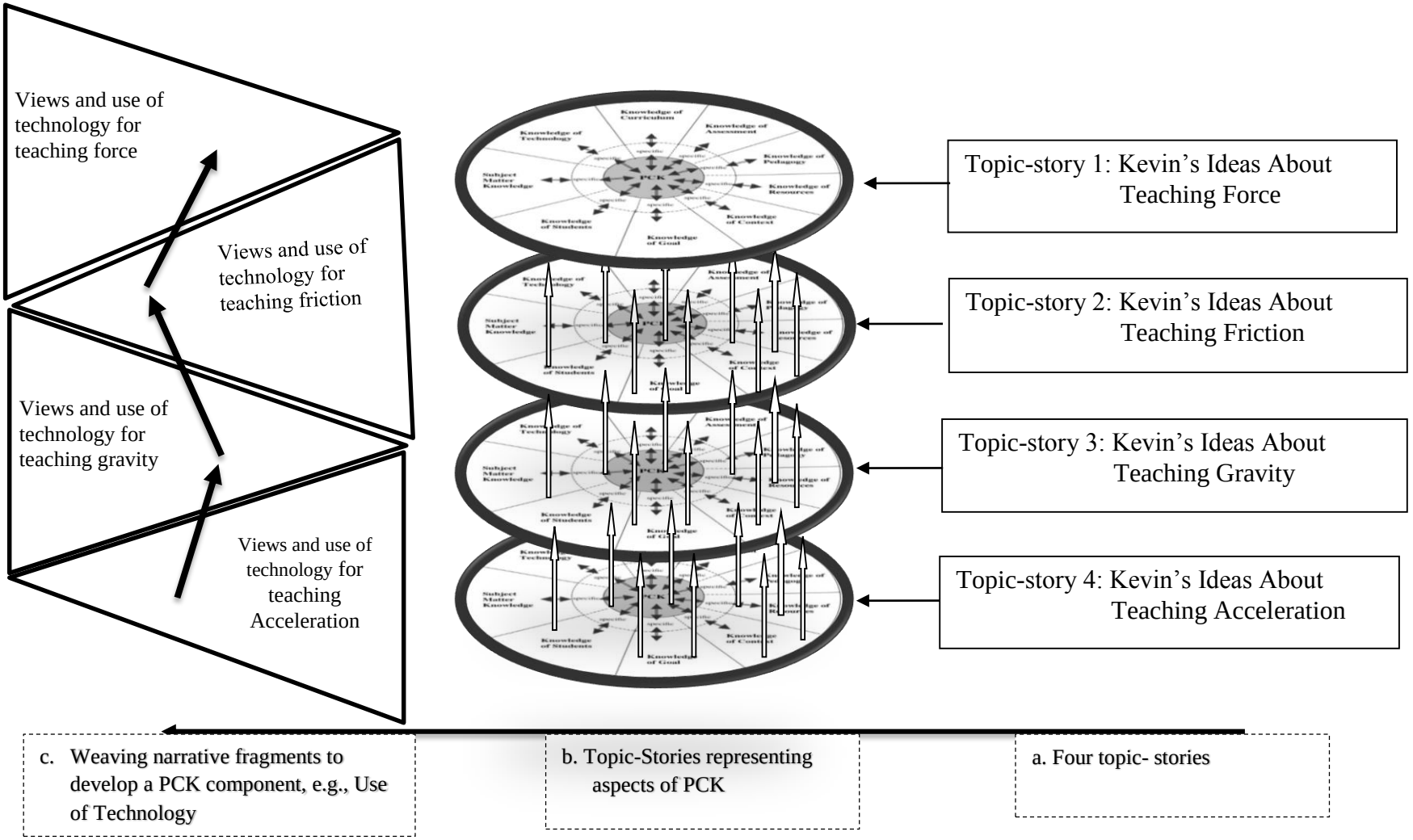


Figure 3.6: Process of analyzing data (triangulation) for developing Kevin's story teaching

I have described the research process in detail using Kevin's case because his case has less information as compared to the other three participants, which was manageable as the process needed to repeat some of the information. Moreover, he was the first to be interviewed, and his data were the first to become available to me for analysis. Figure 3.6 shows the triangulation of multiple data sources, where Kevin's four topic-stories are triangulated to represent and organize Kevin's topic-specific science PCK. The figure highlights the process of weaving together the PCK elements in the category, knowledge of technology, which helped in developing a section on Kevin's story of teaching—Kevin's views and ideas about using technology to teach various force and motion topics. The above process was repeated to develop all ten sections representing the profile of Kevin's PCK. Each section represents one of the ten PCK components as identified in the conceptual framework, comprehensive topic-specific science PCK.

As noted above, each teacher discussed between four to twelve topics with me, so to analyze the topic-specific science PCK of teaching force and motion, a multilayered inter-story triangulation analysis was performed, as shown in Figure 3.6. Because of the number of topics Kevin discussed, I developed four topic stories, thus number of layers of the inter-story triangulation analysis for Kevin is four. Therefore, number of topic-stories developed for the other three teachers varies depending of the number of topics they discussed, which was affected by their time, availability, and willingness to share their stories. The inter-story triangulation process was used for developing a story of teaching force and motion for each participant teacher, however, the number of stories varies in each case varied.

The stories of teaching I developed are not necessarily constructed in chronological order. These stories are organized around the theme, pedagogical content knowledge. The conceptual framework developed and discussed in Chapter Two and illustrated on page 47

offered a temporal sequence to the incidents and events I collected to feature the topic-specific PCK of participants. Each *story of teaching* consists of three main sections:

1. An introduction to the participant science teacher

2. The orientation of the teacher to teaching science, particularly force and motion ideas

3. A profile of the teacher's PCK in the context of his or her ideas and experiences about teaching force and motion

***Section one*.** Section one describes the academic preparation and background of the teacher, reasons they chose to become a science teacher, their interest in science, their experiences of teaching science in general, and their experiences of teaching force and motion topics

***Section two*.** Section two attempts to interpret and describe the individual teacher's *orientation* to teaching science in general, and teaching force and motion topics specifically. My approach to this was through an overall analysis of their topic-stories of teaching and sometimes also their conversations, focusing mainly on the instructional strategies they used.

Section three. Section three presents the participant science teacher's pedagogical content knowledge related to force and motions ideas, using ten subheadings representing the ten teacher knowledge aspects contributing towards their topic-specific PCK.

Figure 3.7 shows an outline of "The Story of Kevin's Teaching." This story of teaching begins with an introduction to Kevin, which provides a glimpse of his life, education, background knowledge, and preparation for teaching science. The representation of Kevin's PCK related to force and motion ideas consists of ten subheadings, each representing one of the ten knowledge aspects of Kevin's topic-specific science PCK. Each of these ten subsections attempts to present Kevin's grasp and use of features of that particular knowledge category in his

teaching of the topics related to force and motion. Overall, this section reveals Kevin's unique understandings of force and motion topics, and his views and thoughts about teaching these topics to junior high school students to develop their conceptual understanding.

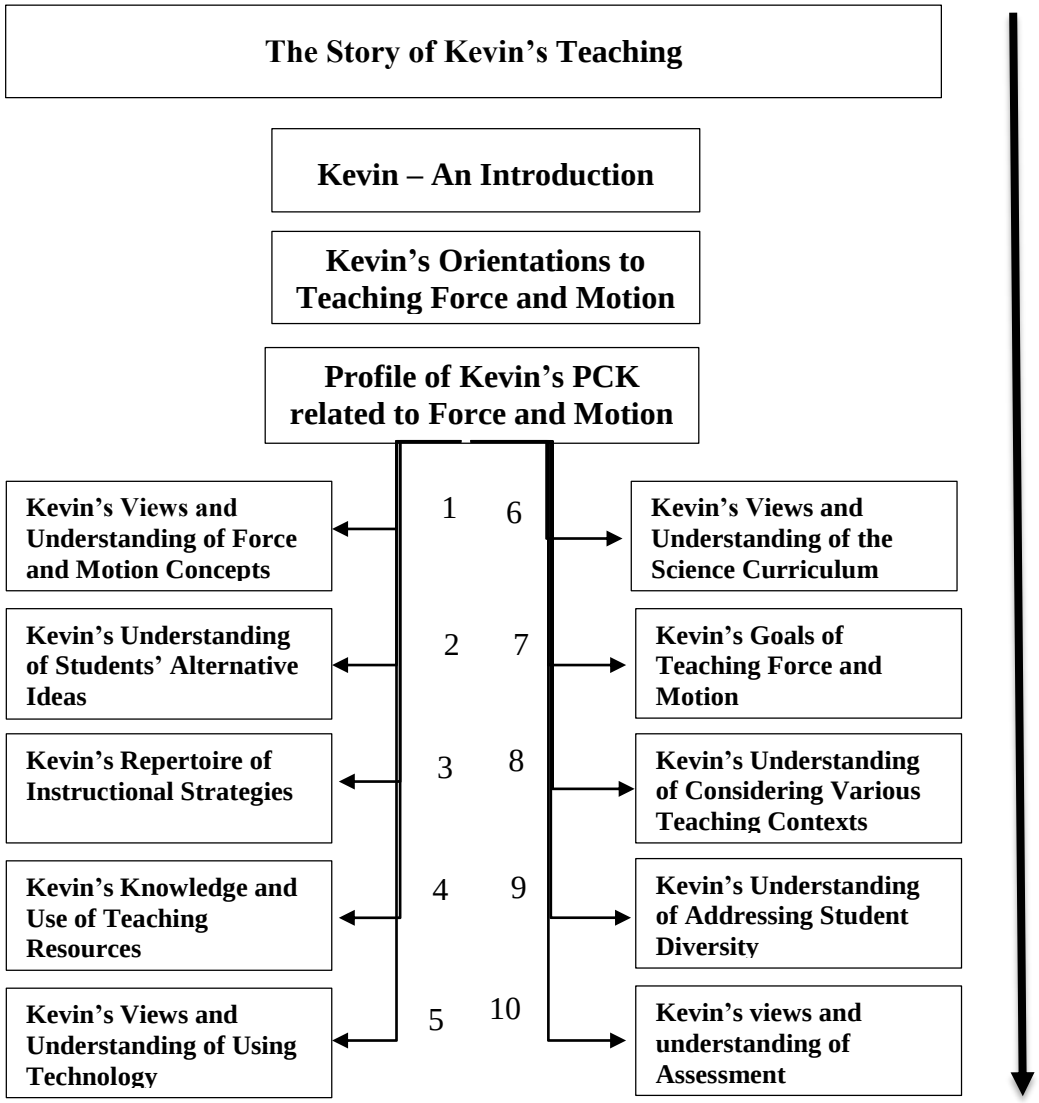


Figure 3.7: An Outline of Kevin's Story of Teaching

This section covers Kevin's understanding about:

- The concepts he believes should be taught to junior high students, and how these ideas should be organized and introduced to them to facilitate better conceptual understanding (content knowledge for teaching)
- The concepts he believes are difficult for students to understand, why they are difficult, and how students can be helped (knowledge of students' alternative ideas)
- The effective instructional strategies to teach these topics (knowledge of effective instructional strategies)
- The teaching resources he finds helpful to plan instruction (knowledge of resources)
- The technologies that he uses to teach science, and how these technologies help students understand these topics (knowledge of technology)
- The ways he uses the curriculum guide and text resources to plan, organize, and prioritize the curriculum (curricular knowledge)
- The goals that he has for teaching these topics at a particular level (knowledge of goals)
- The strategies and techniques he uses to assess students' learning (knowledge of assessment)
- The ways he considers teaching a specific content through curricular, local, provincial, national, and international settings (knowledge of context)

3.5.4.2 Performing analysis of the narratives

The second goal of this research study was to develop tools that can be used to engage pre-service science teachers to support the growth of their topic-specific PCK. To achieve this goal, the participant teachers' stories of teaching of were used as data, and were analyzed through the process of "analysis of narratives" recommended by Polkinghorne (1995).

The development and discussion of these pre-service teaching, learning and assessment tools is rooted in my experience as a researcher in this study. I have focused on transforming the findings in this research study to be used for my own professional development and the future skill development of pre-service science teachers. This process is a reflection of what Dewey identified as the continuity and the developmental aspects of *experience* (Dewey, 1938). According to him, "teaching and learning is a continuous process of reconstruction of experience . . . . and education is a development within, by and for experience" (p. 28). From Dewey's standpoint, the purpose of the experience is growth and development, which is one of the goals of this research study.

3.5.4.2.1 Developing formative assessment tools

Clandinin and Murphy (2007) suggested that the knowledge developed from narrative inquiries is textured by incompleteness and idiosyncrasy that leads less to generalizations and certainties and more to refreshing old ideas and alternative possibilities. Therefore, I decided to look for alternative possibilities for using the research findings, the stories of teaching, to develop formative assessment tools for teaching and learning in science teacher education. To assist in the process of developing PCK tools, I used *analysis of narrative* and highlighted various aspects of science PCK in each participant teacher's story. For this analysis, I focused on the problems of learning they identified and the solutions they suggested to deal with a particular problem. Using these two pieces of analysis, I developed a particular scenario and a few related questions to combine together in the form of a formative assessment tool. To present as examples, I developed eight such PCK tools, discussed in Chapter Five.

These tools can be used in pre-service science teacher education to facilitate the development, exploration, and assessment of topic-specific science PCK (particularly force and

motion-related material). These PCK tools are offered to the science teacher education community to achieve several goals:

- To engage pre-service science teachers in thinking about approaches to teaching the force and motion topics at the secondary school level
- To develop teachers' topic-specific science PCK
- To assess aspects of pre-service science teachers' PCK related to teaching force and motion topics at the secondary school level
- To assess and critique the value of the PCK tools and suggest ways to further develop and improve them

3.5.4.2.2 Developing PCK cases

In addition to PCK formative assessment tools, I also suggest that *cases* can be developed from the research findings, especially the topic-stories. I developed one such example from Monica's story by using the *analysis of narrative* technique, where I focused on the parts of her story that contained aspects of alternative ideas of science. I found a particular segment in her topic-story of teaching gravity, which carries the potential alternative idea that when falling from the same height, a heavy object will hit the ground before a light object. Monica presented the desired information that both falling objects will hit the ground at the same time, but one of the objects she described that she used for teaching about this concept, a feather, will not provide the same result without keeping it in a vacuum tube. After a long conversation, she could not identify the problem attached to using a feather in the classroom for teaching the above concept. Therefore I used this segment from her story and turned it into a case, and developed a few questions to guide pre-science teachers' thinking to help them develop PCK for teaching the

concept of gravity. The case is presented in Chapter Five as an example. More such cases can be developed by further analyzing stories of teaching.

3.6 Ethical Considerations

Narrative inquiry is a way of enquiring into and understanding an "experience." This research study involves enquiring into the experiences of science teachers and having them share their stories of teaching a specific science curriculum through "collaboration between [the] researcher and the participants" (Clandinin & Connelly, 2000, p. 20). Due to the collaborative and relational aspects of narrative inquiry, ethical considerations were of prime importance throughout the process.

Narrative inquiry promotes a collaborative and non-judgmental relationship that takes its lead from the participants, thereby increasing authentic dialogue. I made a conscious effort to practice ethical thoughtfulness by being an empathetic and non-judgmental listener (Clandinin & Murphy, 2007) throughout the conversations with research participants. I attempted to engage in authentic dialogue, valuing and respecting the participant teachers' voices, by acknowledging and considering them as valuable sources of information with wide range of experiences. To further facilitate this dialogue, I made it clear from the outset that the participants needed to share only what they felt comfortable with. In addition, I used an informal conversational style and a non-directive interview stance in an effort to enable the participants to tell their stories in their own way. Due to the nature of the research topic, there was a need to go deep in our conversations about teaching force and motion ideas, and to achieve this I asked probing questions to enrich the data and the research texts. The aim was to make the interview useful to the research participant as well as the researcher by developing a supportive and reflective space

(Maxwell, 2005) and using a reciprocal style (Rogan & de Kock, 2005) in which I also sometimes shared my own experiences.

Through narrative inquiry, researchers may interpret conversations they had with their research participants into the research texts, such as stories, narrative accounts, and case reports. The research texts are then shared with wider audiences, which can make the complexity of the participants' lives visible. This research, like any other qualitative inquiry, involves the danger of making certain aspects of the participant teachers' professional identities visible. Within an ethical framework, these issues of anonymity and confidentiality are of added importance. In this research study, pseudonyms are used to conceal the participants' identities and locations to ensure that connections between the persons and places are not identifiable. Moreover, the stories of the participant science teachers are developed and shared in a way that respects their professional lives in their respective discourse communities.

3.7 Achieving Trustworthiness

The qualitative nature of the present research has embedded concerns of trustworthiness. In this section, I address these concerns and the strategies I employed to enhance the trustworthiness. I made an attempt to achieve trustworthiness in this research study at two levels: (a) the overall trustworthiness of this qualitative study, and (b) the trustworthiness of narrative research in general.

- To establish overall trustworthiness in this research study, I considered four criteria suggested by Guba (1981): credibility, transferability, dependability, and confirmability. I made an explicit attempt to establish *credibility*, however, other three criteria were also achieved implicitly.

- To establish the trustworthiness of the narrative accounts or stories developed, I found relevant the idea of *meaningfulness* (Elbaz, 1991) and the ideas of *coherence* (Lieblich et al., 1988).

The following sections describe the procedures followed and the criteria used to establish trustworthiness.

Ensuring *credibility* is one of the most important factors in establishing trustworthiness (Lincoln & Guba, 1985). Credibility "deals with the question of how research findings match reality, how congruent are the findings with the reality? Do the findings capture what is there?" (Merriam, 1998, p. 201). The idea of credibility is also conceptualized as "verification" by Creswell (1998), which according to him increases the trustworthiness. To achieve credibility and verification in this research I used *triangulation*, *member checks* (Creswell, 1998; Merriman, 1988)), *clarifying researcher's bias* (Creswell, 1998), *careful selection of the participants*, *thick, rich descriptions.*

3.7.1 Using triangulation

Triangulation is conceived at the methods level or the data level to solve the problem of relying on one data source or method (Huberman & Miles, 1994). I attempted to achieve triangulation at the data level by examining the participants' experiences of teaching across various science topics, since a wide range of related science topics was used as the context. Another layer of triangulation was added by presenting several participants' stories to determine the consistency of findings from different data sources (Patton, 1999). In addition to collecting data from the four participants, the participants came from different school boards and had various curriculum backgrounds, which allowed the collection of diverse perspectives. These

strategies contributed to achieving data triangulation to ensure that an account is rich, robust, comprehensive, and well developed.

3.7.2 Using member checks

Member checks is one of the strategies in qualitative research to ensure that the meanings correctly represent experiences as the participants described them. Lincoln and Guba (1985) consider member checks as the single most important technique to strengthen credibility in a research study. Lieblich et al. (1988) called it *correspondence* and considered it an important criteria for credible narrative research. This is usually achieved by taking the data or findings back to the participants to engage them in a dialogue to refine those data and findings. As noted earlier, I developed narrative constructions of each participant's transcript—Stories of Teaching—to represent their pedagogical content knowledge. I shared these stories with the participants and asked for their input, comments, or suggestions to modify or improve the accounts. This process ensured that the teachers' narrative accounts were credibly represented from the participants' perspectives and were not just the perceptions of the researcher.

3.7.3 Using peer-review

To clarify the researcher's bias, peer review (Creswell, 1998) and peer debriefing (Lincoln & Guba, 1985) proved to be extremely useful. The peer reviewer is "an individual who keeps the researcher honest; they asks hard questions about methods, meanings, and interpretation, and provide the researcher with the opportunity for catharsis" (p. 202). My doctoral research supervisor served as the peer reviewer, and she asked critical questions to challenge my biases throughout the research process.

3.7.4 Careful selection of participants

As described above, the research participants in this research study were selected from various schools and school boards, and had diverse range of experiences to allow maximum variations in the findings (Merriam, 2000), which allowed possible transferability of the research findings. These diverse experiences included: in-depth engagement with the content, likes and dislikes about the science topics under discussion, and various roles within their school boards.

3.7.5 Achieving meaningfulness

Focusing on the story itself, Elbaz (2005) argues that the criteria to establish the quality of narrative research lies in the *meaningfulness* of the story developed and in preserving the *voice* of the research participants. The meaningfulness of the story "depends on the listener [researcher] who plays an active role in making sense of the story" (Elbaz, 2005, p. 6), and hence is inherently subjective. In the case of a particular narrative research study, meaningfulness emerges out of the guiding research questions (Elbaz, 2005).

In this research study, the meaningfulness of the stories lies in presenting various aspects of the topic-specific PCK of the participants, which was achieved by organizing data using a specially designed conceptual framework (comprehensive topic-specific science PCK). This also provided a "sense of innovation" and "originality" in presenting the story and analysis (Lieblich et al., 1988, p. 173).

During the process of developing stories to represent participant science teachers' topic-specific PCK, I attempted to ensure that their voices were not only preserved but honoured. Choosing the teachers' descriptions of their experiences as data was a way to honour and favour the participant teachers' voices over the researcher's. In addition, narrative fragments (Clandinin & Connely, 1986) were used, which represented pieces from long conversations, "to draw the

outlines of narrative unities for a particular purpose" (Elbaz, 1991, p. 6). I used pieces of conversations using narrative analysis to develop narrative accounts or stories of the participants (Polkinghorne, 1988).

3.7.6 Achieving coherence

To make these stories *coherent*, I sought internal and external coherence. To establish internal coherence, I made an effort to use different parts of the transcripts to create complete and meaningful illustrations of the topic-specific science PCK of the participants. To establish external coherence, I drew links between these illustrations and existing theories on science PCK.

3.8 Summary

In this chapter, I have described the methodological approach, design, and procedures I engaged in, to studying the pedagogical content knowledge of secondary school science teachers. I described my worldview, which led to designing a qualitative study using a narrative inquiry approach. I outlined the way I used the long interview (McCracken, 1988) approach to develop interview questions and to employ interview. I also illustrated the specific procedures devised to analyze and present the narrative data. Lastly, the ways used to enhance the trustworthiness of the research study were discussed.

Chapter Four presents the findings of the research study based on the narrative analysis technique employed to develop the stories of participants' teaching in the context of force and motion topics. Each of the four sections begins with the participants' personal backgrounds as a science teacher, his or her orientations to teaching force and motion topics, and his or her profile of pedagogical content knowledge related to force and motion ideas.

Chapter Four: THE STORIES OF TEACHING

In this chapter, I present analysis and results pertaining to the knowledge that teachers can articulate about teaching a specific science topic—their pedagogical content knowledge. The chapter describes teachers' views, thoughts and understanding about teaching force and motion topics. Findings are presented in four sections. Each section is a narrative configuration of the data, which I call The Story of Teaching. Each story of teaching provides insight into the background of each teacher, as well as an illustration of his or her pedagogical content knowledge entailing ten teacher knowledge categories and relating teacher knowledge aspects to illustrate individual teacher's PCK related to force and motion topics. This is not, by any means, a definitive and complete picture of the topic-specific science PCK of these teachers, but presents the use of the research process that allowed insight and access into their PCK.

The chapter is presented in four parts. Each part represents story of one of the four research participants' teaching, and consists of three sub-sections: (a) an introduction of the individual participant, (a) his or her orientation to teaching these science topics, and (c) a profile of their PCK related to force and motion ideas. Part I presents the story of Kevin's teaching, which is used an example to show the data analysis process used to develop each Story of Teaching, thus also contains four topic-stories of his teaching of individual topics. Part II displays the story of Jason's teaching, which is presented in detail to show his in-depth content understanding and details of the ways he teaches these topics. Part III, represent the story of Monica's teaching, and Part IV presents the story of Dave's teaching.

The next four sections present four stories of teaching, to reveal components of pedagogical content knowledge in the participant teachers' teaching.

PART 1: THE STORY OF KEVIN'S TEACHING

I first asked Kevin about his education and teaching experiences to understand him as a science teacher, and to provide an introduction about him in his story of teaching. I analyzed my conversations with Kevin to recognize his orientations to science teaching that might have shaped his pedagogical content knowledge.

I had conversations with Kevin about Five topics: (a) force, (b) reaction force, (c) friction, (d) gravity, and (e) acceleration. I decided to combine conversations about force and reaction force because of an overlap. Therefore, I developed four topic-stories before developing the story of Kevin's teaching, which contains his profile of pedagogical content knowledge. Therefore, Kevin's story of teaching does not encompass the full breadth and depth of his topic-specific pedagogical content knowledge, but his PCK of teaching the topics selected. The Profile of Kevin's PCK related to force and motion ideas consists of ten subheadings representing one of the ten knowledge components of Kevin's topic-specific science PCK. Each of the ten subsections attempts to present Kevin's grasp of and use of the features of that particular knowledge category in his teaching of force and motion topics. Overall, this section reveals Kevin's unique understanding of these topics, as well as how he has taught these topics for a conceptual understanding of his students.

The next three sections covers: (a) an introduction of Kevin, (b) his orientations to teaching science, and (c) a profile of his pedagogical content knowledge.

4.1 Kevin - An Introduction

Kevin holds a teaching license in Alberta and has been teaching in a junior high school through a school board in Calgary and area. Like many secondary school science teachers, Kevin has a prior bachelor's degree in a science-related field. He completed his BSc with a major in

Biology and a minor in Outdoor Environmental Education from a public university in Alberta, and obtained his BEd from another public university in the same province.

At the time of our conversations, Kevin had spent eight years teaching science and mathematics full-time in one junior high school. During those years, Kevin's experiences of teaching science had varied. During his pre-service practicum, he taught the Water Systems unit to grade eight students, and Electric Principles and Technology unit to grade nine students. His experiences of teaching topics related to force and motion include teaching Structures and Forces unit to grade seven students, a few times at the beginning of his career, and regularly teaching the Mechanical Systems unit to grade eight students. Most recently, He has repeatedly taught science and mathematics to grade eight students. Kevin described that he had taught force and motion topics seven times in total, approximately.

With his two-year BEd after-degree, Kevin specialized in secondary science, but he said that he did not "remember specifically either taking a class in physics . . . a discussion [on physics] . . . [or] on force and motion [in his BED program]." Nonetheless, he appears to have a special interest in physics as he took three courses in physics during his BSc, which included some discussion about force and motion topics. It seems likely that his interest in physics was a motivational factor for also attending a session at an outreach conference on bringing hands-on physics into the classroom, which focused on acceleration.

After both taking physics courses and some professional development, Kevin stated, "I [feel] confident to teach [physics topics] for sure." He also said that he, "will brush up on [physics concepts] and then teach . . . [to] make sure that [I not only] memorize it, but . . . can apply the concept…like, teach[ing] any other topic."

After introducing Kevin, I present the Four Topic-Stories about Kevin's teaching of the force and motion topics that I developed by analyzing our conversation using the narrative analysis procedure described in Chapter Three.

4.2 Four Topic-Stories: Kevin's Thoughts and Experiences about Force and Motion Ideas

I first developed four topic-stories before developing a Story of Kevin's Teaching, partially a profile of his PCK. Each topic-story represents Kevin's thoughts and experiences about teaching one of the topics he discussed with me. The four topic-stories of Kevin's teaching are presented in the following sections.

4.2.1 Topic-Story 1: Teaching force

When asked for a memorable incident or event to provide insight into his experience of teaching about force, Kevin started the conversation by saying, "I always do less teaching and more discovery." To provide an idea of the type of discovery he employs in his teaching, he described, "I would have something setup, . . . [alternatively], I would [just] do something . . . [for example], have a student come up and push my shoulder or something like that, and [then] ask the kids, what just happened there?" Kevin claims that this type of beginning will take his students "down the road of discovery" so that they will share their ideas to answer the focus questions. He noted that "eventually somebody would come up with . . . [the idea that] . . . he pushed you and made you move."

After students understand the underlying idea, Kevin then gives a name to the idea—in this particular case, the concept of force. He conveyed that he also makes sure that his students develop the scientific language needed to describe the phenomenon of force, to represent what a force does. He said that he expects his students to be able to tell, whether force is a push or pull.

The specific learning outcomes Kevin seeks to achieve when teaching about force are that students can:

1. Demonstrate what a force is
2. Measure the force
3. Identify a relationship between mass and force

According to him, the first learning outcome is achieved when his students can push an object and say, "I just applied a force on the pen and made it move." He feels that the second learning outcome is achieved when his students "could get . . . some understanding of measuring a force,. . . not necessarily using a formula and doing a calculation, but even if they could see if I apply a big force to a small object I can send it flying." To achieve the third learning outcome here, Kevin wants his students to play around with objects of different mass and, by applying different amounts of force on each of these objects, learn for themselves the connection between mass and force, and "then being able to [demonstrate] if I apply a big force I am pushing hard or pulling hard and it moves farther, . . . [the] idea of distance."

Kevin shared some interesting examples of his students' naive ideas about force and motion. One involved students' thinking about the concept, force influenced by the *Star Wars* movies. He noticed that some of his students "make some unnecessary and wrong connections between force and the various ideas from *Star Wars* movies" and indicated that the concept of "the force" as a mystical power—which is what these movies present—"is somewhat close to the idea of energy," although not, of course, anything to do with actual force. He stated that he believed those students who have developed this view of force from these movies are, however, severely hindered in their learning about this topic in his science classroom. Kevin asserts that he "has a hard time teaching about force" when his students come to class with this alternative idea

of force already established. Another interesting alternative idea Kevin encountered from a student, which he thinks is also sourced from some TV shows or games, was the comparison of force with plasma, with the student saying that force is a state of matter.

Kevin stated that he believes in addressing, not ignoring, naïve ideas or theories students bring into class. He says, the students will keep thinking about these ideas, and suggested that it is better to stay with them in their process of learning. This means either helping them discover reality if possible or letting them research and find that these ideas have not been proven yet. He also encourages them to think of innovative ideas that they may themselves test in the future as part of their post-secondary school study of physics. For Kevin, these instances also provide learning opportunities to teach them about the nature of science:

> [Nature of science] is an important part of science. . . .We have theories, and sometimes theories are in the process of being tested, and we do not necessarily have…definitive universal concepts . . . . , and that is the way it is. [Moreover, here] is always a need . . . to test theories . . . [in class].

He used the example mentioned above when one of his students brought into class the idea that force is a state of matter called plasma, and said that his response was, "Let's talk about that, and let's test it [if possible]." In that example, he said that he used computer searches as a tool to let students explore and get an answer. He also provided an encouraging comment to this student: "Maybe when you become a physicist you can prove that."

Kevin said that the best way to help students understand that the force is a push or pull was by using the "inquiry process, doing labs . . . [using] questions . . . [and finding] answers to the problem." Kevin compared his discovery teaching technique with a traditional knowledge transmission technique, saying,

> That idea of letting [students] . . . play . . . and let [them] discover it [is better] . . . than just put[ting] on the board a definition [of] what force is, and giv[ing] them a written example of how a force can be applied to a dinky car.

He repeated that we should let them play, "give them [small] cars, and let them discover. Kevin elaborated his strategy of discovery for teaching about force, stating that

> "you could set up . . . some experiment . . .to push this car. . . [or] push this block of wood. . .[and ask]. . .guided questions. . . . [for example]":
>
> "What happens when you push it?"
>
> "What happens when you pull it?"
>
> "What happens when you push it harder?"
>
> "What happens when you pull it harder?"

Kevin said that using this strategy, "If you let them play they will figure out . . . [that] if I push that [car, for example] gently it does not go very far . . . [and that the] car goes farther than the block, and so on."

Kevin told me that he uses lab-sheets sometimes when teaching with this "discovery approach", which provides the problem and some guiding questions to channel thinking. Some lab sheets also have blanks that the students are to fill in after identifying the variables. Sometimes he asks them to "manipulate a variable in response to a control variable."

Throughout our conversations, Kevin referred to the value of using various manipulatives and the ways he has used these when teaching about force and motion. These manipulatives include miniature cars, wooden blocks, and his own bike. Kevin also mentioned that he has used a few video clips for teaching these topics. When asked further how he uses these resources, Kevin said,

> Having [grade seven students] pushing and pulling things . . . [and during] mechanical systems for grade eight [students] . . . I would ride my bike to school, so somebody . . . can hold the bike and they can apply that force to pedal it . . . And [then] we can talk about the changing of motion . . . and the force [involved].

Kevin finds textbooks great resources for students as well teachers, saying that he uses the textbook, *Science Focus* and the teacher resource binder that comes with it, which he thinks has many useful ideas to help him facilitate differentiated learning. About textbooks, he said,

> I will make sure that I would . . . definitely . . . eventually come back to the textbook because there will be . . . that graphical representation . . . [or] it is supposedly written at [students'] level so that they can do some reading [after] . . . they have listened to [what] they have participated in [or what] they have done.

Kevin noted that he used "visual learning a lot." He said that he tried to find interesting video clips about the difficult concepts to show his students, for example, zero gravity or defying gravity [devices or machines to work against gravity]. This is a technique he "would definitely be using" when teaching about force and motion. When asked about specific video clips, he talked about the *Bill Nye the Science Guy* video series. He also talked about using these videos while teaching other topics, as he uses them frequently in his teaching.

Kevin described using technology in the classroom as "cool." He stated that these days, "you could just even go to the Active Board, and with the marker make a nice thick line and just move the pen across the board and say, 'So tell me, what forces are applied here?'" Kevin said that in doing this, students "may pick up . . . that you would apply that force both when holding a pen to the paper and [writing on the paper]." Kevin mentioned that he believes the same thing can be done using paper and pen, but that using new technologies can engage more students.

When asked about using the Alberta Science Program of Studies, the curriculum guidelines, in reference to the help it gives him to teach force and motion, Kevin said that they help him organize his curriculum and "prioritize the topics and concepts. . . .It, even, allows me to determine how long to spend on [each topic] . . . and how important a concept is based on the other information that I have to get across in that unit."

Prioritizing topics, as a science teacher "is a very subjective thing" for Kevin. Therefore, he does it collaboratively with colleagues, explaining the collaborative process in these terms: "As a science department . . . three of us . . . sit down [together] . . . go through the curriculum and look at how important a concept is." The team uses a three-point rating scale, where each member rates every concept. If a concept is "*one* . . . you have to spend a little more time on it; [if] it is *two* . . . make [students] familiar with it, [and if] it is *three*, just kind of touch on it, and it is not a big concept." Obviously then, based on mutual consensus, they set priorities for all the topics.

Kevin identified the three major areas of focus provided by the Alberta Science Program of Studies—Knowledge, Skills, and Attitudes— as helpful, and said that he is usually "able to hit those areas for the important concepts." To illustrate (with force), he stated that he teaches his students "so they understand a force [knowledge] and understand how forces are measured [skill] . . . and a general attitude of discovery in science [attitudes]."

When further asked about the emphasis of the Alberta Science Program of Studies, with its Science-Technology-Society (STS) approach, Kevin noted, "In my classroom I try as much as I can to use technology." When I reminded Kevin that he had used his bicycle in his science classroom to teach various topics, he said, "To me it is just . . . natural . . . that makes sense to me. . . . And, it is not something that I will look for other people to do necessarily. . . . Maybe I

have a broader sense of technology, and it does not have to be an electronic device. . . . A bike is a technology." Kevin expressed his concern that "people may have a limited understanding of the technology and think of it as information technology [only]."

He further explained that he uses the *Science Focus* teacher guide that "definitely has those ICT [information and communication technology] outcomes, and how to get the technology in the [classroom]" He described one example, which he believes is off topic, but is still a good critique on technology integration expectations:

> [The Science Program of Studies] recommends . . . for example in . . . the water [unit] . . . the idea of using an Excel spreadsheet and making or generating a circle graph from a set of water use data . . . we just finished [this activity] . . . which is right in the Teacher Resource binder, which would definitely come from fulfilling ICT curricular expectations.

According to Kevin, this is not a good approach to integrate technology in science education.

When asked why it is important for junior high students to understand the concept of force, Kevin said,

> I think this is an important concept. . . . There is a reason to teach force to junior high school students . . . a very practical reason [I guess]. At the junior high school level, they start learning how to drive. . . . In a vehicle, you are dealing with a huge velocity. . . . Therefore, if it hits something, there is a massive force applied. . . . So, maybe it is an important concept to understand safety. . . . [Moreover], before they drive, they bike, and they play hockey; understanding what those forces are is important too. And . . . if they understand the idea of force, [it] is push or pull that helps them to understand . . . for example Newton's Laws. . . .Definitely [understanding force is] something that is

important, before they go to high school, and [are] taking physics . . . that they have that basic understanding of what the physical laws are, and what the laws of motion [are].

When asked how he would teach about force if the learning context were different, Kevin quickly responded that he "can teach force in the middle of [a] basketball [game]." It is interesting to note that Kevin is a basketball coach at his school.

4.2.2 Topic-Story 2: Teaching frictional force

When asked for about a memorable incident or event that stands out about his experience of teaching frictional force, Kevin said, "I find friction easy to teach. . . . Maybe it is because you have laid the ground work with force." He continued, suggesting, "the kids get it [friction]. . . . It is so hands-on, the idea of heat given off by friction is very easy to explore by rubbing hands together, and they can get that instant gratification . . . .[thus] I do find it fairly straightforward for them to grasp the idea of friction."

When queried further about any conditions that facilitated or provided obstacles to teaching friction, Kevin revealed thoughtful ways to facilitate his students' learning of frictional forces.

R: As you said, demonstration of rubbing hands helped . . . It facilitated their learning . . .

K: For sure, absolutely, always

R: Anything that did not work?

K: I guess you have to be careful about…the idea of measuring different frictional forces. And then making sure that surfaces that are used have a big enough difference, to have the students either measure with the spring scale or something like that…[so that] there is a difference in the amount of force that it requires to pull an object.

R: Do you mean using manipulatives, which can provide an observable difference?

K: Yes, absolutely…the idea of…the skateboard and drip tape, and then . . . the kids get it because the difference is evident.

Kevin noted that the friction should be understood "from an efficiency standpoint as well as practical," since "friction has an impact on efficiency." The goal of Kevin's teaching about friction, "especially for grade eight science" is that his students should be able to understand that by "decreasing friction they can increase the efficiency of the machines." Also, he wants his students to "explore why reducing friction increases efficiency . . . [and] why certain surfaces will be chosen for certain applications, [for example] surfaces of bridges . . . why they are grooved concrete in some cases." He expects his students to be able to understand that these bridge surfaces "are to increase friction, so there is better traction for drivers."

Kevin acknowledged that his students often have some prior understanding of friction before he teaches this idea. He stated, "[Friction] is a common thing to experience in life." This is especially true in a rural context he thought, which is where many of his students live and where friction can be part of the family talk at the dinner table: "They will be definitely talking about engines and that kind of stuff."

When asked about any prior understanding that his students may have that *interferes* with their learning about this topic, Kevin said, "Some students have trouble understanding what friction does for efficiency." He attributes this learning difficulty to his students' common belief that "machines are 100 % efficient." He thinks this is probably why they "may have trouble with the idea that friction is loss of energy or transfer of energy into a different form."

Kevin deals with this misconception about machines as 100% efficient by using "more examples . . . [and] asking where efficiency has gone down due to frictional forces." Kevin also shared an activity that he said he "always" uses to help his students overcome alternative ideas

about friction. In this activity, he uses various surfaces—for example, smooth, sandpaper, rough, grip tape—and lets his students pull a wooden block across these surfaces and asks them questions about this: "[What happens] when the wooden block crosses the grip tape? And when the block crosses the sandpaper?" Through this activity, he wants his students to understand how efficiency decreases, and that they need to increase the force in order to do the same amount of work.

When I asked him to describe his typical lesson on friction, Kevin said he usually starts by asking his students what they think friction is, and asking them to identify a few examples. He uses this to access students' prior knowledge or any alternative ideas about friction. Then, he "uses common objects" and usually does a "demonstration of rubbing hands and/or moving their binders on their desks." He usually follows this with a lab in which a wooden block is moved across different surfaces (described above) to let students explore the connection between friction and efficiency.

Kevin also talked about seeing a manipulative at another school that he thought was "amazing." He described that it looked "like a bicycle, but just pedals and a crank part, [and] there were three of them . . . One [of them] was . . . lubricated [and] well-maintained, the other one [had] fine ball bearings in there but was not lubricated, and [the third] was without ball bearings." Kevin said that he believes this is a very good resource as students can "turn the cranks and . . . feel the temperatures of it" to understand the "idea that the lubricated one is the coolest and . . . [and] is the most efficient . . . [because] there is less friction." Kevin believed these manipulatives were specially manufactured for teaching grade eight science to explore relationships between friction and efficiency.

I asked Kevin to think of what he would do and how he would teach his students about friction in a situation where he did not have his favourite manipulatives—a wooden block and multiple surfaces. He responded that he " can use anything" or can ask kids to volunteer and bring objects they find, and then do "more of an inquiry . . ., and set up for them where they have to pull different objects that they are choosing and then see what the difference is in the frictional forces."

Kevin also used a website to help his students understand frictional forces. He said that explorelearning.com, has "gizmos that you can use to present real-world situations. . . . There is one in there . . . [with] . . . an inclined plane . . . [where you can] change the surface of the inclined plane, and measure friction." This lets the student move an object across the inclined planes, which have various surfaces.

We talked about the role of the Alberta curriculum guide in his teaching of friction. He noted that, while he knows it is there, he was doubtful about the intention with this, wondering if he was wrong to think it might be there "in order to get an understating of efficiency." Kevin clarified that he had explored the Alberta Science Program of Studies, but "not for [the topic, friction], particularly." He further explained that he has used textbooks to teach this topic, and commented that he "thinks [textbooks] help too.

Kevin also expressed that as a science teacher he understands the importance of understanding the concept, friction for junior high kids. He explained that this understanding "has a huge impact on their understanding of efficiency . . . and the [idea of] transfer of heat . . . , [especially] for grade eight students."

When asked how he will teach about friction in different learning contexts, Kevin stated that he would probably teach it the same way in any context, whether rural or urban. When I referred to an earlier comment he made, he changed his answer:

R: You did talk about [students] with the rural backgrounds and their prior knowledge of engines, etc. Does that change your teaching someway?

K: Yeah…I would….I guess. In an urban school as compared to a rural school…there would be a difference [in my teaching]. . . . [In a rural school] some kids may have the concepts with the idea of efficiency and simple machines.

Kevin thus affirmed that his students' diverse backgrounds have an impact on his teaching of friction. He added that "how much time or effort was spent on [a topic] in elementary school, would have an impact on that." He said he always asks his students when they enter junior high school if they know what this word [friction] means. Did they learn it in their past science classes? Alternatively, did they learn it in their past math classes? By asking these questions, Kevin said that he wants to understand the impact of being taught by different teachers.

> [Because] different teachers put emphasis on different [topics]. . . .There are always kids [who say] yes we know what that [concept] is . . . and then there are kids, who either did not do it, or it was not focused on . . . so they do not remember [the concept].

Kevin confirms that these situations do indeed make a difference to his teaching strategies.

When assessing his students' understanding of the idea of friction following his lessons, Kevin said that he wants to make sure his students can "come up with a conclusion from a friction lab." This conclusion should illustrate that "they understand how friction affects the efficiency . . . , and if friction increases efficiency decreases." Kevin also wants to ensure that his

students "can relate friction to the amount of effort [force required] to move an object . . . and [transfer of] heat." To test his students' understanding, Kevin said that, other than using lab reports, sometimes he uses "just the multiple choice questions," which he noted can also help him assess his students' understanding of friction.

Kevin mentioned using real-life examples to facilitate his students' understanding of friction, and he identified examples of relating friction to farm machinery, riding a bicycle, and different types of tires. Kevin explained that he asked his students questions while using those real world examples: About machines, he asked about, "How machines change or . . . reduce friction?" About tires, he asked, "Why race cars use one type of tires and racing bikes one type of tires, and mountain bikes use different types of the tire?"

I spoke to Kevin at some length about my concern about how sometimes real world examples or experiences are used—which may result in confusion or just fun—and may fail to accomplish the intended content learning outcome. Kevin agreed that sometimes a science activity fails to serve the purpose of learning. He shared a memory from his own grade six classroom experience when he was a child, which he called "extreme teaching":

> I had a grade six teacher who took us up to a pond, which is awesome. . . . And what we had to do [was] . . . to play . . . [and] when we pushed off on the ground, which was . . . a shoveled sidewalk or whatever . . . there was friction there . . . and then we had to go to the pond…it was ice. . . and friction was reduced. I remember it becoming a free-for-all of us pushing each other down on the pond [Laughing].

When talking about using technology for teaching about friction, Kevin again brought out an example from *Bill Nye the Science Guy* video series that he has used. He said he did not

remember the whole video, but "it is a video where he spills . . . marbles and walks on . . . the marbles . . ." to show that friction will be reduced, which makes it difficult to walk.

Kevin confirmed that he models his teaching about friction after some of his own teachers. He stated, "I do teach . . . very similarly . . . the way I was taught." However, he refuses to use the strategy that his own grade six science teacher used, that of taking students to a pond during a snowy winter, because "there is no such place around [his school] and there are serious safety concerns also." He did indicate that he uses a similar technique indoors, where he asks his students to volunteer and then "to slide across the floor . . . [with] shoes on and [then] shoes off."

4.2.3 Topic-Story 3: Teaching gravity

Field reaction forces are the type of forces that are applied within a field without any direct contact and are also called, "non-contact forces," though less commonly. Various field reaction forces like gravitational force and magnetic forces are part of the science curriculum and are taught by junior high and senior high science teachers. Despite teaching about gravity on a regular basis, many science teachers do not know that gravity is a field reaction force. Kevin was also among those science teachers who are unaware of this terminology, although he has discussed it in his classroom a few times. However, he said that gravity "is typically one topic that we just kind of breeze over. I cannot think of doing a lab or anything like that for gravity."

Despite this, he willingly participated in a conversation about teaching gravity, because he believes gravity is an "interesting topic." When I asked him to describe incidents of teaching or discussing gravity, after a brief silence, he pointed out:

> I think the idea of gravity is harder for [junior high school students] . . . [It] is a leap of faith for a lot of them . . . It is almost like a little bit of a hurdle to having [students] believe that . . . we just have to understand that there is gravity. The interaction of the centre of

> mass between two objects creates this magic kind of idea, and that is hard for some [students] to understand. They just do not believe, . . . and a lot of them . . . are so critical of what they are told in the classroom, . . . [though] some of them do [believe].

This led me to inquire about his students' faith in their teachers' knowledge, and whether they trust that the information their teacher gives them is true most of the time. Kevin stated that this was the case, but he clarified that teaching the concept of gravity it is not about merely telling them gravity exists. He does some "explorations . . . [such as] dropping things and watching video clips. He further explained, "Still [gravity] is that idea that you just have to believe is there."

Kevin said, "[gravity] is a force," and to understand it students should be able to grasp "how it is generated, [and] why we have a gravitational force." He also added a few additional thoughts about what he wants his students to understand about gravity, saying that "the interaction of planets . . . , and understanding the centre of mass [is also important], I think."

Kevin said that he finds the idea of gravitational force "tricky for [students] to understand" and according to him, the probable reason is that "it is not visible . . . although [they] . . . are constantly under the force of gravity, and . . . [are] affected by it." He asserted that despite having daily experiences with gravity, students "still struggle with the idea that there are forces" like gravity. They may sometimes carry this to the extent that they think gravity "is imaginative or magical . . . kind of thing."

Talking further about the instructional strategies that he has found effective to teach about gravity, Kevin stated, "It is just basically a classroom discussion" along with using some "video clips on zero gravity . . . or less gravity." He also noted that he will sometimes use an online simulation, "an airplane simulator where [students] can momentarily defy gravity."

4.2.4 Topic-Story 4: Teaching acceleration

Kevin was unable to recall an incident or event from his teaching of acceleration, as he said that this is not "a huge concept" at the junior high school level. After much thought, he eventually said, "I think acceleration is a fairly new concept for kids" which he thought they had not yet been exposed to. He also noted that he does not deliberately teach this concept to grade eight students. He talked about the topic only when a question arose, or a discussion requires that this concept be clarified. Kevin said that he believes that motion is an aspect of force, and, therefore, any discussion about motion is incomplete without at least touching on acceleration. Our conversation led to the connection between acceleration and Newton's second law of motion, where Kevin pointed out that students should understand acceleration qualitatively as well as quantitatively.

I inquired about underlying concepts or ideas Kevin thinks students need to understand to grasp acceleration. After careful consideration, he said, "I think that . . . forces come into play hugely there . . . as well as mass. So, if they understand these little pieces [they can understand acceleration]." He elaborated, adding that students can understand acceleration "through examples and doing lots of practice, as far as calculating and that kind of thing."

I expressed the concern that sometimes students can do calculations and find the right answers but do not have a conceptual understanding of what acceleration is or how we can accelerate things. To ensure that students' understanding, beyond just how to do acceleration calculations, Kevin said that he wants his students to "get the idea of objects speeding up and slowing down, . . . acceleration and deceleration. He also thought that if his students "are able to make predictions about the role of friction in acceleration, they have a good understanding of acceleration."

Kevin was initially unable to share alternative ideas about acceleration that his students brought to class. However, when I mentioned my experience of some students not being able to distinguish between a constant velocity and constant acceleration, Kevin quickly responded that showing graphs can help to deal with this problem. He added, "If they see graphs of [two types of motion] . . . [and] they see a straight line versus a curved line . . . they get that." Then, he talked about another strategy to help students distinguish between two types of motion using three examples: "a car is driven with cruise control on highway; the accelerated car [going] off the highway; the car [stopped] at the traffic lights." Kevin notes that these examples are effective because even if they have no driving experience, "they have all driven in cars and have the experience of driving with their parents with cruise control on the highway."

Kevin also uses graphs and the above examples to teach about acceleration, saying, "Acceleration seems like a tricky concept, but maybe at this level it is fairly straightforward." He added that he uses different graphs because this "is one way to show the difference between speed, velocity, and acceleration." He also uses more car examples in classroom discussion, where he asks his students the difference between driving in the city as compared to on the highway using cruise control and speed limit. Then, he asks further about a car going at a constant speed as compared to when a car accelerates from a stop light. When I asked him to describe *how* he uses graphs in his class. Kevin said that he has "graphs in notes" (as hard copy) and that he did "not have graphs up on the board."

He also has Geo Algebra software, which is compatible with Active Board, a program he described as useful for constructing "quick and easy online graphs." He stated that he has plans to develop and use graphs on an active board in the future. This led into a conversation on other online graph simulators he has used for teaching about acceleration, which reminded Kevin of a

gizmo he found at the www.explorelearning.com, although he did not remember how he used it. He added that "bicycling . . . would be another way that [students] would understand accelerating and decelerate."

I wondered what he did with students who had no experience with cars at all, and when I asked about this, we began discussing other types of acceleration experiences. He said, "Oh yes, there might be students who have never driven . . . but I think everybody. . . I would say that everybody in my classroom has been in a car, maybe not driven, but have felt the different acceleration. He added, "You could even talk about an airplane . . . taking off . . . [and] accelerating versus cruising speed." He pointed out that "less [students] would have that experience [though]." Kevin explained his rationale for using these examples, saying "I think everybody could take that lead, from not actually pushing the gas pedal and feeling the acceleration but actually [experience] the acceleration [as a passenger]." When I queried further, Kevin said,

> Any automotive transportation you can look at, you can even show videos of . . . predatory animals like cheetahs, or horse races or something where an animal accelerates. And then [you have] more of a continuous speed so going from a small speed to that of a burst and that of acceleration and chasing. . . .That would be really rare, but you can do that."

I wanted to know how Kevin ensure that his students had understood the concept, acceleration. In response to my questions, and he called his strategy "pretty simple," stating that he uses a quiz and later checks their understanding through a unit test. When asked to share an incident or event he remembers from his experience of being a high school science student, particularly related to acceleration, Kevin said,

> I do remember in junior high school in a science class talking about . . . I do not remember what it was . . . if it was velocity or acceleration, or something [else] . . . I remember my teacher having a Hot Wheels track . . . and have it starting up high and track coming down . . . and showing that the car is speeding up. But, I do not know how [the car was speeding up]. . . . Maybe we just took his words that the car started slower, and got faster, and as it went out at the flat, it slowed down, . . . because I know we did not film it, or have a radar gun showing the speed change or anything like that."

In response to the question, "Does he ever use the "Hot Wheels" tracks in his science class? He said no, but explained that he "just never thought of it . . . [and] almost forgot." He seemed pleased to now consider this idea and remarked, "I am going to [use them]."

4.3 Kevin's Orientations to Science Teaching

As noted in Chapter two, orientation is a general way to view science teaching, which guides a teachers decisions to teach a science content in a particular way. Some of the orientations to teaching science as identified in literature are: (a) importance of discovery, (b) process of science, inquiry, (c) science as a body of knowledge, and (d) conceptual change.

The conversations I had with Kevin about his experiences as a high school science teacher and as a learner of science in high school, reveal that Kevin has developed a similar orientation to teaching science that he recalled that his own teachers held. As I analyzed my conversations with Kevin, especially those about the effective instructional strategies he uses for teaching force and motion ideas, I gathered insight into his orientation to teaching these science topics. Kevin appears to emphasize discovery learning and conceptual change as his orientations to teaching science.

4.3.1 Discovery teaching

Kevin said, “I always do less teaching and more discovery.” He explains that he helps his students “find answers for themselves.” When asked to provide an idea of the type of discovery he facilitates, he said, “I would have something setup . . . [alternatively], I would do something . . . or have a student come up and push my shoulder or something like that, and ask the kids, what just happened there?” Kevin claimed that this type of beginning will take his students “down the road of discovery” and that students will share their ideas to answer the focus questions. In his experience, “eventually somebody would come up with. . . [the idea that] . . . ‘he pushed you and made you move.” Kevin affirmed that after the students understand the underlying idea, then he gives a name to the idea, and in this particular case he introduces the concept of force. Then he makes sure they develop the science terminology to describe the phenomenon and what a force does. He expects his students to be able to tell whether that force is a push or pull.

4.3.2 Conceptual change

Kevin appears to consider students’ naive ideas and theories seriously. He stated that if ignored students keep thinking about these ideas, so he addresses them in order to help with the learning process of his students. He described his strategy to support conceptual change in his students is by modifying those alternative ideas if possible, or to use their naïve ideas and theories as learning opportunities to discuss the important aspect of the nature of science that scientific theories are in a process of continuous development. He also uses opportunities like this to encourage students’ interest in science and inspire them to consider perhaps becoming a scientist in the future to test and hence prove their theories.

4.3.3 Kevin's own learning experiences: Influences on his orientations

Kevin indicated that he models his past teachers, saying, "I do teach . . . very similarly to the way I was taught." However, he refused to use one particular strategy that his grade 6 science teacher used—taking students to a pond during the freezing winter to explore the concept of friction. He explained the reason, noting that "there is no such place around [the school], and there are serious safety concerns also." He said that he uses a similar technique, but indoors where he asks his students to volunteer and then to "come . . . and try to slide across the floor in your shoes, and [then] take your shoes off and try to slide across the floor."

When asked to share an incident or event he remembers from his experience of being a high school science student, particularly related to acceleration, Kevin said,

> I do remember in junior high school in a science class talking about... I do not remember what it was ... if it was velocity or acceleration, or something [else] ... I remember my teacher having a Hot Wheels track... and have is setting up high and car coming down… and showing that the car is speeding up. But, I do not know how [the car was speeding up].... Maybe we just took his words that the car started slower, and got faster, and as it went out at the flat, it slowed down… so, it is accelerated and then it is decelerated… because I know we did not film it, or have a radar gun showing the speed change or anything like that.

When asked if he ever used any *Hot Wheels* in his own science class, he said that he did not. Explaining the reason, he said, "I just never thought of it . . . I almost forgot," but he seemed happy to be reminded of them as he said, while laughing, "I am going to [use them]."

4.4 Profile of Kevin's PCK Related to Force and Motion

Kevin shared moments, incidences, thoughts, and his accumulated experience of teaching related to the specific secondary school science curriculum of force and motion, which are organized above as his topic-stories. He has developed a conceptual understanding of the content (force and motion ideas), and a unique understanding of how to teach this content to junior high school students. I have interpreted Kevin's accounts, and below divide them into ten segments that reveal various aspects of Kevin's PCK related to force and motion topics. These segments are developed by using inter-story triangulation process discussed in Chapter Three, therefore are somewhat repetitive.

4.4.1 Kevin's views and understanding of force and motion concepts

Kevin has developed a unique understanding of force and motion concepts, especially as it relates to teaching grade eight science and helping his students to achieve a good comprehension of the concepts. The following subsections describe aspects of Kevin's understanding of this material.

4.4.1.1 Understanding force

During our conversation on teaching about force, to get a glimpse of Kevin's conceptual understanding of the topic, I asked him to define force and explain the underlying ideas or concepts he wants his students to understand. In response, Kevin said, "force is a push or pull." He further stated that being able to define force is not enough to understand it. To achieve a conceptual understanding of this topic, Kevin states that he believes that his students first should be able to demonstrate that force is a push or a pull. He said that this understanding is achieved when his students can "push an object and say, 'I just applied a force on the pen and made it move'."

Kevin also contended that measuring force using appropriate devices and standard units is an important aspect of understanding force. He said he planned his lesson in a way that his "[students] could get. . . some understanding of measuring a force . . . [which includes] not necessarily going to a formula and doing the calculation, but even if they could see if I apply a big force to a small object I can send it flying."

In addition, Kevin noted that his students should be able to understand the relationship between mass and force. He described the strategy he has used to achieve this understanding, which reveals his own understanding of the relationship between mass and force, affecting motion. He stated that he let students do an experiment with objects of different mass—by applying different amounts of force on each of these objects. Using this experiment he said that they can learn for themselves the connection between mass and force, they can say, "If I apply a big force I am pushing hard or pulling hard, and it moves further," and by doing so, "they get the idea of distance,"

The specific learning outcomes Kevin seeks to achieve in a typical lesson on teaching force also reveal his understanding about the concept, force. He stated his goals of teaching force: (i) students can demonstrate what a force is, (ii) they can measure a force, and (iii) they can identify a relationship between mass and force.

4.4.1.2 Frictional force

Kevin picked the topic of friction from the list of topics that I presented to him, and provided details of how he teaches about friction. He described the frictional force as a type of force caused by two surfaces rubbing against each other, which also has an effect on motion. Kevin also discussed the idea of friction as reducing the efficiency of machines due to friction between various parts of the machines, which involves the transformation of energy. To get an

insight into Kevin's views of the important conceptual understanding of this topic, I asked what underlying concepts about friction he wants his students to understand. Kevin responded that friction should be understood "from an efficiency standpoint as well as practical" use.

Kevin says he "think[s] that friction has an impact on efficiency." His content objective when teaching about friction, "especially in grade eight science," is that he wants his students to understand that by decreasing friction they can increase the efficiency of the machine." Also, he wants his students to "explore why reducing friction increases efficiency . . . [and] why certain surfaces will be chosen for certain applications, [for example] surfaces of bridges . . . why they are grooved concrete in some cases." He expects his students be able to understand that these bridge surfaces "are to increase friction, so there is better traction for drivers."

4.4.1.3 Gravity

Field reaction forces are the forces that are applied within a field without any direct contact. They are also called "no-contact forces." This terminology is less common, but various field reaction forces—like the gravitational force and magnetic forces—are part of the science curriculum and are taught by junior high and senior high science teachers. Despite teaching about gravity on a regular basis, many science teachers do not know that this is a field reaction force. Kevin is among those science teachers who are not aware of this terminology, even though he is well aware of gravity. He finds it an "interesting topic" and has discussed it in his classroom a few times, but not as a full topic. This is because, he said, it "is typically one topic that we just kind of breeze over. I cannot think of doing a lab or anything like that for gravity." Despite this, when presented with the opportunity, Kevin talked about gravity in detail.

Kevin described the underlying concepts and ideas that he wanted his students to understand. According to him, "students should know that [gravity] is a force" and . . . how [it] is

generated, and why we have gravitational force." Kevin said that it is also important for students to understand "the interaction of planets, and the centre of mass" as related to gravity.

4.4.1.4 Acceleration

Kevin indicated that he thought acceleration is not "a huge concept" at the junior high school level. It seemed from our conversations that he talked about the topic only when a question arose, or a discussion required this for a clarification of another concept. Kevin tried to define acceleration and said, "I think that . . . forces come into play hugely there . . . as well as mass. So, if they understand these little pieces [they can understand acceleration]." He affirmed that motion is an aspect of force, and that any discussion about motion is incomplete without touching on acceleration. He also thinks that understanding acceleration is a prerequisite for understanding Newton's second law of motion. Therefore, Kevin wants his students to understand acceleration. He went on to say that this can be achieved "through examples and doing lots of practice, as far as calculation [is involved]."

4.4.2 Kevin's understanding of students' alternative ideas

Effective teachers usually have the common characteristic of knowing their students, which at a minimum involves understanding their students at a personal level and being able to connect with them. For science teachers understanding their students' learning difficulties and specific learning needs, and hence being able to help them understand specific science topics is an important aspect of their knowledge. The following sections describe Kevin's understanding of his students' learning difficulties as well as their alternative ideas about the topics related to force and motion. The segment closes with a description of the strategies he uses to address learning difficulties and to help students modify their ideas to ensure a renewed conceptual understand of these topics.

4.4.2.1 Everyday meanings of the word "force"

Kevin noted that his students' alternative ideas about force and motion are rooted in the everyday use of the word force, which is often derived from their indulgence in various TV shows and movies—specifically the *Star Wars* movies. Kevin shared with me that he has a hard time teaching about force because his students make unnecessary and wrong connections between force as a science concept and the ideas of force in the *Star Wars* films, where it is a mystical power. The movies' presentation of force has created a great hindrance to his students' scientific learning about force. He noted that although the movies' version of force has nothing to do with actual force, it is somewhat close to the idea of energy.

Kevin also had a student comparing force with plasma, saying that force is a state of matter. Kevin thinks this alternative idea is also sourced from some TV shows or video games.

4.4.2.2 Machines are 100% efficient

Kevin notes that his students have some prior understanding of friction, which they bring to his science classroom, because "it is a common thing to experience in life," especially in a rural context where friction is part of family talk at the dinner table. One such prior understanding that Kevin noted, which interferes with his students' learning, is a common belief that "machines are 100 % efficient." He proposed that this is probably why they "have trouble with the idea that friction is loss of energy, or transfer of energy into a different form."

4.4.2.3 Lack of trust in gravity

Kevin said that he also has students who lack "trust" in the idea of gravity. According to him, many of his students think gravity "is imaginative or magical . . . [although they] are constantly under the force of gravity, and . . . affected by it." He further described, "They still struggle with the idea that there are forces [like gravity]" or gravity is a force.

4.4.2.4 Role of friction in acceleration

Kevin wants his students to "get the idea of objects speeding up and slowing down . . . [which is] acceleration and deceleration." He said that sometimes his students need help to be able to make predictions about the role of friction in acceleration, which he expressed is a requirement to have a good understanding of acceleration.

4.4.3 Kevin's repertoire of instructional strategies

One aspect of a science teacher's PCK is knowledge of pedagogy itself, which means knowing and using general and content-specific instructional strategies that help students develop conceptual understanding of science topics. In sections below, I review *general* instructional strategies that Kevin states he finds effective in teaching force and motion topics. The section that follows then takes up Kevin's teaching strategies *specific* to force and motion.

General Instructional Strategies: A review and analysis of the teaching strategies that Kevin shared during our conversations reveal his understanding of the general instructional strategies that he follows during his teaching of the topics related to force and motion. Kevin might have uses these strategies when teaching other science topics as well.

4.4.3.1 Inquiry process

Kevin said that the best teaching strategy to help students' learning is using the inquiry process. He described how he uses this process by using pre-designed labs, a quick lab, or everyday examples for students. Kevin explained that he asks guiding questions during the inquiry process to lead his students' learning so that they can find answers for themselves. Kevin also said he uses lab sheets, when using this method. When asked to describe these lab sheets, he explained that his lab sheets present a problem and some guiding questions to channel students' thinking. Some lab sheets also have blanks, which his students have to fill in, after

identifying the variables. He said that sometimes he asks his students to "manipulate a variable in response to a control variable." Kevin said that the best teaching strategy to help students' learning is using the inquiry process**,** which he also described as a "discovery" process.

4.4.3.2 Using questions and classroom discussion during the inquiry process

Kevin said, "You could set up . . . some experiment . . . [and ask them to] push this car. . . [or] push this block of wood. . . [and ask guided] . . . questions." Some possible questions that he suggested are:

- "What happens when you push it?"
- "What happens when you pull it?"
- "What happens when you push it harder?"
- "What happens when you pull it harder?"

Kevin uses thoughtful questions to engage his students in the inquiry process. I also had an opportunity to sit in on one of his classes, though not on force and motion, and it is evident that he establishes a classroom environment where ideas are discussed, modified, and reframed.

4.4.3.3 Accessing students' prior knowledge

Kevin said that he uses questions and asks for examples from students at the beginning of his science classes. He uses this strategy to gain access to his students' prior knowledge and alternative ideas. He brought up his class on friction as an instance when he typically does this.

The following sections present the topic-specific instructional strategies described by Kevin.

***Instructional Strategies Specific to Force and Motion*:** Kevin shared, both explicitly and implicitly, a number of instructional strategies he has developed and mastered over the time that he finds useful for specifically teaching force and motion ideas. These *specific* strategies, many of which are discussed below, also reveal Kevin's understanding of many effective *general* instructional strategies that were covered above.

4.4.3.4 Using inquiry labs

To help his students understand that force is a push or pull, Kevin uses an inquiry process with his specially designed lab sheets. Sometimes, in the moment, he is able to turn an example or a question into an inquiry process. In Kevin's words:

> I give them [mini] cars and let them discover. . . . If you let them play, they will figure out . . . [that] if I push that [car] gently it does not go very far . . . [the] car goes farther than the [wooden] block and so on.

A typical lab he employs involves moving a wooden block across various surfaces (described above) to let students explore the connection between friction and efficiency.

Kevin also uses this lab to allow his students to measure the forces. Based on his experience, Kevin suggested:

> It is important to be careful . . . and to make sure that surfaces that are used have a big enough difference . . . [so that] there is [observable] difference in the amount of force that it requires to pull an object . . . [when] the students either measure [a force] with the spring scale, or something like that.

Kevin recommended using a skateboard and a drip tape since the "difference is evident."

4.4.3.5 Using demonstrations

Kevin described some simple demonstrations that he had used in his science classroom to teach about force and motion.

"Push my shoulder". To demonstrate that force is a push or pull, Kevin sometimes asks his students to come and push his shoulder, and then pull his shoulder. Then he engages his students in a discussion by asking thoughtful questions, leading them to an understanding that (i) by pushing or pulling they apply a force on his shoulder, and (ii) and his shoulder moves.

Kevin explained that he has used the same demonstration, using student volunteers, where one student will push the shoulder of the other student, and they will discuss force applied by one student on the other student. Similarly, he has also repeated the same idea using mini cars, or wooden block.

***Rubbing hands*.** Kevin stated that he used a demonstration of rubbing hands to teach about friction. He explained that he uses this demonstration because he thinks "it is so hands-on, [and] the idea of heat given off by friction is very easy to explore [by] rubbing [one's] hands together."

4.4.3.6 Using manipulatives

As mentioned above, Kevin uses manipulatives like mini cars and wooden blocks. He said that he also uses these manipulatives to teach about friction, and if he does not have access to these particular manipulatives, he "can use anything" or can ask kids to volunteer and bring objects they can find. Then, he said he uses "more of an [open] inquiry . . . where they have to pull different objects that they choose and then see what the difference is in the frictional forces."

4.4.3.7 Using video clips and classroom discussion

Kevin said that he uses video clips often in his classroom, and he frequently combines them with classroom discussion to engage his students. For instance, to teach about gravity, and

win his students trust in the idea of gravity, he described how he has used "classroom discussion" while using some "video clips on zero gravity . . . or less gravity."

During our conversations, Kevin also identified many videos from *Bill Nye the Science Guy* video series that he uses for teaching the topics related to force and motion.

4.4.3.8 Using graphs

Kevin explained that he uses graphs to teach about acceleration, which he has designed especially for this purpose. He believes that using graphs "is one way to show them the difference between speed, velocity, and acceleration."

4.4.3.9 Using real-world examples

Kevin uses real-life examples to facilitate his students' understanding of friction. Some examples include the following: relating [friction] to farm machinery, riding a bicycle, and different types of tires.

Different types of machines. Kevin stated that he used examples of various types of machines for teaching about friction, including farm machinery. He said that he usually asks his students, "How [does this] machine change or . . . reduce friction?"

Different types of tires. Some examples Kevin noted are winter tires, all-season tires, and racing car tires. While using the examples of various tires, he described that he asks his students "why race cars use one type of tire and racing bikes one type of tire, and mountain bikes use a different type of tire?" He explained that he wanted his students to understand the impact different tires have on friction, and which tire is suited for a particular situation involving friction.

Driving a car. To teach his students about the force and motion ideas, Kevin uses everyday life examples, and driving a car is one such example. When asked to provide details of how he

uses this example, he responded that he it becomes a way to initiate a classroom discussion, where he asks his students the difference driving in the city versus on the highway using cruise control. He said that he further asks about the difference when a car going at a constant speed versus when a car accelerates from a stop light. Kevin repeatedly referred to these examples during our conversations, mainly when talking about acceleration.

***Riding a bicycle*.** Kevin added that "bicycling . . . would be another way that [students] would understand the accelerating and de-accelerating." He said he rides his bike to school, especially the day he wants his students to explore the acceleration. In Kevin's words, "So somebody . . . can hold the bike and [students] can apply that force to pedal it." He explained that after having this experience, "now we can talk about the changing of motion . . . and force."

4.4.3.10 Taking a critical stance on using instructional strategies for conceptual understanding

Kevin conveyed that he believed in not ignoring, but addressing, naïve ideas or theories students bring into class. He said that the students will keep thinking about these alternative ideas, so it is better to stay with them in their process of learning—either helping them discover the reality if possible or letting them research the ideas themselves and find that they have not been proven yet. He stated that he liked to encourage students to think of innovative ideas, which they may test in the future as part of their graduate study of physics.

For Kevin, this is an opportunity to teach students about the nature of science. He said that this "is an important part of science . . . [that] we have theories, and sometimes theories are in the process of being tested, and we do not necessarily have that. . . definitive universal concepts. . . and that is the way it is." Kevin insisted, "That is always needed . . . to test theories . . . [in class]." He used the example of an idea that one of his students brought, that force is a state of

matter called plasma. He said that his response was, “Let’s talk about that, and let’s test [it].” In this example, he said that he used computer searches as a tool to encourage his students explore and get some answers. He said that he provided an encouraging comment to this student and said, “Maybe when you become a physicist you can prove that.”

To modify the alternative idea of some of his students that machines are 100% efficient, Kevin stated that he uses “more examples . . . , asking where efficiency is reduced due to frictional forces.” Kevin also shared an activity he does that he said he always uses to help his students overcome alternative ideas about friction. In this activity, he uses various surfaces, such as smooth and rough material, sandpaper, and grip tape, and lets his students pull a wooden block across these surfaces. He asks them, “How is it when the wooden block crosses the grip tape? And how it is when the wooden block crosses the sandpaper?” Through using this activity, he wants his students to understand how efficiency decreases, and that they need to increase the force in order to do the same amount of work.

When engaged in a conversation about a common misconception many high school students have—the inability to distinguish between uniform velocity and uniform acceleration—he quickly responded that showing graphs can help in dealing with this problem. He said, “If they see graphs of [two types of motion] . . ., they see a straight line versus a curved line trend, and . . . they get that.” Then he came up with another example he thinks can be useful to help students distinguish constant velocity and constant acceleration: He suggested using three examples: (a) a car driven with cruise control on the highway, (b) the car slowing down to leave the highway, and (c) the car speeding up from a stopped position. He noted that these examples were effective because, in spite of not having driving experience, “they all driven in cars and experience their parents drive with cruise control on the highway.”

During a conversation about using examples and other learning experiences effectively, we entered into a discussion that examples, or the way those examples are used, can leave students confused. In the context of how friction helps us walk on earth, Kevin shared a similar memory from his grade six classroom as a student, which he called "extreme teaching." He said:

> I had a grade six teacher, who took us up to a pond. . . . What we had to do…we had to play [laughing] . . . and when we pushed off on the ground, which was . . . a shovelled sidewalk or whatever . . . there was friction there . . . and then we have to go to the pond. It was ice when we went out there, and friction was reduced. And I remember it becoming free for all of us pushing each other down on the pond [Laughing].

When I asked Kevin if he ever used this activity in his teaching of friction, He said "NO" because he thinks safety is a concern. However, he has found a similar activity, which he uses inside the classroom.

4.4.4 Kevin's views, knowledge, and use of teaching resources

During our conversations, Kevin mentioned many teaching resources that he finds effective to support classroom activities for the force and motion unit. The following sections describe some of these and how he uses them to help his students develop conceptual understanding.

4.4.4.1 Using manipulatives

Kevin uses various manipulative when teaching about force and motion. These include miniature cars, wooden blocks, which he uses to demonstrate a force, to measure a force, and display the effect of friction on the motion. Kevin also sometimes asks his students to bring materials such as empty boxes or cartons that he will then use in class for open inquiry work with friction.

4.4.4.2 Access to a specially designed manipulatives

Kevin shared his experience of having seen an amazing set of manipulative:

> They were like a bicycle but just pedals and the crank part [and] they were three of them . . . One [of them] was . . . well maintained [with ball bearings, and] lubricated, the other one [had] ball bearings . . . but was not lubricated, and [the third] was without ball bearing [perhaps].

Kevin said that this is a very good resource for students to "turn the cranks and . . . felt the temperatures of it" to understand the "idea that the lubricated one is the coolest and [thus] is the most efficient . . . [because] there is less friction." Kevin said that he believed that these manipulative were specially manufactured for teaching grade eight science for exploring relationships between friction and efficiency.

4.4.4.3 Use of textbooks

Kevin finds textbooks a great resource for students. He said, "I will make sure that I would . . . definitely, eventually come back to the textbook because there is that graphical representation . . . [and] it is supposedly written at their level so they can do some reading." Kevin believes that after "[students] have participated in [activities] . . . have done [labs] . . . or have listened to [class discussions]" they can better understand the materials given in the textbook.

4.4.4.4 Use of textbook teacher guide

Kevin, as mentioned above, uses the book series, *Science Focus* and the teacher resource binder that comes with it. He thinks that the binder has many useful ideas, which he uses in his class when teaching about force and motion. He pointed out that he also gets help from this binder to facilitate differentiated learning for his students.

4.4.5 Kevin's views, knowledge, and use of technology

Kevin showed his concern that "people may have a limited understanding of the technology and think it as information technology [only]." He clarified that for him "technology can be broader." He commented that he had a broad sense of technology, considering a bike as "a form of technology." He uses a bicycle to teach his grade eight science students about various force and motion concepts, saying that "using technology in the classroom is "cool." He stated that he "goes above and beyond" with respect to using technology in his classroom.

Kevin further explained that he uses the *Science Focus* teacher guide that "definitely has those ICT [information and communication technology] outcomes, and how to get the technology in [the classroom]." He described one example that he suggested was off topic, but still a good critique of technology integration expectations:

> They will recommend . . . for example in . . . water [unit] . . . the idea of using an Excel spreadsheet and making or generating a circle graph from a set of water-use data . . . we just finished [this activity] . . . which is right in the teacher resource binder, which would definitely come from fulfilling [ICT] curricular expectations.

Kevin has Active Board technology in his classroom, and he said he used it regularly for teaching science and mathematics. He is a big fan of the *Bill Nye the Science Guy* video series, and as described above, uses some of these videos in his teaching of force and motion. He also uses some particular websites. The following sections describes how he integrates technologies into his teaching of force and motion.

4.4.5.1 Use of Active Board in classroom

While explaining his strategies to demonstrate a force to students, Kevin said that "these days, you could just even go to the Active Board, and with the marker make a nice thick line and

just move the pen across the board . . . and [ask students] . . . , 'What forces are applied here?', . . . tell me." He added that the same can be done using paper and pen, but using technology can engage more students. Kevin described how, after observing carefully and thinking "[students] may pick up that you would apply that force both when holding a pen to the paper and [writing on the paper] whatever it is . . . and moving along."

4.4.5.2 Digitalizing resources

Kevin told me about how he used some graphs for teaching about acceleration (discussed above). He said that he has "graphs in notes" as hard copy, but that now he has the software "Geo Algebra, a program for Active Board [which] is an online program [for] quick and easy online graphs" and so has plans to develop and use graphs on the Active Board in future.

4.4.5.3 Using video clips

Kevin uses visual media a great deal in his teaching, and tries to find interesting video clips to show his students difficult concepts—for example, zero gravity or defying gravity. Kevin said that when teaching about force and motion, he "would definitely be using a video." As noted, when I asked about specific video clips, he talked about the *Bill Nye the Science Guy* video series, which he uses a quite a bit. Kevin brought out an example of one of these videos that he has used for teaching about friction, and said, "It is a video where he spills . . . marbles and walks on . . . the marbles . . . to cross it."

4.4.5.4 Using website and simulations

Kevin said that he has used the website www.explorelearning.com to help his students understand frictional forces. He said that this website has "gizmos that you can use to present real-world situations. . . . There is one in there…that is using . . . an inclined plane . . . [where

you can] change the surface of the inclined place and measure friction." Kevin also shared an example of an "airplane simulators where [students] can momentarily defy gravity."

4.4.6 Kevin's views and understanding of the science curriculum

Kevin said that he uses the Alberta Science Program of Study (POS) to organize his curriculum and "prioritize the topics and concepts." Kevin identified the three major focuses of the Alberta Science POS: knowledge, skills, and attitudes. In his words, "It even allows me to determine how long to spend on [a topic] . . . and how important a concept is based on the other information that I have to get across in that unit." He explained with the example of force, that the POS shows him how to be "able to hit those areas for the important concepts . . . so [students] understand a force [knowledge], and understand how forces are used [skill] . . . and a general attitude of discovery in science [attitudes]."

Talking about one area of emphasis within the Alberta Science POS, specifically the Science-Technology-Society (STS) approach, Kevin said that "in my classroom I try as much as I can to use technology. . . . To me it is just a kind of natural [process] . . . that makes sense to me . . . or maybe I have a broader sense of technology. . . . It does not have to be an electronic device . . . like a bike is technology."

Kevin was not completely sure of the specific content objectives of the force and motion ideas in the Alberta Science POS. For example, with regard to friction, he knew it was in the POS, but he was not sure if it is "there to teach in order to get an understating of efficiency." Kevin said that he has explored the Alberta Science POS, but "not for [friction] particularly."

Kevin uses the textbook for teaching about force and motion, and notes that "textbooks help" to implement the curriculum.

Kevin asserted that prioritizing topics as a science teacher "is a very subjective thing," which is why he does it collaboratively with colleagues. Kevin explained this collaborative process, saying, "As a science department, that is three of us. And we sit down [together] . . . go through the curriculum and look at how important a concept is." They use a three-point rating scale, where each member rates every concept. He explained that if a "[concept] is [rated as] *one* . . . you have to spend a little more time on it; [if] it is *two*, [you are] going to make [students] familiar with it, [and if] it is *three*, [you] just kind of touch on it and it is not a big of concept." So, based on mutual consensus, they set priorities for curriculum topics.

4.4.7 Kevin's goals of teaching force and motion

The prescribed science curriculum from the Alberta Science Program of Studies has specific goals for teaching different topics related to force and motion at various grade levels. Science teachers, influenced by their own beliefs and values, may have some other, personal goals to achieve when planning and teaching these topics.

For example, when I asked why it is important for junior high students to understand the ideas around force and motion, Kevin stated that force is an important concept for these students. He said that if students understand about force and motion, they can learn about the safety issues involved in driving a car. In Kevin's words, "In a vehicle you are dealing with a huge velocity and therefore if it hits something there is a massive force applied . . . so . . . there is a reason to teach force to junior high school students . . . [a] very practical reason."

Kevin conveyed that one of the goals of teaching force and motion ideas at this level is to help the students understand forces involved when riding a bike or playing hockey: "Before they drive, they bike, and they play hockey; understanding what those forces are is important too."

In addition, Kevin indicated, "If [students] understand the idea of force [a]s a push or pull

that helps them understand . . . for example, Newton's laws" of motion [and] . . . definitely [it is] something that is important before they go to the high school and take physics." Kevin further explained that if students "have that basic understanding of what the physical laws are, and the laws of motion, they can be successful in high school.

Kevin believes that it is important for grade eight students to understand the concepts of friction, because "that has a huge impact on their understanding of efficiency . . . and the [idea of] transfer of heat."

4.4.8 Kevin's views and understanding of considering various teaching contexts

Kevin said that that he would not change anything about his teaching about force, whether he is teaching in a rural or urban school, or teaching anywhere. When asked how he will teach about force if he does not have any manipulatives or technology to use in the classroom, he replied, "I can teach force in the middle of the basketball [court]" by just using the ball. He used this example perhaps because he is a basketball coach. However, when talking about friction, he indicated that "in an urban school as compared to a rural school . . ., there would be a difference" because Kevin believes that rural kids have some prior knowledge of efficiency and simple machines. Hence, he assumed that his teaching in a rural context would be different from an urban context for this topic.

4.4.9 Kevin's views and understanding of assessment

Effective science teachers need to know and apply various assessment techniques to make sure that their students have developed the intended understanding of the concepts and ideas taught to them. Some specific assessment techniques have also been developed and used to get to know the prior knowledge of the students, especially targeting their alternative frameworks for the ideas under study. Moreover, assessing students' learning also give science teachers some

idea about whether their instructional strategies were effective or not. During our conversations, Kevin identified some techniques that he uses to assess his students' understanding of topics related to force and motion. The following sections describe those techniques.

4.4.9.1 Creating and using lab-sheets

In checking his students' understanding of the idea of friction, Kevin wants to make sure his students can "come up with a conclusion from a friction lab," which should illustrate that "they understand how friction affects efficiency . . . that if friction increases, efficiency decreases . . . [and] they can relate friction to the amount of effort force to move an object . . . and transfer of heat." Therefore, when marking students' labs, he looks for these explanations.

4.4.9.2 Using multiple-choice questions

Kevin said that sometimes he uses "just the multiple choice questions," which he believes can also help assess his students' understanding of friction.

4.4.9.3 Using classroom quizzes and unit tests

When asked how he assesses his students' understanding of acceleration, he answered, "pretty simple: using questions Then he explained that he also uses a quiz in classroom and checks his students understanding, later, through a unit test.

4.4.10 Kevin's views and understanding of addressing student diversity

Kevin teaches in a school that is not very multicultural. Nonetheless, he presents a clear understanding of the difference in teaching students with rural and urban backgrounds. During a conversation about the role of other varied backgrounds of students in their learning of these force and motion topics, Kevin's revealed his potential to be an inclusive science teacher. For example, I challenged him about his example of driving a car, and asked, "What will you do if there are students in your class with no experience of driving or even being in a car" He cleverly

responded, “Oh yes, there might be students who have never driven . . . but I think everybody . . . I would say that everybody in my classroom have been in a car, may not be driven, but have felt the different . . . acceleration.” He added, “You could even talk about aeroplanes . . . accelerating—taking off . . . versus cruising speed.” He explained, “I think everybody could take that lead from not actually pushing the gas paddle and feeling the acceleration but only feeling the acceleration. Kevin further explained,

> The odd chance where I have students who have never experienced sitting in a car . . . that would be different. . . . Any automotive transportation you can look at, [or] you can even show videos of . . . predatory animals like cheetahs, or horse races or something where an animal accelerates, and then has more of a continuous speed, so going from a starting speed to that of a burst and that of acceleration and chasing. . . . That would be really rare but you can do that.

A summary of the story of Kevin’s teaching is presented in Appendix E, on pages 403 to 413.

PART II: THE STORY OF JASON'S TEACHING

4.5 Jason - An Introduction

Jason obtained his teaching licence in Alberta in 2004 after completing his BEd and accepting a full-time position as a high school science teacher in 2009 in a school district in Alberta. At the time of our conversations, he had accumulated two years of high school science teaching experience, which included mainly teaching Physics 20 and Physics 30. In addition, he taught introductory physics to first-year university students for three years as a sessional instructor. He had also worked as a teaching assistant (TA) for six years in a university physics department during his graduate study (PhD). His supervised teaching experiences during his BEd Program also include teaching Physics 20. Moreover, he tutored at various levels during his studies at the university.

Unlike an average student teacher, Jason entered his BEd Program with a strong academic background in science and diverse teaching experiences, which makes him a unique and ideal candidate. He holds two bachelor's degrees, one in Chemistry and the other in physics, and a PhD degree in physics with a focus on computation physics. He has also completed a post-doc in physics. Jason recognized that he took a long and extraordinary route to his career as a high school science teacher because it was not his first career choice. Despite having extra academic preparation, Jason states that a BSc in physics and a B. Ed. is enough for anyone to start teaching science (physics) in high school.

Unlike a beginning high school science teacher, Jason had multiple diverse opportunities to teach physics, especially the area of mechanics. He has been teaching Physics 20 every semester during his career as a high school science teacher, a course that includes basic mechanics. He taught introductory physics to first-year university students for three consecutive

years, which also encompasses mechanics. He has also been involved in teaching mechanics to first-year university students as a TA for six years. Even as a student teacher, he had the opportunity to teach Physics 20. His tutoring experiences, to high school and university students, are also predominantly in physics and mechanics. When asked how many times he had the opportunity to teach topics related to force and motion, Jason said,

> Physics 20, I have taught . . . five times now in two years. In the university, I did the first-year [courses] 211 to 220, which is all mechanics, four times. Then [as a] TA [I taught] consistently mechanics stuff for six years. So, I guess six times as TA as well. [As a student teacher] in junior high [school] . . . we were doing more heat and thermodynamics related stuff, but in another student teaching we [did] Physics 20 once.

Altogether, Jason taught these topics 16 times, all in the context of basic mechanics at the high school and post-secondary levels.

Jason had plenty of experience**s** related to physics and teaching physics prior to starting his teacher education program. This is not common for a standard teacher education candidate. Usually pre-service science teachers enter their teacher education programs with a bachelor's degree in the case of an after-degree program, or with two years of university study in the case of a combined BEd program. During our conversations, Jason showed a deep understanding of teaching physics, specifically on topics related to force and motion, which is unusual for a beginning high school teacher like him. He denied learning anything specifically about teaching physics during his B. Ed. Program. Jason conceded that most of his knowledge of teaching physics is sourced in his experience of teaching.

Jason described his BEd Program as a general science education program that had at least two semesters of active science education courses. He stated that the science education courses

focused on broader concepts like the nature of science (NOS), field trips and so on, but "there was no explicit discussion on science, science teaching, or specifically physics teaching." The practicum was the only component for Jason where he had an opportunity to learn about science (physics) teaching. He had an opportunity to plan a unit in his science education course, but he was not sure how effective it was as an opportunity to learn to teach science. Jason argued that the number of student teachers with physics backgrounds is usually small, so perhaps that was the reason for the lack of focus on physics teaching in his BEd program. He explained that there were 400-500 pre-service teachers enrolled in his B. Ed. and among the group of 40-50 in secondary science specialization, only three had experience in physics and wanted to teach high school physics. Jason indicated, "Physics is bizarrely small as compared to everything else in [his B. Ed. Program]."

In Jason's opinion, an ideal BEd program should provide opportunities to understand content knowledge deeply. He said, "It will be nice to have something more directed towards physics education . . . and for the other subjects as well. . . .There should be deep discussions on the content knowledge of science or physics." Jason further expressed**,** "It will be really interested to split [science content] . . . [to show] how this particular topic is going to be taught, or not going to be taught, as it might go wrong [teaching a particular topic in] that way."

Jason told me that students' alternative ideas in these concepts should be considered seriously. However, he acknowledged the fact that without teaching in a real classroom, it would be almost impossible for student teachers in a BEd program to understand teaching science effectively, because they cannot experience students' learning difficulties and misconceptions in a practical setting. He also suggested that student teachers should be provided with opportunities to observe students in real classrooms, and do inquiry about learning and teaching.

Jason expressed that his experiences working as a teaching assistant and teaching introductory physics in university helped him clarify his content knowledge of physics. He said that these experiences "gave . . . [him] a really solid place to start [teaching] high school [physics], in terms of mechanics." Based on his experience of working with undergraduate physics students, Jason pointed out that he, "saw and talked with [many student**s**] who are also TAs . . . [who] get . . . some fundamental concepts wrong because it is entirely possible to take a bachelor in physics and not really understand mechanics . . . [as it] is always tough to understand." Jason affirmed that teachers need to reflect on their teaching and hence improve it, throughout their teaching careers. He considers regular reflections on one's teaching as an essential skill for successful science teaching.

Jason recognized that his long and extraordinary route to his career as a high school science teacher allows him to bring a deeper understanding of physics to his students, along with plenty of opportunities to teach it. However, being humble, he said that his knowledge of physics was sufficient for him to *start* teaching, though "in truly unpredictable ways."

4.6 Jason's Orientations to Science Teaching

Because of Jason's unusual journey to become a high school science teacher, he brings particular values and orientations to his science teaching, which are apparent in this classroom. These are shaped by his unique experiences of being engaged in the study, research and teaching in the field of physics. Observing Jason's teaching, I could clearly see that he is trying to make his students think deeply by asking them question after the question so they can find answers for themselves. I noted that he is a master of holding his thoughts until every student in his classroom has at least an answer or explanation. He brings many inquiry activities, labs, technology and real life scenarios to his classroom to provide opportunities for his students to

learn. Three key aspects are reviewed below, based on my analysis of my several conversations with Jason.

4.6.1 Inquiry activities

Jason used predict-observe-explain (POE) problems for teaching about force. In his own words,

> We do a lot of predict-observe-explain (POE) stuff. I want students to make predictions that have the opportunity to be wrong. I think you probably can learn more when you are wrong than when you are right. So this is something that we talk about a lot of as well, because it is the nature of science.

The philosophy underpinning POE problems is constructivism, and it is a tool to incorporate structured inquiry learning. Thus, it appears that Jason provides inquiry learning opportunities to his students through the use of POE activities.

4.6.2 Interactive and collaborative learning environment

Jason appears to believe that knowledge is socially constructed. Therefore, he tries to create an interactive and collaborative classroom because he believes that social interactions are fundamental for any learning to happen.

He puts his belief into practice by encouraging a silent group of students in his class to ask questions and add comments. Jason experienced in his early career in high school that the classroom had a culture of silence and students were not ready to talk with each other or with the teacher, even by asking questions or simply adding comments. He not only changed that culture but created a climate where interactions happens all the time and lots of collaborative learning opportunities are created for students so that they can work together and learn better. In Jason's words,

> The first things I will try to do is to set up a culture where . . . [the students'] negotiations with each other are really, really important. . . . This is something I do—not only do in the forces units, but in everything else . . . [and] the assignments I give. . . . I want the students to collaborate; I want them to teach each other how to solve these problems. And the more they work in groups, the more everybody wins on [assignments].

4.6.3 Jason's own learning experiences: Influences on his orientations

Jason proudly admits that the way he teaches physics is influenced by the way he was taught physics:

> I think that…certainly, especially . . . , the way I teach physics has a great deal in common with the way I was taught physics, in the sense that I was taught in a classroom where it was sort of focused around some of the examples, and then some time to do work. And that is a sort of general structure and this is definitely the way I teach.

One of the major influences he takes from his science teachers is ensuring a structure or classroom routine. A typical class of Jason starts with everyday examples to introduce new concepts and hook the students. Then, he works through at least one example to help students understand, and then make**s** them work on their own and practice problems so they master applications of the newly introduced concept.

Jason also explored some new ideas and strategies to teach physics. For example about predict-observe-explain (POE) activities, he said: "I am not sure if POE, for example, is something we [as a learner] ever did." Jason told that he learned about this teaching strategy during his BEd program in one of his secondary science curriculum courses.

Another new shift in his ideas about teaching science was an inclination towards a conceptual understanding of physics, rather than just solving numerical problems, an approach

rooted in his experiences as a teaching assistant during graduate school. Another source of his turn toward teaching for conceptual understanding is the popular physics book by Paul G. Hewitt, *Conceptual Physics* (1987). He told me that he want**s** to do the things mentioned in this book—indicating that teaching physics for conceptual understanding is something he turned to on his own.

Jason also told that his teachers lacked a balance between lab work and problem solving. However, he tries to keep this balance—using labs that are needed and providing students with enough time to practice solving numerical problems to prepare them for exams, because they need to pass exams at the end of the course.

4.7 A Profile of Jason's PCK Related to Force and Motion Ideas

Based on his extensive and diverse experiences of teaching force and motion topics, Jason developed a conceptual understanding of the content and a unique understanding of how to teach this content. During our conversations, he shared with me moments, incidences, and his accumulated experience of teaching this material, revealing various aspects of his pedagogical content knowledge.

4.7.1 Jason's views and understanding of the topics related to force and motion

As noted, Jason teaches Physics 20 on a regular basis and also has experience**s** of teaching introductory physics to first-year university graduates, which are largely about mechanics. In both of above, force is discussed as a way to affect motion and cause acceleration. However, in junior high science force is discussed in the context of structures and mechanical systems, of which Jason has no experience. In both these contexts, a deep understanding of a set of related topics is required by teachers to teach these topics. Jason presented a unique understanding of the following 13 topics and concepts during our conversations, and discussed

the ways these topics should be introduced to students for a conceptual understanding of force and motion.

4.7.1.1 What a force *Is* vs. What a force *does*

According to a fundamental definition, force is a push or pull. This definition is the most common and popular, especially in the contexts of junior high and elementary science. Jason acknowledged that the concept of force as push or pull is a useful concept that cannot be discarded. However, Jason stated that students need to be told at a particular stage and grade level that there is something more than push or pull to force. This is particularly important for students who want to go further in physics. To bridge a gap between junior high and senior high science, Jason said it is better to discuss force as push or pull in the context of an interaction between two things.

Jason also criticized the idea of treating force as an object or a thing, and trying to find what this thing is. He thinks it is not important for students to know "what a force is" [in terms of push or pull] and thus is against the view of spending too much time on trying to understand what a force is. He conveyed that he rather prefers to define force operationally—what a force does, and he has a specific way of doing so.

4.7.1.2 Defining force operationally: The three-step criterion

Jason told that force is an abstract idea and should be defined operationally, because defining things operationally is the best way to understand things that we cannot observe. He said that it is critical at this point (Physics 20) for students to be able to define force operationally, and to do this they need to know three things about it: (a) force is a vector, (b) force needs to act on something, and (c) every force needs to be applied by something. In Jason's

view is that once they know these three things about force, and can test any force on this three-step criteria, they can do pretty well in mechanics.

4.7.1.3 What a force is NOT

Jason also believes that to understand what a force is, it is important to understand and sort it out what is NOT a force, and the three-step criteria is the way to do this. He indicated that the third step particularly helps students eliminate many of the non-forces (proxy forces) they usually think are forces. This is because when they have to identify that force is applied by "something," they try to identify what that something is that is applying the force to the given body. For example, they get rid of their biggest misconception (involving an alternative idea) that a moving object has a force, which sometimes they name as "force of motion." or "thrust force." Jason asserted that his students are able to overcome this misconception because, when testing against the three criteria, "force of motion" is not applied by anything.

4.7.1.4 Free body diagram problems

In Jason's view a transition from the idea of what force is to the idea of what force does, students need to identify the forces acting in a specific situation. This is where the concept of a free body diagram comes in. According to Jason, a Free Body Diagram is a concept that helps students understand different types of forces involved in a situation. Understanding how these forces act on an object leads them to an understanding of the net force. These free body diagrams also help students understand the proxy forces (non-forces) they may have initially identified as forces

4.7.1.5 Types of forces

There are many different types of forces included in the Alberta Science Program of Study and in science textbooks. At the junior high level, the types of forces included in the unit

on Structures and Force are compression, tension, torsion and sheer. At the senior high school level, in Science 20 and Physics 20, the types of forces discusses are gravity, friction, reaction forces, and field reaction forces. Jason's perspective is that understanding force also means understanding different types of forces that exist in real life situations, such as reaction forces, friction forces, and gravity.

According to him, different types of forces are better understood as *examples* of forces in the context of various other topics. For example, he thinks that reaction forces are better understood within the framework of Newton's third law of motion. He described this as when two objects interact, with one object applying a force to the other and the second object pushing back with the same force, this is a reaction force. It is the same in magnitude but opposite in direction. Similarly, he thinks that force of friction is understood better in the context of Newton's second law of motion, where force causes acceleration. So, force of gravity—a field reaction force—can also be understood in the context of Newton's second law of motion, especially applied to free-falling objects.

4.7.1.6 Adding forces and resolving a force into components

Jason said that force is a vector quantity. As such, he asserted that to successfully solve numerical problems high school students need to deal with adding force and dividing a force into horizontal and vertical components. To achieve this skill, he said the students must understand, vector addition, coordinate systems, and components of a vector, topics he introduces right after the topic of Free Body Diagrams.

4.7.1.7 Application of force(s)

Jason made the point that the concept of force should be taught in terms of how it applies in various situations. For him, the concept of what a force does "is a link between the idea of

forces and the idea of acceleration," and this can be better understood during the discussion of Newton's second law of motion. He wants his students "to see [Newton's second law of motion, F=ma] as a tool" that can be applied in a situation involving an object in motion when a force is applied. He further explained that he "want[s] students to . . . understand the force, and get all of those [forces] involved in a situation on [the] left side of the equation, itemize and get direction of all those [forces]." He continued explaining: "[Similarly] if they [students] understand the acceleration [they] . . . put everything on the right side, and then Newton second law [F=ma] becomes a way of making sense of this [by] . . . filling any gaps.

4.7.1.8 Velocity

Jason argued that the discussion about velocity fits in the bigger discussion about "what a force is." According to him, it is a great idea to keep velocity separate in order to keep the discussion about Newton's laws of motion "neat". He asserted that it is important to make it clear to the students that "Newton's laws do not care about velocity at all."

4.7.1.9 Newton's third law of motion and reaction forces

Jason said that he prefers to discuss reaction forces in the context of Newton's third law of motion. He wants his students to understand that "if the object A pushes on object B with a force of . . . whatever type in some direction, then object B will always push on the object A with a force of the same type in the opposite direction and the same magnitude." Jason went on to say that the "force on the object A due to object B is a reaction force." Jason is also of the opinion that it is important to understand where the idea for Newton third law has come from and what some of the conditions are the Newton's third law is relevant.

4.7.1.10 Newton's second law of motion and acceleration

Jason describes that Newton's second law of motion as a relationship between the force applied on an object, and the acceleration caused as a result of this force. He clarified that in the context of real life situations, understanding Newton's second law means understanding several things: the acceleration caused by a force, what force should be applied in order to achieve a certain acceleration, or acceleration in a certain direction. In addition, he holds that understanding Newton's second law of motion involves applying Newton's second law equation, F=ma, to solve second law numerical problems.

Jason understands acceleration as the rate of change of velocity. He said he wants his students to understand "that acceleration is not about how speed changes, acceleration is how velocity changes**.**" He further explained**,** "The students [also need to] know that we can accelerate [an object] without changing [its] speed."

According to Jason, to understand the concept of acceleration it is necessary to understand the net force on an object, which includes the direction of the net force as well. He said, "One of the really big ideas . . . is 'what is the direction of the acceleration of an object?', . . , which is actually Newton's second law reframed again." Jason asserted that understanding the direction of acceleration in various scenarios is one of the critical concepts in force and motion: "If [students] can picture what direction the total force on something [is], they [can] talk about the net force they have [on an object]. . . . If they can tell . . . what direction the total force on something is, then the acceleration is in that direction."

Jason also envisaged that his students should be able to apply the concept. For example, when "they [must] get . . . this object moving towards the right and . . . slowing down . . . [and they can determine] . . . what direction [will they] . . . have to push on that [object] to make that

happen?" Jason said he then expects that his students to be able to "tell that . . . [they] need to push it to the left." He clarified that this is possible only when students "know that the acceleration is towards the left because that is the direction where you need to push on this thing to make that happen."

In Jason's view, acceleration is better understood in the context of Newton's second law. According to him, it is another way to interpret this law. He explained, "Even before we do dynamics we introduce [students] to the Newton's second law, kind of backwards, by saying that if you can picture this force you got your acceleration." Further, he said "And then it comes up repeatedly when we do dynamics."

4.7.1.11 Newton's first law of motion

Jason expresses his belief that understanding Newton's first law of motion is not as important as understanding Newton's second and third laws. He said that he chose not to "spend much time on Newton's first law of motion." However, he believes that his students should be able to understand that an object at rest stays at rest, and an object in motion stays in motion, unless a force is applied.

4.7.1.12 Circular motion

According to Jason, the fundamental concept involved in a circular motion is that the object is accelerating throughout, and the direction of acceleration is towards the center of the circle (inward) during the circular motion. Moreover, he thinks that his students should understand that Newton's laws of motion applies to circular motion so they can solve numerical problems related to circular motion. So, it becomes crucial in his view that "the students know that we can accelerate without changing speed."

4.7.1.13 Energy

Jason noted that when an object is moving it has energy, called kinetic energy, and it also has energy due to its position or height from the ground, called potential energy. His position is that the topic of energy can be understood in the context of amusement park physics, such as how roller coasters work. Students can demonstrate their understanding of the topic of energy, according to Jason, when they are able to apply the concept in several numerical problems related to roller coasters.

4.7.2 Sequencing these topics

Jason talked about how important it is understand students' prior learning when planning the sequencing of topics to be taught. The material students have covered in junior high school will influence how well they learn in senior high school. Because of this, at the beginning of the force and motion unit he reviews with the students what knowledge they bring with them from junior high school.

Jason presented a clear understanding of how he organizes various concepts related to force and motion to teach them effectively and maximize students' conceptual understanding. When I presented him with a list of force and motion topics, Jason took no time in choosing a starting point for our discussion. He said that the best way to start any discussion about force and motion is by generating a fundamental understanding of what force is. He said he uses the Free Body Diagram concept to achieve this—a most important topic to help students understand different types of forces involved in a situation and how these forces act on an object. He stressed that different types of forces should be introduced as examples of force. Further, Jason said that the discussion about velocity fits in the bigger discussion about "what … force [is] quite naturally because students asks questions about force and motion at this stage.

Jason stated that he introduces the topics of vector addition, coordinate systems, and components of a vector right after the topic of Free Body Diagram. He then follows this with Newton's second law of motion because it is easy for students to understand acceleration after knowing about the forces in detail. He indicated that he discusses frictional forces in the context of Newton's second law. Jason clarified it might be a good idea to discuss different forces here as examples—such as normal forces, frictional force and gravity—to make clear these relationships. For Jason, the best way to introduce circular motion is towards the end of a discussion about acceleration, so this happens after covering Newton's second law. Introducing, As Jason said that a discussion about reaction forces takes place in the context of this law. He emphasized that he discusses gravitational force just as an example of force, again, in the context of Newton's law. Jason likes to close the unit by covering energy, usually in the context of amusement park physics.

Based on his experiences of teaching force and motion ideas, Jason says that some students have serious misconceptions around what is force, which he said becomes more evident during their learning about Newton's second law of motion. He explained that when students are asked to identify the forces on an object, sometimes they name the forces that are not there. Jason shared one popular misconception about forces, which his students call "force of Motion", and said that the students think there is a force [on a moving object] in the direction of the motion, so they name it force of Motion. Jason shared another example of students' alternative ideas, where some of his students consider acceleration as a force. He said that some students also bring the strange idea of force of net forces. Jason believes that if any such misconceptions are observed in a class, it is a good idea to spend some time on what a force is not. He suggested that a discussion about what is not a force should be a crucial part of the discussion about what is

a force. He believes that the best way to conduct a discussion about force is to have a brainstorming session by asking students to bring examples of what they think is a force, and list these on the board. Jason asserted that he incorporates a discussion about fundamental forces. Jason states that it is critical at this point for students to be able to define force operationally, and he said that means they need to know that force needs three things: (i) force is a vector, (ii) force need to act on something, and (iii) every force needs to be applied by something. In Jason's view if once they know these three things about force, and can test any force on this three-step criteria, they do pretty well in mechanics. Jason believes that this helps them eliminate many of the non-forces, which he calls "proxy forces", they usually have on their list while identifying forces on the body. Jason claims that many of his students get rid of their biggest misconception, which involves an alternative idea that when an object is moving it has a force, which they call sometimes as "force of motion" because when tested against the three criteria, mentioned above, it is not applied by anything.

4.7.3 Jason's views and understanding of students' alternative ideas

Jason has noticed his students bring alternative ideas about the concepts related to force and motion to his science classes. He said that he pays special attention to these alternative ideas as they help him understand what learning hurdles the students bring to class. He further explained that he would thoughtfully planned and used various strategies to help his students change these ideas. The following sections describe some of these alternative ideas that Jason observed and articulated:

4.7.3.1 Everyday meanings of force

Jason has found that some of his students bring alternative meanings of "force," which they have acquired because of the everyday use of the word force. In his words:

> One of the things that we struggle with . . . [is] the word "force". . . [It] inform[s] so many concepts that are used colloquially, a thousand times more often than they are used in the physics classroom, and force is one of them. So, these students come in with an idea of what force is, [and] what [force] is not . . . informed by their prior education in Science 10, or physics. [This understanding sometimes] . . . is informed by the fact that . . . the last night they heard that somebody [in] a reality show that they were watching [said,] "it is a real force of nature" or something like that."

Jason noted that "for every word that we use in physics, we have ten ways that we use [them] not in physics." Jason stressed that "we need to make that distinction with students, and make sure when they are talking about something, [they] use very specific [ideas], and as long as they are [inside] the classroom, they need to be in that frame of mind." He added, "When we talk about energy, we had the same [problem] with the use of the word "energy'." He commented that the same issue comes up with "power" and "work."

4.7.3.2 "Force of motion"

Jason identified also that his students are repeatedly bringing to his classes the idea that a moving object has a force, which sometimes his students call "force of motion" or "thrust force." He said that "often [they] . . . use a proxy" a self-created name for a force. Jason believes that the possible reason for using these non-existent titles is "that they know there is . . . [a force], which they do not know, so they use a proxy for the force that they cannot identify." Jason's understanding is that this learning difficulty is rooted in the students not understanding that force is applied by "something." Therefore, he thinks that when they do not understand this something they use such ideas as a proxy for the unidentified force. He asserted that if this idea is not checked, it may become a part of their mental model and hinder their science learning.

The approach that Jason used to overcome this learning difficulty is to provide a list of legitimate forces to his students, and ask them to use *only* these forces to solve kinematics problems. Jason explained that he provides clear directions to his students during a lesson, and says to them, "You are not going to put that force in, unless it is one of these [forces, provided in the list]. . . . You are not [going to] . . . put that force unless you can justify to me what [or who] is applying that [force], and why [this force] is there." He elaborated that "**s**tudents need to be trained not to use proxy forces, to be successful to solve kinematics problems."

4.7.3.3 Friction force only opposes motion

Another alternative idea pointed out by Jason relates to friction force. In Jason's words,

> It is very difficult for them to understand that a friction force could be used to accelerate something. That friction force could be used to speed something up, as well as to slow it down, or to make it turn a corner. A friction force can be used to do anything that any other force can be used for.

Describing the reason that many of his students hold this alternative idea of friction force, Jason said, "They have got this idea somewhere, [that] the friction force stops motion." He offers them a better explanation to overcome this alternative idea by suggesting to them that the friction force "stops sliding." Based on his frequent confrontation with this alternative idea, Jason said that he "would rank it [the] second and third most important misconception [students] have . . . . It makes [it] . . . very difficult for them to understand [frictional force] if they think [this] is just to stop motion."

Jason shared his observation that many teachers in fact teach their students that friction force is something that stops motion, which is the root of this misconception since they get this impression from the classroom teaching, discussion, and the textbooks. Jason also showed

concern that teaching friction force as an opposition to motion reinforces the common misconception of "thrust force" or encourages students to use a proxy force when they are not able to fit friction into the situation of motion.

4.7.3.4 Distrust in Newton's third law of motion

Jason stated that many of his "students have a lack of trust in Newton's third law" due to two major naive ideas they hold. He described these ideas as "students [who] . . . believe that [an object] . . . that is larger is going to apply a larger force to [the other object]. . . . [And, an object] moving faster will apply a larger force than [an object] which is stationary." He commented that some of his students are unable to observe that larger objects do not move when the other smaller object applies a force because the acceleration is small. The mass is different for both the objects, and hence causes smaller or bigger acceleration, an application of Newton's second law of motion.

Jason suggested that both of these learning difficulties "are dealt with by clarifying Newton's third law" which leads to winning their trust in this law of motion. He does this by presenting two example**s** in a logical sequence. First, he uses example of "an elementary interaction, [where] . . . an electron interacts with another electron. . . . [It] makes a great deal of sens**e** . . . that this electron is pushing on [the other electron] . . . with a certain force, and [the other electron] pushes back with the same force." Then, he uses another example of "a freight train hitting a fly, [where] the forces are the same, but acceleration is dramatically different [due to the difference of mass]."

Jason shared an experience where using these two examples was successful. He "had a [student] jumping off the table and saying, the force of gravity [acts] down on them, and [they

apply a force back] up on the earth, the idea that the force is the same but earth does not move . . . [or] accelerates because it is much heavier."

Jason stressed, "Where [students] believe that Newton's third law does not hold, it is actually really worthwhile taking time and ask[ing] them why they think it does not hold, and [then] addressing why it holds, even when it seems like it would not."

He asserted that students "have some difficulty separating the force from acceleration . . . and that is something we [need to reinforce to overcome] . . . the trust issue." He said, "I spend a lot of time in class **. . .** treating it**.**" However, he admitted that sometimes it is actually almost treating Newton's third law as rote learning."

When confronted with situations where his students distrust Newton's third law and display any of the above learning difficulties, Jason said that he uses the examples of interactions in a logical sequence to demonstrate that this third law is trustworthy. These could be an interaction between two small objects (e.g., electrons) together with an interaction between one small and one very large object (e.g., a train hitting a fly). He states that in these interactions, his students can see how mass changes the acceleration, which explains the reason why, in an interaction between a small object and a large object they cannot see, the larger object move.

4.7.3.5 Acceleration is change in speed, not velocity

Jason has experienced many of his students thinking that acceleration is caused by a change in speed alone, which is a remarkably wrong idea because acceleration is caused by a change in the velocity. To help his students to change this idea, he draws "a really quick motion diagram or something that changes direction but not speed—subtracting velocity is what the aim is." Jason suggested that this should be done by "progressive refinement" so that students can build upon ideas to develop a better understanding of acceleration.

4.7.3.6 Missing the direction

In Jason's experience, it is common for many of his students to miss or ignore the direction of force and acceleration. In the case of force, he said that many times students are unable to identify the direction of net force on an object. In the case of acceleration students have a similar problem, which is more evident in the case of an object in circular motion. Jason explained that when his students are not clear that when an object changes direction it has acceleration he uses the example of circular motion.

4.7.3.7 An object changing direction always has acceleration

Jason asserted that many of his students miss the point that "if an object is changing direction, it must have acceleration, [such as] an object moving along a circular path." He states that if students understand this point, they can understand numerical problems better and solve them efficiently. Therefore, he said that he pays special attention to helping his students understand this point. He described a demonstration in the POE format he uses to address this learning difficulty. In Jason's words,

> I bring an overhead projector . . . [a marble and a tape]. . . . [I make] a swing model around the whole of the tape. [Then] I get them to do a POE. What I say is [that] I am going to get this [marble] moving, and then I am going to lift the tape very quickly, so this marble is going to go. I want you to tell me what direction the marble is going to go (Predict).

Jason then makes his students observe carefully while he demonstrates (Observe). He said that he want**s** his students to observe that when the marble was moving in a circular path, the direction of acceleration is inward, towards the center of the circle (Explain) and the direction of

acceleration of the marble while moving along the circular path is along the tangent to the circular path.

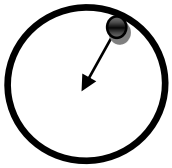


Figure a: Marble is moving inside the tape and the direction of acceleration of the marble is inward towards the centre of the circle

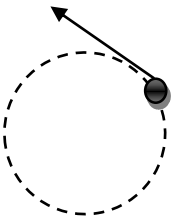


Figure b: Tape is lifted and marble move along the Tangent to the circular path

Talking about how this problem persists, Jason said, "Every year I think this is the class that . . . is going to get it right, [but] consistently . . . they will not"

Jason explained that it is important to make connections between different force and motion ideas constantly, so that the students can understand how these ideas interact in a real life situation. He uses the above demonstration "not [as] an example of a specific or single concept" but as an integration of the many ideas involved. He think**s** that if "we tie these things together more . . . we understand how these [ideas] relate. . . . The more . . . we had that is sort of [a] controlled [experience] . . . the more we just come to understand what we were talking about in [the] first place.

To achieve this in the context of the above demonstration, Jason uses a series of thoughtful questions to highlight the interconnected ideas. He asks his students,

"When we have the tape down, why [does] the marble keep going in a circle?" Jason usually gets the required response when they say, "Well, because there are forces on [it]." That is when he says that he asks about what force this is. Jason told me that, as expected, the students reply that it is "normal force." He follows this with another question: "So, what direction was that normal force?" Jason is sure that "because they know that the normal force is always perpendicular . . . they will say . . . that grab you towards the center." Jason conveyed that these questions guide his students' thinking process, and when he "lifts the tape and [asks] what happened to that normal force?" his students note that the force is gone, or is not touching the tape anymore. When Jason asks, "So what is the acceleration now?" and his students respond that it is zero, he queries them about what is happening. Usually he gets the expected response from his students, that the marble will continue travelling in the straight line.

4.7.3.8 Error of omission

Another learning problem that Jason has experienced is one that he thinks is "a deeper misconception…which is not even just about physics, but it is about what it looks like to be an expert?" He articulated that this problem is mainly related to the problem solving where his students think, "If they just knew acceleration for this problem, then . . . [they] could solve the problem." Jason thinks that this issue is rooted in their typical image of an expert, who is on a fast track and can choose to skip a step to be more efficient. Jason said that he has observed his students trying to be such experts, and skipping some important steps in problem-solving. The result is that they are not able to solve the problem at all.

4.7.4 Jason's repertoire of instructional strategies

During our conversations, Jason shared explicitly and implicitly a number of specific instructional strategies teach force and motion topics related to that he has developed, mastered

and found effective over time. These specific strategies also reveal an understanding of many effective general instructional strategies that Jason follows as he teaches this material. While he is a certified teacher, with a BEd, he gives most of the credit for learning and using these instructional strategies to his extensive experience of teaching at the post-secondary level during his graduate school studies.

Specific Instructional Strategies This section addresses the instructional strategies Jason found particularly effective for teaching force and motion topics.

4.7.4.1 Especially designed criterion

Teaching about force(s), which is sometimes considered simple, is actually very difficult. Sometimes teaching students that force is a push or pull, and having students be able to define force this way is considered sufficient. However, when exposed to various types of forces in senior high school science, many of these students not only fail to identify forces in real world situations but identify some proxy forces that are not, in fact, forces at all. Realizing that at a certain point the push or pull criterion is not sufficient to identify and define forces, Jason developed the set of three criteria noted above (force is a vector; force needs to act on something; every force needs to be applied by something). He introduces these criteria at the beginning of the unit, and then uses throughout the unit, whenever students need to clarify the concept of force.

Jason expects that his students should be testing any force against this three-step criteria, and should be able to state, “The thing or person applying the force, the direction of the force, and the thing or person acted upon by the force.”

Jason said that this specially designed criteria also works as a formative assessment strategy to assess if students understand what a force is.

4.7.4.2 Free body diagram and itemizing forces

To teach about a free body diagram, Jason uses a resource he also used as a teaching assistant at university—an article published in *Physics Teacher* by James E. Court in 1993. This article contains well-defined free body diagram problems, which involve different types of forces acting on a body, and are designed in a developmental sequence from simple to complex scenarios. Jason finds this resource very useful and has used it successfully for many years now.

He provides his students these free body diagram problems, and asks them to "itemize forces" on a given body in a given situation. Itemizing forces includes making a list of forces acting on the body and then identifying the type of force. After the students have listed and named these forces, he initiates a discussion by picking one of the forces from a student's list and asking him or her to justify their answer. He expects his students to justify their answers using the three-step criteria discussed above to evaluate a force. He keeps asking questions of various students, and provides them with an opportunity to evaluate and refine their understanding about the concept of forces and different types of forces.

Jason continues the same routine of using free body diagram for numerical problem solving, saying that "whenever there is a new problem, and [I have] to guide students through, [I] will start by drawing a free body diagram on the board." He says that he also uses the free body diagram to help his students understand the scenario presented in the numerical problem, then identify the forces involved, and think about how to solve the problem.

Jason said that he uses one entire 90-minute period to introduce free body diagram problems. He begins by doing them on the board and then gives students worksheets so they can practice solving these problems. He drew this strategy from Court's 1993 article.

4.7.4.3 Four-step process for numerical problem-solving

Jason stated he has designed and uses "a four-step process," which he runs through to solve any force-related numerical problems systematically. It is as follows:

1. Draw a free body diagram
2. Choose a coordinate system
3. Develop a table of components
4. Solve the problem using Newton's laws of motion.

Jason explained that he devised this process because he found that his students "make their mistakes . . . because they are choosing their forces wrong, or because they are doing components incorrectly, or because they have omitted a force entirely." He communicated that he thinks this process encourages the students to be creative and imaginative before starting the actual mechanics of the numerical problems. By not just plunging the students into solving numerical problems mathematically, they develop a better understanding of the topics related to force and motion and minimize the chances of making mistakes..

By promoting this four-step process, Jason reasoned, "I want [my] students to understand that using a free body diagram is not a crutch, it is not a sign that [you] do not know what you [are] doing." He tells his students that "it is exactly the way [I] would start a problem in dynamics."

4.7.4.4 Predict-observe-explain (POE) activities

Jason stated, "If students are not clear about the idea that if something changes direction that it has acceleration" he uses a demonstration, as described above, where he brings an overhead projector, a marble, and a tape to perform a demonstration using POE approach. Jason explained the directions he gives to his students, "I say . . . I am going to . . . this [marble]

moving [inside the tape, and] then I am going to lift the tape very quickly, so the marble is going to go." He asks his students to predict and say, "I want you to tell me what direction the marble is going to go?"

To guide their thinking and to help them *predict*, Jason explained that he usually provides his students three options to select their prediction. He said, "[marble] continues to curve along the direction of tape, [marble moves] . . . straight ahead, and [marble moves on the path] curling inwards the outside. Figure c Shows the these three options

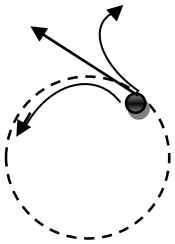


Figure c: Three options to make a prediction

Jason then performs the demonstration on an overhead project, so that his students can observe a magnified image on the screen or wall, with the intention that they should be able to *observe* the direction of motion of the marble.

Then he starts a discussion though asking questions, which lead towards the *explanation* that the direction of acceleration of an object moving in a circular path, at any point around the circle is inward, towards the center of the circle and when the object leaves the circle it moves straight along the tangent to the circular path.

To help students reach these conclusions, and to understand how different concepts are related to each other, Jason asks his students the following question.

Jason asks, "So, what happens there?" He then asks specifically, "When we have the tape down, why is the marble keep moving in a circle?" He said that some students say, "because there are forces on [it]" He continues and asks, "What force?" and some of his students reply,

"Normal force." He said then he asks, "So, what direction was that normal force?" and expects that his students understand by this time that "normal force is always perpendicular" and will be able to identify the direction of force, inward, towards the center of the circle. Jason explained, "So, we have the force towards the center, and [according to] Newton's second law, so the acceleration then must be towards the center as well."

Jason described that he further asks his students, "[When] we lift the tape . . . what happens to that normal force?" He said that in response his students "say [the normal force] is gone". He further asks them, "So, what is the acceleration now?" and he said that his students usually say, "[It] is zero." He then asks, "So, what it is going to do?" and his students are able to reach a conclusion and say, "It is going to keep travelling in a straight line."

4.7.4.5 Conceptual change strategies: Specially designed and sequenced examples

Jason described how he uses examples of interactions between two objects in a logical sequence to gain his students' trust in Newton's third law of motion, which he has noted may often be missing due to the misconceptions described earlier.

Example 1: Interaction between two elementary particles

He asks his students to imagine an "elementary interaction . . . an electron interact[ing] with another electron." Then he asks questions: What force one electron applies on the other?" And what force the other electron applies back on the first electron? Jason described that his students easily understand that electron [one] is pushing on [the other] one with a certain force, and that [the other electron] pushes back with the same force"

Jason then, "extend[s] that…to larger objects" and uses an example of a fast moving train hitting a fly.

Example 2: A freight train hitting a fly

Jason uses another imaginative example of a fast train hitting the fly, right after the examples of elementary interactions. After asking students to imagine a fast moving train hitting a fly, he asks his students, which force train applied on the fly? And what is the force that fly applies back on the train?

He uses this example mainly to clear the alternative idea that large and heavy objects apply a larger force back. He wants his students to understand that "the forces [in this Newton's third law pair] are same but acceleration is dramatically different"

Jason uses these examples so that his students can see how mass changes the acceleration, which explains the reason why, in an interaction between a small object and a large object they cannot see, the large object move. Jason told that after these two examples discussed together his students at least show trust in Newton's third law.

4.7.4.6 Collaborative case scenarios: A box on a truck

One of Jason's teaching strategies is to have students work collaboratively on a complex problem. One such problem presents a scenario where he uses a "diagram of a truck . . . accelerating to the left with a box on the back of the truck." This example scenario involves a number of Newton third law force pairs**,** and also includes many different types of forces, such as frictional force, gravity, normal force, and applied force. Jason described how he asks his students to "spend five minutes . . . to find every Newton's third pair in this problem." Then he invites his students to come to the board and draw these force pairs. Jason said that he "has students who have written down three of them or more" and encourages them to "keep looking." Jason said that students "look and then they find . . . 12 or 14. . . Newton's third law pairs"

Jason expressed that this is a "really rich problem**,** and it is [a] good opportunity for [his students] to see that [Newton's third law force pairs] are all over the place." He considers this problem an opportunity to help refine students' understanding about forces, and how these forces interact in everyday life situations. He affirmed his students can see that there are "normal forces . . . gravity, [and] friction force[s]." Jason indicated that this example can help clarify the frictional force. According to him, when we say, "if a truck is moving faster and faster, the truck actually exerts a friction force on the box, and in return box exerts a friction force backward on the truck." Jason believes that later they can apply the same rules when "they pick up the textbook and try to accelerate, and move it faster."

I had the opportunity to observe Jason teaching when he was using this scenario problem, and it was almost a complete re-enactment of our conversation. I saw him draw a picture of the scenario on the board, and then students come up to the board and identified different forces in play in the scenario of a box placed on the truck. The students were engaged, and they actively participated in solving this problem. After each student identified a force, he would ask the whole class if they agreed or not, or if someone wanted to challenge this idea. In a way, he provided an opportunity for the whole class to evaluate each of the ideas before contributing to the solution of the problem. With continuous motivation, encouragement and guidance, his students as a class identified 15 Newton's third law force pairs.

Jason told me that he also uses this example as a reminder to refine the idea of force if some students have missed it. He reminds his students to follow the rules to identify a force (three-step criteria), and then to draw forces by using lines and arrowheads to represent Newton's third law force pairs in this problem. He also refreshes the idea of a free body diagram. I observed him doing many of these activities when I had the opportunity to sit in his class.

Jason told me that he came across this example during his time as a university TA for the physics department, and said that he has used this example every time he has taught the topic of Newton's third law. Jason finds this example an effective transition from single isolated-object problems to a system involving multiple objects and forces, which are closer to the way real life situations involve forces. Moreover, Jason stated that this example "naturally leads into doing ropes and pulleys" by providing a nice start to Newton's second law problems.

4.7.4.7 Using everyday life examples

Jason has collected a repertoire of numerous real world examples that he uses to teach about force and motion ideas. He uses these examples to deal with students' alternative ideas, clarify concepts, and sometimes evaluate his students' learning. Here are some of the examples from his vast repertoire.

***A person jumping off the tab*le.** An example that Jason uses in a pedagogical situation to clear the misconceptions students hold about Newton's third law is "a person jumping off the table where [the] force of gravity acts down towards the earth . . . the forces involved are the same but earth does not move because of its huge mass.

***A fast moving car vs. an open Jeep, going around the corner*.** In Jason's experience, even after having multiple discussions on kinematics and dynamics some of his students still do not trust Newton's third law. Therefore, he adds another example when he is teaching about circular motion, another effort to win his students' trust in Newton's third law.

He discusses the scenario of a person sitting in the car moving fast around the corner, and asks his students if they would feel a force: "What is the direction of that force?" He finds many of his students fail to realize that "if they are in a car they feel somehow pulled towards the outside" because they are wearing a seat belt when sitting inside car. That is when he brings in

the next scenario and uses a sequence in which he says to the students, "Suppose you are in your friend's [open] Jeep. There is no door because it is a Jeep, and you are not wearing a seat belt." He creates a visual image for them and continues using their imagination by asking questions like, "If [the Jeep] is moving really fast, and you are around the corner, is there a force on you? and which direction you will move?" Jason points out that towards the end of this class discussion his students begin "understanding that [they] . . . moved towards the outside." Then, he brings back the example of the car and asks his students, "What happen[s] when you [are sitting] inside a car?" and most of them "can understand . . . that the door actually pushes [them] to the center of the turn"

Jason said that he also sometimes expands this discussion by asking additional questions about other forces involved in this scenario, such as the force applied on the seat and the seat applying force back on the person. Jason affirmed that he notices his students also "understand that . . . we are sitting in a seat, [and the] seat [is] pushing [us] up," a Newton's third law pair. Jason has discovered that "this [scenario] shed[s] light on all kind of things about Newton's third [such as] . . . apparent weight . . . [and] centripetal acceleration."

A person on a planet. Jason stated that he introduces different types of forces as examples in various scenarios, and then furthers that discussion in other topics. He talked about an example where "a person [is] standing on the planet." He conveyed that he thinks his students "love that [one] because . . . they get [that] there is gravity on the person . . . [precisely] there is a gravitational force by the person on the planet. . . . and [there are] normal forces by the planet on the person, [a] Newton's third law pair.

Jason also commented that this example made his students interested in learning more about gravity, which can help in solving problems related to free fall motion and Newton's

second law. Jason could not remember where he got this example from, but said that "I do not know if I ever have seen this in the textbook"

***Rubbing hands*.** Jason uses the example of rubbing hands to expand his students' understanding about various types of forces. He says that he also uses this example to introduce frictional forces. He said this is an example "where [students] feel more difficulty" and he believes that this example "is a really good one . . . and deals [with a friction force] on the ground."

He described how he demonstrates rubbing his hands in front of the whole class and asks students a series of thoughtful, carefully formulated questions to guide their deep thinking about forces. For example, he asks them, "What is the direction that I feel on my hand, when I do this [action of rubbing hands]?" He focuses on the direction of force involved and identifying Newton's third law force pair. He also asks: Which force(s) is involved? What is the direction of the force on one hand? And which force is applied on the hand, and what is the direction of this force?

Jason noted that he also uses this example in connection with the "box on a truck" scenario, to clarify the direction of the forces involved. Jason discovered that "this is the problem where they can assess that . . . the truck pushed in return backward on the ground, and . . . they may understand a little better the idea that the ground is pushing forward on the truck."

For a deeper understanding of force, Jason described that he has "buil[t] up . . . five or six [examples] . . . , purely conceptual and purely pictorial . . . problems, [where students] pick [the force] up, and tell what the direction [of the force] is, and tell . . . what kind of force [it] is."

***The hammer hitting the nail*.** Jason said that when he introduces Newton's third law of motion, "the discussion is really not about Newton's third law, it is about picking up Newton's

third law pairs because that is such a central thing in Newton's third law. . . . [I] think if you can pick up the pairs, rest is easy." For this purpose, Jason uses a hammer and nail example, where he "draw[s] up on the board, a hammer hitting a nail. [I ask] give me some pairs of forces here" Jason has found his students understand quickly that a "hammer is applying a force on the nail, and the nail applies a force back."

The accelerating train: Separating Newton's third law from Newton's second law. Jason demonstrated his deep understanding about the complex issues students have in learning about Newton's laws of motion, especially noting that they are often confused about the second and third laws. According to Jason, "There are very particular examples that [I] like to use . . . [for] separating Newton`s second law from Newton`s third law."

One such example is "a scenario where a train is accelerating towards left and the train engine is pulling two cars A and B." He asks his students, what force car A exerts on car B, and what the force is that is exerted by car B on car A? He clarified that after "[we have] got force on A due to B, and force on B due to A, which is . . . Newton's third law problem?" He wants the students "to tell . . . the force that the engine exerts on car A" which is a Newton's second law problem.

Using this example Jason stated that he is able to help his students distinguish between Newton's second and third law problems, and help them conceptually understand both the laws. He noted that sometimes he expands discussion on this example by considering "the direction of the acceleration where something is speeding up [in] response to gravity" because he thinks "this is . . . a really good time also to bring back the students to the idea [gravity]."

General Instructional Strategies. While the teaching strategies covered above reveal Jason's understanding of how best to teach force and motion topics, this section reviews what he had to say about general strategies for teaching science.

4.7.4.8 Using visualization

Jason described how he uses plenty of everyday life examples to help his students understand how physics is applied in everyday life, everywhere. He said he facilitates discussions in ways that ensures his students can imagine these everyday situations and visualize the interplay between several concepts within them. To achieve this, he draws diagrams on the board, (as explained above in case of box on a truck problem) and describes a situation in detail (as in case of the car versus jeep example). He adds various aspects of the real world problem in a progressive form during the classroom discussions, so that his students can understand how science is applied in that situation in the real world. As they visualize them, he said that he asks the students to draw these situations on paper or the board in the form of free body diagrams. Jason described this part as "creative," an additional part to the essentially mathematic/numerical problem-solving part that he claims to be crucial for conceptual development.

4.7.4.9 Questions, wait-time and discussion

Jason explained that it is important to spend time asking students about their reasoning processes as their understanding of the particular science concepts develop. This helps shape his own pedagogical choices, as he refines what best facilitates his students' emerging understanding.

For example when students show distrust in Newton's third law of motion, Jason said about this, "It is actually really worthwhile taking time and ask[ing them] why they think it does not hold, and addressing why it holds, even when it seems like it would not." Jason understands that

it requires not only that he choose suitable examples, but also asks thoughtful, probing questions to guide their thinking.

He said that while he uses the examples of interactions between two objects of varying masses, he repeatedly asks the same questions: "What force does object A apply on Object B?" And "what force does object B applies on object A?" He claims that these questions guide students towards thinking that the reaction force is always equal and opposite in direction in each interaction. From there it is also easy to lead students' thinking that both force and mass are the variables involved in acceleration. In the example of a train hitting a fly, asking questions leads them towards the thinking that in this interaction the forces are same but the acceleration is different, and that is because of the mass.

Jason also commented that students need time to process their learning, so he said that he provides sufficient "wait-time" to his students, which he describes like this: "I give them . . . time to think about . . . [the question asked] and then we talk about [the idea], for example the forces involved and [I ask again] . . . are forces different?"

Jason usually initiates a discussion by asking questions, targeting the initial question to a single student or whole class depending on the situation. For example, in the case of a free body diagram, he said he typically begins by directing a question to an individual and then involving the whole class in the discussion. In contrast, in the case of a Newton's third law complex scenario (box on a truck), he asks questions of the whole class and asks them to think carefully for five minutes and formulate their answers to share with the class.

4.7.4.10 Idea progression: Developmental instructional design

Jason said that he uses various examples developmentally—from easy to difficult—to facilitate the progression of ideas. For example, in the context of Newton's third law, he

describes the scenarios, “You . . . are sitting on a chair” and starts by identifying one force himself: “There is a normal force that the chair applies to you.” He said that he gives special attention to developing the language of physics and Newton’s laws. He guides them and waits until they begin to use appropriate vocabulary and language. For example, in the chair scenario just mentioned, he asks them what force the person applies on the chair. He expects his students to identify that force because they have already completed a discussion about forces and worked through various free body diagrams.

He described his approach—that he facilitates in a manner that his students can begin to describe the situation properly using the three-step criteria (of the type of force; who is applying it, and the direction of that force). He said that he “want[s] [his students] to say . . . this is a normal force by you on the chair down.” Jason thinks that if students get into the habit of using this type of language by gradually getting more practice with it, to explain a force or a force pair, they can more easily understand and solve Newton’s law problems.

Jason described that he uses examples further to gradually put forward the idea that whenever there is an interaction between two objects, Newton’s third law of motion applies and a Newton’s third law force pair can be identified.

For example, here is a couple of examples that Jason has used in a developmental sequence:

Example 1: A car hitting another car from behind, at a red light

> Jason describe the scenario to his students: “If we have a car that is sitting at the light and another car comes up and hits him from the behind.” Then he identifies one force, saying “this car exerts [a] force on a stationary car”, and asks his students, “Tell me about the Newton’s third law pairs in this case?” He expects his students to say, “stationary car

exerts force backwards on the other car . . . and it is the normal force and is the same magnitude." Jason says, "It makes sense [to his students], because it is slowing down the other car."

Based on his experience, Jason knows that the students' learning of Newton's third law is incomplete till the time they are able to say that if they replace the truck instead of a car, on the red light in the above scenario. He uses the changed scenario in Example 2.

Example 2: A car hitting a truck from behind, at a red light

Jason adds to the above scenario**,** and said,

It is very big truck now . . . or a car full of something . . . , and continue the same discussion till the time students understand and say that "if we have two things, the force of the one on the other is equal in magnitude [and] opposite in direction . . . and same type of the force.

4.7.4.11 Conceptual change

Jason shared his common experience where his students are confused while identifying a force, identifying Newton's third law force pairs, and confusing Newton's third law with Newton's second law. For example he identifies a typical scenario he uses in classes where he asks his students to visualize them sitting in a chair**,** and identify Newton's third law force pair in this scenario. Therefore, it has often occurred during his classes, where a student would say "that there is a normal force up, on me by the chair and gravitational force down on me by the earth" and he says "that is Newton's third law pair." Jason suggested the this response shows that the student is confusing Newton's third law with the second law, and hence is not able to identify the Newton's third law force pair which is "normal force that the chair exerts on me , up, and the Newton's third law pair is me exerting a normal force, down the chair." Jason said that in this

situation, there is a need "make clear [that] these are not the same kind of force, which is the part of reason why this does not count". Jason said:

> I think it is really important, because again in understanding the scope of this [Newton's third] law we have already done at that point apparent weight. We already know that the normal force by . . . on you from the chair does not have to equal your weight force. . . they need to understand even though that can be true . . . [but] even if this is accelerating the normal force by you on the chair is still equal in magnitude to the normal force by the chair on you.

Jason appears to be trying to make a concerted effort to help his students change their unacceptable concept into an acceptable one. In this case this particular conceptual change is critical to understand how Newton's third law is distinct from Newton's second law of motion, and can lead students' understanding that "Newton's third law always say this [that forces are equal and opposite]" but " Newton's second law sometimes have force balanced, not always"

4.7.4.12 Encouraging students' deep thinking

Jason said that he wants his students to think deeply about how various science concepts are working in everyday life situations. As described in the above examples, he formulates his questions for classroom discussion to encourage his students to think deeply about various scenarios. To answer his questions, usually his students think about more than one concept to understand how these topics are connected in real-life situations.

4.7.4.13 Using real world problems

Jason states that he is capable of engaging his students by using their everyday life experiences, because students "bring with them a tremendous amount of experience of world." He said that he presents these experiences in the form of examples. He understands that problem

solving is one aspect of successful learning, but if we focus only on numbers that does not help students develop an understanding of how science is behind most of the things we observe or experience in everyday life. He says that sometimes "a lot of [demonstrations] . . . unnecessarily turn into numbers" which he thinks, "at the end of the day are not really . . . honest anyway" and do not help learning.

Jason said that learning not only depends on textbook examples and problems. He takes the initiative to formulate his examples based on everyday life experiences. For example, He designed the example of the open Jeep on the ramp with or without a seat belt himself while he was driving and thinking about these topics.

4.7.4.14 Students' collaborative learning

One instructional strategy Jason said he often uses is collaborative learning. He uses this strategy in the classroom during discussions, problem-solving, and assignments. During classroom discussions, he provides an opportunity to his students to evaluate others' answers and contribute. This creates student-student and student-teacher interactions, and gives students ownership of the learning in the classroom. Jason also uses group work to provide collaborative learning opportunities to his students. He designs assignments in a way where his students cannot copy each other's work, but where they can still provide help to each other to complete these assignments.

4.7.4.15 Special attention to problems of understanding (Students' alternative ideas)

Jason pays special attention to what is hindering or helping his students' understanding of science. For example, as described above, he knows what is lacking in his students' understanding when they use proxy forces, what causes students to lack trust in Newton's third

law, or what can cause them to have confusion between Newton's second law and Newton's third law. After gaining a deep understanding of these problems, Jason has developed special strategies to target each of these problems so that his students can develop a better understanding.

He has experienced that his "students have a lack of trust in Newton's third law [of motion] . . . where they believe that Newton's third law does not hold." In his experience, many of his "students want to believe that something that is larger is going to apply a larger force to something when it apply back. . . and they [also] want to believe that something moving faster will apply a larger force than something which is stationary." Jason states, "both of those are dealt with by clarifying Newton's third law." According to Jason, the reason behind this thinking is an alternative idea where students think about force only when they think about acceleration, and ignore the mass of the objects completely, which expose that they "have some difficulty separating the force from acceleration." Therefore, Jason "spend[s] a lot of time in class . . . treating [this misconception]" which includes using examples where students can understand that force and mass both play a role in the acceleration, and they can then see what hinders their understanding about Newton's third law.

4.7.4.16 Direct teaching when appropriate

Jason informed me that at times rote learning is the only appropriate teaching option. He admits doing this sometimes, when despite all his efforts, a few students still show distrust in the laws of motion. It is a way to move on: he asks his students just to believe in this idea and move ahead so that the other students do not suffer. He also believes that sometimes understanding is delayed, and can happen later. Describing his reason for direct teaching, Jason said,

> I do not think I do this anywhere else, but I do it in Newton's third law a lot. It is sort of . . . learning by rote. This is really almost just a word game and we can treat it that way. It is not the full understanding but if they understand they can do it that way, [and] then it serves the proxy. I think until they are very comfortable with the idea, it actually always works.

Jason suggested strongly that they will be able to catch up in the future. Thus, he uses rote learning opportunities throughout the unit to refine any missing ideas, especially the lack of trust in Newton's third law.

For example, when it comes to understanding Newton's third law force pairs, Jason presents scenarios and examples from everyday life situations to help his students understand "how" the law works. However, he reports to just telling them where Newton's third law originates from, and acknowledges that this is rote learning

4.7.5 Jason's views, knowledge, and use of teaching resources

Having access to a number of resources is always helpful for busy science teachers. Along with general and common teaching resources like textbooks, white board, and SMART Board, there are some topic-specific resources that can help explain the force and motion topics and engage students better. Jason shared some of the resources he has used for this purpose, which I review below.

4.7.5.1 Appropriate use of white and SMART Boards

Jason uses white and SMART boards on a regular basis because, explaining that visuals or diagrams help students better understand the particular force he is teaching about. He said that he spends considerable time with whiteboards when he introduces the topic of free body

diagrams. He described how he starts by making a point on the board, and by asking questions, then guides his students through the process of drawing a free body diagram.

4.7.5.2 Free body diagram worksheet

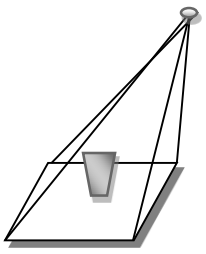
Jason uses the wonderful worksheet idea that he came across in Court's (1993) journal article in *Physics Teacher,* mentioned above. This article contains thoughtfully designed free body diagram problems, which Jason thinks can help students develop a systematic understanding of free body diagrams and help them in solving numerical problems, so he uses it regularly in his high school classroom. He came across this resource during his post-secondary experience as a teacher assistant and has since re-formatted the worksheets to suit his current students' needs.

As a pre-service teacher Jason had no experience with the teaching of force or free body diagrams. He has come to the viewpoint that it is hard for science teachers to start in their first year of teaching without such resources or ideas from pre-service teacher education program,

4.7.5.3 Professional development

Jason stated that he has attended some PD workshops and picked some teaching ideas to use in his science classes. One such resource, that he has used many times in his classes, "is a demo[nstration]" to teach about acceleration. He stated that he performs this demonstration with a platform, held up by strings, with a cup sitting on the platform. He described how he "swing[s it] in vertical circles and horizontals circles." He then asks his students, "What are the forces that are accelerating this thing?

Figure d: Visualization of the demonstration described by Jason



Jason said that this demonstration provides "really good opportunities . . . for students to see, for instance, that normal forces are not something that has to act upward. It is not something that has to just stop stuff and go . . . through stuff, . . . it actually is responsible for things like a cup going in a circle or something like that." Jason explained that the same demonstration also "comes in a really great video [and] . . . students love it [watching]."

4.7.6 Jason's views, knowledge, and use of teachnology

Jason thinks of himself as a technology-savvy person, and said his students expect him to use the latest technologies in his classroom since they know this about him. He also has a graduate degree in computational physics and can write computer programs. Jason has used the following technologies to help his students understand force and motion topics.

4.7.6.1 Use of smart phones

Jason stated that he uses smart phones in his physics classroom to engage his students. He said he does not use timers or stopwatches anymore, but encourages his students to use their smart phone as a tool as much as possible for doing and learning physics. He described how he asks his students to find their own resources in terms of available technology to perform some physics labs from the textbook, such as smart phone Apps such as Accelerator, Giro, and Compass Needle, which he has used in his physics classroom.

4.7.6.2 Custom computer programs for teaching

With his degree in computational physics, it is not surprising that Jason has an immense interest in the field. He told me about writing a computer program to arrange a set of assignments for his students. Jason said that he has used this program to generate assignments across the units, "so [his student] have different numbers for each [question on the assignment], [and each student] has different answers . . . [although] the questions are the same." He described his

intention here—that his students should apply their own knowledge to do these assignments and that their chances of copying are almost negligible.

4.7.6.3 Using motion sensors (Xplorer GLX)

The school where Jason teaches has GLXs in the labs, and physics teachers make use of this technology to help their students better understand the physics course content. Jason said that he likes using GLXs for teaching physics because he finds that they make physics as more real, because they can present a motion instantly as graphs.

4.7.6.4 Calaway Park, Calgary

Calaway Park, in Calgary, is a place where students can learn a great deal of amusement park physics and Jason has taken his students there on field trips. In his opinion, we should not be teaching students that physics happens only in the classroom and not in real life. He also told me of an incidence where one of his students visited Six Flags, another amusement Park in Canada and shared his experience with Jason that he was thinking about how fast rides should move and what forces they would produce. In other words, the student was not there just enjoying the rides, but thinking about physics concepts.

4.7.6.5 Appropriate use of technology

In spite of being a technology adept person and using the latest technologies in his classroom, Jason said, “We need to be careful about how we use technology, especially in the lab. If we train students that physics labs, or something you can do only on GLXs, but otherwise you [cannot], then . . . we are doing [students] disservice.”

Jason suggested that we “need to make sure that we are not training students that physics is something that happens in this room and not outside.” He thinks there is a need to be especially careful while doing labs, because it can take students’ learning away from the real

world. He also pointed out that this is the responsibility of a science (physics) teacher after they teach physics concepts. They should encourage student to identify these concepts in real world problems. The student mentioned above who visited Six Flags and consider physics principles while he was there was for Jason "a giant win."

4.7.7 Jason's views and understanding of the science curriculum

Jason stated that he considers the Alberta Program of Study (POS) a guide to plan for teaching science to high school students. Specifically, it identifies his legal responsibility as a high school science teacher, and what must be taught to Physics 20 students. However, he also indicated that the content selection and its organization is personal and rooted in the learning needs of the students. This needs to be improved constantly, based on the teacher's reflections on teaching.

4.7.7.1 Content selection

Jason stated that the program of study covers certain topics and concepts, but many teachers may disagree with the selection of these topics. The major disagreement seems to be in what is central to teaching kinematics or dynamics to Physics 20 students. Jason said, "I make the claim that within dynamics the idea of Newton's second law is actually really a central one. I would be stunned to find the teacher who did not think the Newton's second law was an important concept in dynamics."

Jason also noted that there are fewer disagreements in physics, or more generally in the science curriculum, with respect to content selection as compared to the ELA and social studies. Jason explained the difference and said that to develop "Physics 20 from scratch . . . there would be an enormous amount of overlap on what [all physics teachers] chose to do . . . [regardless of] whether their [students] want to become engineers, physicists, or whatever." He asserted, "There

is not a lot of disagreement on . . . which concepts are the important [in physics].” Contrary to this, in his view, when teachers “are doing English, and somebody says. . . whole metaphor is one of the most important things we are doing in this course,. . . [then], . . . there might be a thousand people who will disagree with them.”

4.7.7.2 Content organization

Jason strongly believes that in terms of content arrangement, curriculum is something personal to a teacher, especially when it comes to planning their curriculum. The sequence of teaching ideas related to force and motion, discussed above, is evidence of his personal curriculum planning.

Jason, as described above, gives special attention to the order or sequence in which various related topics are introduced. He argued that to engage students who may have difficulty understanding these topics, the order with which the topics are presented is important. In Jason’s word, you are “not going to lose half [of] the class based on what order you approach [the concepts, but] . . . you can pick that 20%, those who did not quite get that [concept]” by organizing content using introducing concepts in a thoughtful sequence to help these students conceptually understand these ideas. Jason stressed, “I think that is what [we as teachers] are aiming for.”

Textbooks are often seen as a curriculum material and a teaching resource. Each textbook uses a unique sequence to present various topics. Jason elaborated his view of curriculum planning and teaching a science curriculum that follows a unique and personalized sequence of topics. He said, “I disagree with the textbook as well.” He asserted that he changes the sequence of presenting topics in the textbook, and follows the sequence that helps his students understand these topics, based on his experiences of working with these students.

4.7.7.3 Teaching and planning

Jason appears to be a very well-organized science teacher who, within the first two years of his high school science teaching career, planned his lessons in detail and kept these organized and saved on his laptop. He showed these lessons to me during one of our conversations**.** As a reflective teacher, he had notes on most of his lessons. When I enquired about these notes, he said,"

> After most of my classes I sit down, and make notes on it, that say next time [what I will do], . . . what I saw going on and [am] not sure what to do with . . . or what I think might work better. [For example] the train and bus [example] that we talked about earlier [comparing it] with "waves" is something [I noted] at the top of [the lesson]. . . . [Next time] I approach that unit, I will trip over what I found last semester or last year, and [hope] that would be better next year.

4.7.8 Jason's goals of teaching force and motion

The Alberta POS has listed both general and specific goals for each grade level in all subject areas. Jason was critical of some of these objectives, but also agreed that many goals should be taken seriously. Jason disagreed with an objective related to Information and Communication Technology (ICT) in the POS, and especially the way students are taught and evaluated for this objective in diploma exams. He brought up an example of a diploma exam question that "bothers [him] consistently" where students are asked to "interpret what is essentially an excel spreadsheet" to cover ICT objectives. Jason expressed strong disagreement about this, saying "I do not think that teaching students . . . the grammar of Microsoft Excel should be part of our task" but ICT objectives should address the direct integration of science, physics, and technology. He used an example of using and iPhone in a physics classroom, and

said that "to use the iPhone is not a curriculum goal, [but] getting them to use iPhones in approaching physics is [the goal]." So in this context, he argued that the objective should be how to integrate iPhone technology into the classroom, but that the iPhone itself should not be the objective.

For Jason, the bottom line is that "technology is not an end goal, but a way to achieve the goal. The end goal has everything to do with physics, [and] . . . how the students approach physics, and how they interact with that."

4.7.9 Jason' views and understanding of considering various teaching contexts

Janos has taught force and motion topics to adults in university before teaching these topics to high school students. When asked if these experiences has changed his teaching, Jason said that it has changed in terms of using less independent learning in high school classroom. He Described:

> When I was teaching . . . [about] free body diagram there [university] . . . the peer teaching was enormous . . . [and] the students needed to sort out for themselves. [in high school] students need to make sense of it, over time.

To prepare his high school students as independent learners, Jason says that he "give[s] them opportunities . . . [and] show them where they might best look."

4.7.10 Jason's views and understanding of assessment

According to Jason one of the goals of teaching physics to high school students, in particular force and motion ideas, is to prepare them for further physics study. This then means making sure they are able to pass the exams. He strongly believes that his students need to

develop a deep conceptual understanding of several interrelated concepts to be successful in physics and to do well on the diploma exams.

4.7.10.1 Formative

Jason said that he uses formative assessment strategies throughout his teaching to make sure that his students have developed sufficient understanding of these topics. To practice for final and diploma exams, he stated that he conducts unit tests so that his students can evaluate their own progress in the course. Some of these formative assessment strategies are:

***Questioning*.** Jason believes that asking questions helps him understand the degree to which his students understand the material and which segments need more support and attention. He stated that he has used specially designed multiple-choice questions to assess pre-conceived ideas of his students and to check conceptual understanding of the students about force, with the Force Concept Inventory (FCI). He described learning this technique when teaching in a large university classroom. There, he said that he has used similar questions using clicker technology in order to assess the knowledge of his students about force and motion ideas.

In his high school science classroom, Jason said he engages his students in discussions and asks them questions to establish an interactive classroom. Jason notes that all these formative assessment strategies help him track his students' levels of understanding. He added that using questions also "help[s] with assessing not only where [they] are but also where they are . . . going, as we progress." However, he noted it is also important to understand the way a question should be phrased or asked, to effectively promote inquiry-based learning among his students. He stated that he pays attention so as to provide students enough wait-time to process their thinking before sharing their ideas. For example, he said during the "box on a truck" scenario

discussed above, “I want you guys to spend 5 minutes here and I want you to find every Newton’s third pair in this problem that you can identify.”

Similarly, he uses appropriate questions in the context of Predict - Observe -Explain (POE) activities to help his students predict thoughtfully, observe carefully, and engage in discussion in order to understand the scientific explanation of the phenomenon under study. For example, during the POE activity related to a demonstration with a marble moving inside the tape, discussed above, Jason explained that well before asking prediction questions, he asks questions so students can observe carefully, and ask questions to guide students thinking during classroom discussion.

Interactive collaborative problem-solving. Another formative assessment strategy Jason uses is what I call “interactive collaborative problem-solving.” He said that he uses this strategy at least once somewhere in the middle of the unit, with the intention of strengthening understanding of various interrelated force and motion concepts, the application of these concepts to real life situations, and to practice solving numerical problems involving force and motion. He said that he chooses a complex scenario, and he wants his students to demonstrate knowledge of various types of forces, larger and smaller forces, the direction of these forces, and so on. Jason’s use of a complex scenario that achieves this, “box on the truck” is explained above, in detail.

He stated that using the board for solving physics problems together with his students as a group, helps him assess his students’ understanding and helps them. In Jason’s words,

> The [students] are very active, . . . with the problems we do on board, so I think that helps as well to see whether they are getting these ideas. . . . It is not just the concepts behind the force but also the strategies for solving force problems.

For example, the box on the truck problem described above, which I also observed him using in class, demonstrated that he evaluates whether his students are able to identify Newton's third law pairs. He also gets a reading on whether they have understood the concept of force, free body diagrams and types of forces.

4.7.10.2 Summative

Jason stated that he uses assignments as his summative assessment strategy, towards the end of the unit. He explained that he has designed multiple assignments for the unit on force and motion, elaborating that he "set up assignments that are different for every student . . . and more meaningful [for them]" (which was mentioned above in the technology section). Jason clarified that he uses different assignments for different students to make sure that each student performs on the assignments, to minimize copying the assignments, which is possible in case of numerical problem especially. He thoughtfully wants each student to work on the assignment and show his true understanding of the content covered.

4.7.10.3 Connecting formative and summative assignments

Jason uses formative assessment to build up the knowledge of various interrelated concepts, and then moves from easy to difficult problems involving various types of forces. He described his goal of preparing his students to solve the complex problem given in final tests and diploma exams. Explaining the developmental process he uses to prepare his students for diploma exams, Jason said that that he first uses free body diagrams as formative assessment, then he solves a few problems collaboratively with his students and gives them the opportunity to solve problems themselves. He claims that he includes more tough problems in assignments "because this is what will be on exam ultimately."

According to Jason, most of the students in Physics 20 and Physics 30 aspire to become engineers or go on to other related technical fields. His position is that it is critical for these students to understand how the concept of forces actually apply in life to be successful in these careers. Therefore, he said that he selects problems accordingly.

4.7.11 Jason's views and understanding of addressing student diversity

The underlying idea of addressing student diversity is planning for a diverse population of learners with various learning abilities or styles. Jason acknowledged the various levels of learning ability of his students and appeared to be interested in designing lessons to include all of them, particularly those who have problems understanding these tough physics concepts. Showing a deep understanding of his students' learning needs, he designs inclusive lessons encompassing various instructional strategies. As detailed throughout several of the sections above, he carefully organizes his curriculum topics, making connections to real-world situations in order to help his students understand a set of interrelated concepts.

In addition to these considerations, Jason works with students from various ethnic and cultural backgrounds, including new immigrants. For many students in his class, English is a second language. He identified the issues and discussed the accommodations he undertook during his planning and teaching about force and motion ideas to help these diverse students in his classroom achieve success.

4.7.11.1 Helping ESL (English as a Second Language) learners

A huge part of the student population in Jason's class is ESL learners and he has experienced various types of issues in teaching science to these students. Jason noted that they have problems understanding the meanings of the different science words, such as force. They also have problems understanding the cultural images used in problems related to force and motion.

***Understanding the English word force*.** Students who struggle with the meaning of this word or have alternative meanings in their mental models do not follow when they are talking in classroom about this concept, according to Jason: "One of the principle problems . . . with [understanding] force, is that even the students who…come in with 15 years of experience in an English-speaking world [and/or are native speakers]" have similar problems. Jason explained, "They think that they already know what force is . . . when they do not." He believes that students' alternative mental models cause hurdles in their understanding of what "force" means in a science classroom. Jason laughed and noted that the "student who is not completely sure what force is, even in terms of [the] English word" would be much easier for him to teach than those native speakers who have alternative ideas of what the word means.

***Problems of cultural images used in physics problems*.** Jason commented that another problem ESL students face is the inability to understand the cultural images used in numerical problems related to force and motion ideas. He calls this a "decoding problem" and described this as a process "from [the] problem that is written on the page to actually. . . deal[ing] with it as a physics problem." Jason indicated that knowing this process of "break[ing] this problem apart . . . [the way a] physicist [would] do it, is what makes you a physicist or mathematician, or chemist."

He pointed out that many of his students with diverse cultural backgrounds fail to understand these local non-inclusive cultural images, and as a result fail to break apart the problem, which is critical to solving it. Jason considered those who write such problems in physics and other sciences are partly responsible since they include only specific or local cultural images. This excludes many students and poses a serious problem for them when they try to solve these problems. Jason showed his concern that in an effort to make physics problems

interesting by presenting novel scenarios, some test writers ignore the recipient. In his estimation, this is unfair for certain students.

Jason gave an example of one of these culturally-specific physics problems: “When Evel Knievel is looking to launch himself over [. . .] five school buses, if he needs to clear the buses, [and the distance between] each bus is 3 to 4 meters, to stop, how fast is he going to have to go as he leaves the ramp?” According to him, if students do not know who Evel Knievel is—that he rides motorcycles in huge, spectacular stunts—it is likely that they will not be able to understand the problem and solve it, which is unfair to those students. Jason, being a caring teacher, helps his students in any such situation, and especially encourages his ESL students to ask if they do not understand any word in a given problem. He emphasized how he helps his students in such a situation, saying

> I make sure my students know that I, no matter what the circumstances are, no matter whether it is a test or whatever, I will stay with them as long as it takes for them to understand [and] for us to agree on what the problem means. Because until they understand what the problem means, they cannot solve it.

4.7.11.2 Students with physical disabilities (Hearing Impairment)

When engaged in further discussion about other student diversity issues, Jason stated that he has “had students who had difficulty hearing, and had to wear hearing aids.” Based on his experience of working with these students**,** he said even “when they were not wearing [hearing aids], we still got a lot across.” In his opinion, hearing impairment did not need any big accommodations because those students were using hearing aids.

When queried him further, Jason mentioned vision impairment as another physical disability. He said that he has not "seen such cases in [his] classes so far" but he showed concerns about being able to deal with such a situation. In Jason's words,

> [I] do not know what I will do. Like [with] the free body diagram, . . . if a student comes in a tutorial . . . or wants help with a question. There has got to be at least an 80% chance that within the first few seconds I will be at the board**,** and they will be at the board and we will be drawing stuff. Drawing and writing out stuff is so central to physics that I feel likely the auditory part is almost secondary.

When I consider Jason's dedication and commitment to teaching science, especially the topics related to force and motion, I expect he will be able to find resources and generate strategies to work with students who may have physical disabilities such as a visual impairment.

A summary of the story of Jason's teaching is presented in Appendix F, on pages 414 to 433.

PART III: THE STORY OF MONICA'S TEACHING

4.8 Monica - An Introduction

Monica is a secondary school science teacher who has been teaching in junior high schools for an Albertan school board for the last 14 years. She started her teaching career as a substitute teacher in 1996, then received some temporary teaching contracts before accepting a full-time teaching position. Since starting her full-time teaching career, she has worked at three different junior high schools, and has been working in her current school since 2003.

Monica knew early that she wanted to become a teacher, and completed a four-year concurrent BEd Program in 1993, which is a combined degree program after completing high school. She wanted to become a math teacher and so she selected secondary mathematics as the curriculum specialization in her BEd Program. During her practicum experiences, she taught *only* mathematics. In her words, "All of my university education was geared towards math education because that is what I wanted to be, I wanted to be a math teacher."

Even though trained to teach secondary school mathematics, Monica taught science at the beginning of her teaching career, and continued to teach science throughout her teaching career. Monica explained that when she completed her BEd there were not many full-time teaching positions available for beginning teachers, and so she took contract work that happened to be in science. She explained the situation,

> The only way to get into the school board at that time was to take any type of temporary contract you can get, because the jobs were so scarce. So, I was fortunate enough to get a maternity contract. . . . She [the teacher] was going on maternity leave . . . and I was able to take the job. It was a three-month contract. But…it was teaching grade nine science,

> something I had absolutely . . . [no idea about]. So, I was going into this job with absolutely no science experience.

Monica shared her feelings about teaching science, despite having no passion for it. She said about this, "Science is not my first subject or my passion . . . actually math is [my passion]. I had to take the job, so that is why I got into science." Monica made the same point on many occasions during our conversations, that she likes mathematics more than science as a subject, and that within science she likes biological sciences more than physical sciences. The electives she took in science at university were also in biological sciences.

Monica felt unprepared to teach grade nine science when she took her first three-month contract, stating that she felt she was "getting into teaching it without any preparation or experience." She gave all the credit for her success during her first teaching contract to her mentor, the head of the science department. Monica described her feelings of unpreparedness and gratitude for the great mentor she had.

> I had no idea. . . . I was going into this job with absolutely no science experience. I had taken some science courses in university, besides maths, as electives. So, that kind of helped me get through the science curriculum. But I also had a lot of mentors, the head of the science department at that school was a very great leader . . . he was helpful and he… pretty much helped me [to] get through those three months. Because I had no idea about the electricity unit, and how to teach grade nine science. . . . Luckily he was a great mentor and he helped with all the labs, with all the setups, and thanks to him I was successful.

Monica called this teaching experience "learn as you go," and described it as:

> You read the textbook at night, you study it, and you memorize it . . . and you learn it, and you try to do an experiment . . . and then you go and teach the next day. It was basically just learning the material as I went . . . I did not have a lot of background knowledge, for example, in the electricity unit.

Monica did not study physics at all during her time at the university, saying that she was not interested in the subject. She commented that she believed that she was not good at physics during high school. Monica only knew about topics related to force and motion from her high school experiences.

Monica continued her graduate education, completing an MEd in 2001, and a PhD in Education in 2010. She stated that none of these experiences included any discussion on teaching force and motion ideas, but she had some professional development (PD) opportunities in science teaching during the late 1990s and early in 2000 to prepare for teaching the new science curriculum. She described the changes during that time that led to her taking the PD workshops.

> I started taking some professional development . . . because at that time there was a curriculum . . . and textbook change as well. We were going away from the "Science Directions" textbook which had the old curriculum. And around the late 1990s the new science curriculum and the new "Science Focus" [textbook] was coming out. So, I started taking more PD after [that]. There was no point in taking PD before, [because the curriculum was the same] . . . but, once the new curriculum came out then there was a push, and . . . more opportunities [were available] to take professional development.

Describing the nature of these workshops, Monica said, "Calgary Science Network (CSN) . . . started giving courses [PD workshops] . . . They had a specific [workshop for] each unit. There are five units in science now, and each unit had a PD [workshop]."

Monica first denied having any professional development to teach topics related to force and motion. However, during our conversation about CSN workshops she could recall, "Yes, there was a PD [professional development workshop] about structure and forces . . . that was helpful."

Monica had the opportunity to teach all three junior high grades (seven, eight, and nine) but for the last five years she has been mainly teaching science and mathematics to grade seven students. When asked, "How many times did you teach topics related to force and motion?" Monica explained:

> When I first started teaching we did have a unit called Forces and Motion . . . and probably I taught that a few time, maybe twice . . . because, I changed to grade nine science [and] sometimes I taught grade eight science.

Monica taught grade eight and grade nine science for a few years, before getting the opportunity to teach grade seven science again. By then the Alberta Program of Study had changed, and the Forces and Motion unit was replaced with the "Structures and Forces" unit, which she said she had taught about five times. Monica believes that the Structures and Forces unit is slightly different from the one she taught earlier. To clarify – Monica stated that she had taught force and motion topics approximately seven times during her 14 years of teaching across the junior high grades.

Monica differs from the other three participants in this study in terms of ethnic, cultural, and language background. She came to Canada as an immigrant with her family at the age of 5 and started her Canadian life and education. Monica is now fully integrated into Canadian life and is proficient in English, speaking with no accent. She is also a basketball coach at her school. She is a visible minority, but believes she is no different from any other average junior high

school teacher. However, she acknowledges that she does bring knowledge of her cultural background, of course, that is also reflected in many Canadian schools. In fact, multicultural approaches in science learning was the topic of her doctoral dissertation.

4.9 Monica's Orientations to Science Teaching

The conversations I had with Monica about her experience as a junior high school science teacher and as a learner of science in high school provided insight into her orientations to teaching force and motion topics. This included uncovering her need and rationale to follow, or not, the teaching practices of her own science teachers. We also discussed what she found to be effective instructional strategies for these topics. Monica appears to emphasize inquiry, discovery learning, and conceptual change as her orientations to teaching science:

4.9.1 Inquiry

Monica appears to change from a traditional science teacher to an inquiry orientated teacher, and stated her reasons for this change. Monica shared her insecurities about teaching about force and the whole unit, during the early days of her teaching career. She admitted giving her students lots of notes, and using less hands-on activities. Monica realized and described the flaws of using traditional lecturing in teaching these topics:

> Well if you just give a definition . . . or a worksheet, and say you know force is a push or pull, and it is measured in Newton . . . and spring scale or a force meter is a device used to measure it. . . . Then you move to the next idea, some of them will get it but half of them, or more than half are not going to understand it, and they are not going to retain it. They are just going to memorize it.

However, with the passage of time as she developed a better understanding of the concepts of force and motion, Monica was able to use inquiry in her teaching of these topics. She stated that

[now] she believes and practices inquiry as her teaching philosophy. She described inquiry as helping her students explore force and motion ideas through hands-on activities, instead of using notes or telling them what these ideas means. She uses inquiry activities, ranging from structured to open-ended activities. She said that she uses hands-on activities to help her students explore these ideas and formulate their own conclusions. Sometimes, she simply asks questions and engages students in discussion about their ideas related to force and motion, to help them construct these ideas themselves.

4.9.2 Conceptual change

Monica also shared her concern that sometimes her students have alternative ideas about force, which is an abstract concept. She explained how she tries to move them to the scientific ideas and described what she would do to facilitate conceptual change for her students:

> So, . . . with concepts [which] . . . are so abstract to them [students], and they do not see them every day, and their definition is different from what the science definition is, [then] . . . you actually have to do activities . . . instead of just saying that this is [a force], otherwise . . . the learning is not going to happen. . . . I am actually going to get them play, and try to figure out things on their own.

4.9.3 Monica's own science learning experiences: Influences on her orientations

Monica shared her own experiences as a science student, which may have guided her to become the science teacher she is today. She said

> Luckily, I had enough good teachers that . . . wanted to inspire what they instilled in me. . . . They used hands-on materials, and they made you question what you were doing and why you were doing it. They made the course and subject interesting. I really got interested in biology, I got interested in chemistry.

Talking about her science teachers, she said, “I had an amazing chemistry teacher. . . I think she was vibrant and made the subject interesting . . . [but] the physics teacher . . . was not an interesting one.” Monica stated that she was good in physics, and according to her, the reason was that she was “very passionate about math, and physics has lots of math in high school” and that she had “a math teacher who was very interesting and helped [her] . . . with physics [too].”

In reference to her own experiences in learning science, Monica said, “I do not remember lots of exciting science classes in junior high school. . . [or]. . . an AHA moment where I loved science. . . but high school was better.” Explaining her reason for liking high school science, she said, “You had that lab component and the teachers . . . know their discipline, and they know their subject matter really well. So, that makes a difference.” She said that she “went into the sciences and math in the university because . . . of high school, [where she] . . . had some good teachers.”

She also made a comment that “the way we teach now is different, our mindset and the kids we have [are different], and the way we teach now is a very non-lecture approach,” which indicates that she may have experienced teaching that was predominantly lecture-based. However, she recalled “doing different labs and . . . activities on acceleration . . . using ticker tape,” mostly from high school. It is interesting to note that in her initial career as a science teacher, when teaching content she was not very comfortable with, she used lectures and gave students notes, but later described that she changed to activity-based and student-centered teaching approaches.

Monica appears to believe in the importance of developing a conceptual understanding of science topics. Therefore, she put effort into understanding the science content before teaching it to her students. She repeated this belief and her efforts to achieve this, during our conversations

about all the topics. For example, when asked about the topic of acceleration, she highlighted the need first to understand it conceptually herself. She emphasized that without this, she would not be able to think of ideas and activities to teach the topic to the students.

When I asked Monica about whether teachers' academic backgrounds influence their decision about going (or not going) into the depth of a science topic, she stated, "the unit I like the most, I teach the best, and I spend the most time on." She further noted that:

> I love the plants unit; I love the heat and temperature unit; I love the ecosystem unit. But,[structures and forces] unit . . . I do not teach…well, because I feel that I am not as knowledgeable as I should be. I mean, I can make them understand some of the concepts, but my subject matter knowledge of the content . . . , I do not know it as well as I know or.. can teach plants or ecology. . . . I do not need a textbook, I do not need notes, [and] I can pretty much come up with the activities. But, with some of the units, especially this one, unfortunately because I am not passionate about it, I tend to do it superficially sometimes.

4.10 A Profile of Monica's PCK Related to Force and Motion Ideas

As noted above, Monica—a junior high school teacher with 14 years of experience in teaching—entered into the world of teaching science with little formal science preparation. She indicated that she felt even less prepared to teach topics related to force and motion because she did not take any physics courses at university. While passionate about teaching mathematics, she nonetheless accepted an initial position as a *science* teacher to gain and retain a teaching position. She found great mentors and survived science teaching at the beginning of her teaching career. Later she developed knowledge and skills of her own to excel in teaching science. However, there are a few topics in science Monica finds difficult and not very interesting to teach: force and motion is one of those topics. She has taught this topic roughly

seven times at the time of our conversations, and she has been teaching these topics to grade seven students consecutively for last five years. The following 10 sections present my interpretation of our conversations, creating a profile of Monica's pedagogical content knowledge (PCK) for teaching force and motion ideas.

4.10.1 Monica's views and understanding of the force and motion concepts

Monica highlighted the need to understand the science content knowledge involved before teaching it to the students. In her words, "To bring some kind of understanding to my students . . . [I need] to find out these things myself [first]." To do so, Monica developed her own understanding of the topics related to force and motion while preparing for planning and teaching these topics—a way to offset her own lack of formal study of these topics. She said that she tries to instil the same ideas that she developed to build her own understanding, to help her students conceptually understand the topics related to force and motion. She also learned about how these topics are connected with each other, to provide a logical sequence for her students to conceptually organize these topics, which was evident from our conversation.

What follows are a breakdown of eight concepts that provides a view of the breadth and depth of Monica's content understanding of the force and motion ideas. I will close this segment with a discussion of the implied learning progression sequence that Monica invokes to teach this material. This will be followed by a description of her sequence for presenting these ideas, which reflect her approach to organize these ideas she deems most fitting for this material

4.10.1.1 What is a force?

Monica used the standard definition of force, that force is a push or pull, when she described her understanding, noting that "when you [are] pushing something or pulling something, that is a force." Monica stated that to build her own understanding of force, she

"go[es] with what the textbook says." So she "read[s] through the curriculum, and . . . the textbook, and . . . understands [it]." If the textbook does not help her understand the concept, Monica said that then she "go[es] to other sources."

4.10.1.2 What does a force do?

Monica thinks that a student understands the concept force only if she or he knows what a force does and is able "to show" this. By this she means that her students should be able to demonstrate a force, wherein she expects her students to "actually . . . physically use a desk or move something . . . [and say that they are] . . . pulling it or . . . pushing it." She also wants them to understand that "Newton is the unit for [measuring] force."

4.10.1.3 Different types of forces

According to Monica, in addition to the idea that force is a push or pull, "you [can also] look at how force can impact objects." And based on this impact, we can differentiate different types of forces. She suggested that "force is a very general term . . . [and] you have to be specific. . . . So, you [should] use words like compression, compressive strength, bending force, or tension." She also proposed that to demonstrate force, "you [should] show [students] . . . what tension forces are, what compression forces are." She asserted that she "talk[s] about specific types of forces." Finally, Monica noted that there are four types of forces, which include, (i) compression force, (ii) torsion force, (iii) tension forces, and (iv) sheer force. In addition to these, she also considers that friction and gravity are also specific types of forces.

4.10.1.4 Internal and external forces

In the context of the Structures and Forces unit, Monica wants her grade seven students to understand why structures fail, and what role forces play in strengthening or weakening a structure. She further explains that when creating structures, compression, tension and torsion are

internal forces but that there are external forces as well, which may be responsible for a structural failure. Monica described a hands-on activity she uses in her class to teach her students about creating and testing structures for strength:

> We talk about internal forces, . . . external forces, . . . metal fatigue, [and] . . . why structures fail. . . . [Students] will come up with ideas . . . when they are designing and testing [their structures] . . . [that they] need more support here . . . [and they] need to have a base there . . . [and they also] need to know why did [their] structure fail?

Monica said that her students "have opportunities . . . within the parameters to rebuild [their structures] so that they can apply their knowledge of internal and external forces. She elaborated that her students "come up [with] some amazing ideas . . . [about] where the deficiency is, and how to make it improved . . . by raising [a part of the structure], by supporting [a certain part of the structure], [or by knowing] . . . how much it weighs . . . , what is the load, and how much it is supposed to carry?"

4.10.1.5 Friction

When talking about a conceptual understanding of friction that she aims to convey to her students, she told me that she "talk[s] about friction as two surfaces rubbing against each other [and] . . . how friction is needed to slow down motion." She thinks that junior high school students should be able to understand, "what friction is . . . where we see it . . . [and] why we need it."

4.10.1.6 Gravity

Gravity "is a force. . . a gravitational force, [which] is basically a pulling force," as Monica described it. She wants her students to understand this concept, that it "pulls objects towards the center of the earth."

4.10.1.7 Acceleration

Monica noted that the topic of acceleration is not "in the textbook, and it is not in the curriculum, so we do not discuss it . . . as a [separate] topic." On reflection, she added that it does become part of the class discussion at times. She stated that she has "a vague understanding of what it is." She explained her understanding of acceleration in these terms: "It is when an object is in motion . . . [and] the speed of the object is changing, so it is accelerating, it is moving faster or slower depending on . . . the forces exerted on it." Then she paraphrased, "So, . . . [an object] is not moving at a constant speed. Either [it] is slowing down or speeding up, depending on the force that is applied." Monica definition could have been perfect by using velocity instead of speed, and adding rate of change of velocity, as compared to change of speed.

Monica affirmed the importance of the topic of acceleration, and said that sometimes it does come into discussion while teaching about friction. In her words, "We discuss it, [during the real world example of friction] . . . when you are driving a car, and you need good tires. . . [We] talk about speeding up and slowing down [of the car], and why [or] how acceleration . . . is related to friction."

4.10.1.8 Newton's laws

Again, Monica pointed out that Newton's Laws are not part of the junior high science curriculum, and she does not teach it directly as a topic. However, she said that sometimes there might be a mention of the topic. Recalling her experience with the old science curriculum, Monica commented, "I know from previous textbooks. . . Newton's first law . . . [states that] an object at rest stays at rest and an object in motion stays in motion unless something counteracts that motion."

Monica stated that if she had to teach Newton's laws of motion, then first of all, "I think . . . I would have to research them . . . and I [would] try finding videos or internet sites, or activities that the kids can do."

4.10.1.9 Sequencing these topics

When presented with a tentative list of topics related to force and motion that I prepared after reviewing the Alberta Program of Studies, Monica selected a number of them that she felt comfortable talking about. These are topics that were just discussed. She also had an opportunity to suggest additional topics in our discussion, others not present in the list, but she chose not to do so. Still, she did talk about concepts relating to structures and structural failure while talking about force. Interestingly, she did not propose a specific sequence that she uses to teach these topics to help her students develop a better understanding of the topics, although she mentioned that she follows the science program of study at various points. Therefore, it is not possible to explicitly identify Monica's learning and teaching sequence for the force and motion topics.

A careful analysis of my conversations with Monica about her teaching of force and motion ideas, does however provide insight into how she organizes these concepts for teaching. By considering the order of topics that Monica implicitly followed during our conversation, I have been able to draw out a likely learning and teaching sequence she may use for these topics. Monica suggested the beginning point for her teaching of force and motion ideas, when she said:

> I start with [the concept of] . . . what is a [force]? . . . [Then I] start getting into different types of forces, [and then] actually show them [these forces]. . . .[such as when] something falls on the ground . . . that is the force of gravity.

So, Monica starts her teaching with the *idea* of force, facilitating an understanding in her students that force is a push or pull. She helps her students by having them demonstrate what a

force does. As a way into this, *she* demonstrates to them pushing an object and pulling an object. Monica noted that force is a general term, so now she prefers to discuss force in particular terms, like compression force, torsion force, tension force, and sheer force, and explains these to her students these as different types of forces, based on the way content is presented in the *Science Focus* textbook, which she uses.

Being a grade seven science teacher for last five years, Monica has taught force mainly in the context of structures, extending her idea of what a force does. She gets into a further distinction between types of forces: internal and external forces. She considers compression, tension, and torsion as internal forces, and discusses these in the context of various structures designed and created by her students. These become measures to evaluate the strength of their designs.

In terms of what a force does, Monica includes a discussion of the topics of friction and gravity, and teaches these also as types of forces. She is aware that the topics of friction and gravity are included in the grade eight science unit Mechanical Systems and the grade nine science unit Space Exploration. As she is not able to go into deep discussion about these topics while teaching grade seven science, this is not a problem from her perspective. Monica has some experience of teaching the old science curriculum, including a grade seven science unit called "Forces and Motion," and she could sustain a discussion about motion as a result of the application of a force causing acceleration. She does not have recent experience of teaching acceleration and Newton's laws, as these topics are not included in the current grade seven science curriculum. However, Monica is able to present an understanding of these topics, though she described this as "vague", but also imagines she could teach these topics if she had to after doing some preparation.

4.10.2 Monica's views and understanding of students' alternative ideas

After years of experience of teaching science, specifically teaching topics related to force and motion, Monica has developed an understanding of her students' difficulties and learning needs in these topics. She also has come up with some strategies to uncover her students' naïve ideas causing problems in learning these topics, and she has discovered ways to help them overcome these problems by changing those alternative ideas. This section provides an account of Monica's understanding of her students' alternative ideas about force and motion topics.

4.10.2.1 Everyday meanings of force

On various occasions during our conversations, Monica showed concern that her students have alternative ideas about abstract concepts like force. She identified one such example where her students have their own "everyday definition of force" and according to her "what they think of force in their real life is not exactly what the science meaning is."

Monica described the strategy that she uses to deal with her students' alternative ideas, which I believe is inspired by constructivist learning philosophy. She starts her teaching of force (and other topics) by "giv[ing] them a couple of questions at the beginning, about what they know [about the topic] . . . [to assess] what their prior knowledge is." She further explained, "I try not to tell them if they are right or wrong . . . I try . . . [to] get as much information as possible." According to Monica, "If [the students] have any misconceptions," that is a starting point for her teaching.

4.10.2.2 Students' diverse learnings backgrounds

Monica notes that junior high school students are able to understand friction because, she proposed, "They come with pretty sufficient [prior understanding]" from previous grades. In her words, "I do not remember if I ever had a problem teaching friction." Monica wondered if

friction is an easy concept for junior high school students because "they can actually visualize, [and] they can see [it]." She believes that friction "is not as difficult as . . . [concepts like] weight and force" that are abstract in nature. Monica asserted "friction is something that they can see in everyday life, whether it is tires, or whether it is runners." She maintained,

> I think it is easier for them to understand what friction is, and how it works, compared to some of the other concepts that they have to learn in this unit. So, I think it . . . in terms of . . . their level, and their age . . . they quite understand it.

However, she also observed, "They all come with a variety of backgrounds. . . . [It is unlikely that] everybody got the same information." As a way to deal with the diverse learning backgrounds of students, Monica suggested that, "it is really important . . . at the beginning of any concept that you are teaching . . . to find out what their prior knowledge is, and then go from there."

4.10.2.3 Gravity and diminishing gravitational pull

Talking about her students' prior understanding of gravity, Monica said that "the kids have a pretty good idea about what gravity is, when they come to the classroom." She further stated that "if you drop something on the floor . . . the kids pretty much know that is gravity . . . , gravitational pull." She added, "For the most part it is pretty self-explanatory, all of the kids know, they have a pretty good idea of what it is."

In response to a query about how she knows that her students have an understanding of what gravity is, she maintained that "they are able to provide enough examples that . . . [show that they] have this understanding about gravity." She did express her concern that "the only difficulty that they [usually] have is . . . when we move away from the earth, the gravitational pull decreases, [and] that is something they cannot conceptualize, because they cannot see it."

Monica explained, “When you just try and tell them . . . the gravitational pull on the moon is less than [that on] the earth [and this] . . . is because the earth . . . has a larger mass than the moon. . . . They do have . . . difficulty with that, but the actual gravitational pull on the earth, they can understand it.”

4.10.2.4 Mass and weight are the same

Monica also identified that her students have problems understanding that mass and weight are two different concepts. In her experience, students confuse these two concepts. In her words:

> They think mass and weight are the same things. In the everyday definition, they might not say, what is your mass, but, how much do you weigh? . . . But mass and weight in science terms are different. Mass is . . . [the] amount of matter in an object [and is measured in] . . . kilograms, where weight is a gravitational pull, [which] . . . is [measured in] Newton. So, they have a tough time understanding those two concepts.

When asked what strategies she uses to deal with students’ confusion about mass and weight, Monica shared an analogy she uses along with introducing the term “weightlessness.” She stated, “This [weight] is a concept . . . [that is] . . . abstract for them, so you try and give them the analogy [that] if they are travelling in space . . . their weight changes.” Monica shared that “there are some internet websites that [she uses] for teaching the concept of gravity.” She also mentioned using The National Aeronautics and Space Administration (NASA) website, but also noted that she uses other websites as well.

4.10.3 Monica’s repertoires of instructional strategies

With her many years of teaching science, and consecutively teaching force and motion for the last several years, Monica has developed a repertoire of effective teaching strategies, which she

calls her teaching "toolkit." Specifically in regard to effective strategies to teach about force, Monica compared two teaching approaches. First, she conveyed the disadvantages of a type of teaching that I understood her to mean is a teacher-centered approach. She said about it:

> If you just give a definition . . . and [tell] that force is a push or pull, and it's measured in Newton . . . and the device which is used to measure it [is] . . . spring scale or a force meter.

Then, in contrast to this approach, Monica suggested using hands-on activities for learning to happen for abstract science concepts (details provided on page 239) in the conceptual change section). I think she is suggesting that a student-centered approach should be adopted for abstract science concepts, by using activities that help students confront and modify their naive ideas about these abstract concepts.

What follows is an overview of the general and topic-specific teaching strategies that Monica spoke about in some detail, and that she believes help her students better understand forces, structures and motion.

4.10.3.1 Cooperative learning

Monica appears to encourage her students to work collaboratively to support cooperative learning in her classroom. She described her strategy of dividing her class into groups when they are doing various activities to learn about force. She shared an example of using group work when teaching her students about different types of forces:

> I break them up in groups where each [group] has to . . . demonstrate . . . what force is, [by demonstrating] . . . the different types of forces. [For example] . . . what is a tension force, [or] what is a compression force].

She described that sometimes she breaks the class into groups, and each group has to demonstrate one type of force. She encourages her students to "demonstrate [force] by cutting a piece of paper to show sheer force or [by] . . . pull[ing] a string [to show] . . . tension [force]."

Then she referred to the jigsaw technique, an advanced cooperative learning strategy, where students must rely on others in the class to maximize and complete their learning. She further explained that she has used the "jigsaw [technique]" where all the groups mastered one type of force, and "then each [group member] will teach each other what this [specific type of] force is."

4.10.3.2 Using questions

During our discussion of teaching about force and motion, Monica described the process of facilitating her students' learning using various types of questions. She descried using question at various points: (a) at the beginning of her lesson to identify students' alternative ideas, (b) during an activity to engage her students' thinking, and (c) towards the end of an activity to help them formulate their understanding.

Monica stated that she usually begins her science class by directing a few questions to her students. This lets her assess what her students already know about the topic or any misconceptions they hold about the topic. She tries to gather as much information about this as she can without letting on whether the students' answers are correct or not. Then she introduces hands-on activities and let her students explore the ideas first, and then asking various questions help them construct new knowledge during the classroom discussions following these activities. Referring to her teaching about gravity, she claimed that she first shows her students "something [that] falls on the ground" and then she asks questions, "What is that? What causes this thing to

fall on the ground?" She asserts, "You can talk about gravity but unless they see it . . . in some kind of context, they do not understand what you are talking about."

Monica told that she usually concludes an activity with "a summary at the end" where she initiates a discussion by asking questions that she calls "how or why questions." For example, "What did you find? What worked [and] what did not work?" and "Why did it not work?" Monica further claims, "I try to make it inquiry-based as much as possible . . . [and] I really try not to give them notes [answers]."

She affirms that she seldom gives notes in her class, but if she has to, these are "very brief" to guide her students' learning process.

4.10.3.3 Hands-on activities

Monica stated, "Force and Motion or Structures [and Forces] units are really hands-on units." She said that, "you can get [students] to come up with really creative ideas" using hands-on activities to teach these units. Monica told that she uses a hands-on activity where she makes her students measure the force. She explained that her aim is to teach her students "about Newton [units of force] and measuring how many Newton this object weighs." She said that she uses "spring scales . . . [to] get them [her students] . . . to measure [force]."

Talking about a typical class of hers where the students were considering the idea of what a force does, Monica said, "I will introduce a concept but before I give them the actual definition . . . I want them to explore on their own what these forces are." She described that she uses "an activity to teach [various types of forces]: compression, tension, torsion, and shear." She uses "different sort of objects . . . [for example] . . . a sponge, a rope, a pair of scissors, and a paper." After her students "have tried all these . . . activities", she talk[s] about what compression is . . . and how it works." According to Monica, her lesson is designed "to demonstrate [different types

of force].” She stated that after completing the demonstration, “then I give them the scientific definition.”

She described another hands-on activity that she used to help her students explore the idea of force in context of structures. She gives them a piece of paper and says, “Build me the tallest tower,” and then she lets them build their tower. Once they have built their paper towers, she conducts a discussion about design, using guiding questions like “What problems did you have building this [tower]? How would you improve your design?”

She discussed a modification of the above activity where she has used the same hands-on activity but asks her students to “Build a golf ball bridge” or some other type of specific bridge. Describing reasons for this modification, she said, “[The unit] is lot about building bridges, so I give them straws and tape and all the materials, and then they build a golf ball bridge.”

Monica stated that she usually does this activity in groups, and claimed that these hands-on activities “really allow them to not only learn the concept but also work in a group, and . . . learn about all the materials and what is going to make this design better or worse.”

4.10.3.4 Inquiry activities

Monica asserted that her teaching of the topics related to force and motion is inquiry based. When asked to describe the structure of such an inquiry-based class, Monica stated that she “just lets them come up with their own questions [and] methods, and try different things . . . [to] come up with their own conclusions.” She said that she avoids “giving them a recipe” where they know “what to do . . . what is going to happen . . . [and] what the outcome is going to be,” by which I understand her to mean to avoid structured or close-ended inquiry. She admitted that she also uses structured inquiry “sometimes but not all the time.” While using such structured inquiry, Monica described how she uses a pre-designed activity sheet, which “includes [sections]

on questions, hypothesis, data, observation, etc." She added that she tries "to mix it up as much as possible", which suggests to me that she means using inquiries that are both open-ended and structured.

***Friction*.** Monica stated that she uses an inquiry activity in her class to teach about friction, where she uses various material resources, including "a number of balls . . . [and] different surfaces." She uses "a smooth surface . . . [and] a surface with . . . bumps" on a ramp. She said she brings enough materials for the students "to build the ramp [using] the materials . . . that they test." They use "a piece of wood that is smooth" to make the ramp surface smooth and sand paper to make it bumpy. She said that she makes her students "measure the distance and time it takes . . . for these balls to go down this ramp, and see what the difference is" when the ramp surface is either smooth or bumpy.

At the end of this activity, she described how she usually has a discussion about how "the smooth surface work[s] versus a rough surface, and how it affects the motion [of the balls]. Monica described this activity as "more inquiry-based" and said that she would "rarely get up and lecture." For this activity, Monica said she prefers to use her own collection of materials that she has acquired for this purpose, rather than using a pre-designed kits available.

***Gravity*.** In order to explain the activity that she commonly uses to teach about gravity, Monica told me how she makes her students drop various objects from a certain height, and observe that all the objects hit the ground at the same time. She pointed out, "Then they come up with their conclusions. . . . That is . . . a pretty important concept and . . . I let them . . . try and figure it out." When asked about the kind of objects she usually uses for this activity, Monica responded, "Anything from lightweight objects to a book, a ball, a piece of wood, a feather, and then they are amazed that they fall at the same time."

Building a structure. Monica stated inquiry-based approach to teaching is well suited for "[abstract] concepts like force [because] . . . you want that they can actually look at, or play with or try [things]." According to her, force "is very foreign to [students], because [they] do not see it day-to-day. Unless you actually use some kind of demonstration or lab activity to make the concept click . . . they are not going to understand it."

Monica said that after her students complete the inquiry activity of "designing [a bridge or a tower, we talk about stability [of the structure] . . . balance, and loads this bridge or tower can hold." She asserted that she builds on the students' "ideas about compression, tension, and twisting forces. . . [and tries] to use the concept of . . . internal and external forces." She said that she "shows them a real-life example of why it is important to study force . . . [and] how it affects your design, how it affects the materials you use." Monica noted that while building their bridges, her students learn "what kind of the things you have to look at. You know, the weight of the bridge, the objects that are going to be travelling on the bridge. You talk about what types of forces are going to [impact] . . . that bridge."

When I engaged Monica in further discussion about the need to demonstrate push or pull in each of these types of forces, she said that "the science curriculum is so packed, we never really get the chance to go into a lot of depth . . . because we have so many other concepts to cover." She expressed her concern that sometimes she just give her students "a little taste of . . . physics and then . . . move on to other concepts," such as ecology, plants, or heat and temperature. She believes that in senior high school "they go into more depth" because they have specific physics, chemistry, and biology courses.

4.10.3.5 Using real world examples

Monica stated that it is important to make connections between science concepts and the way these concepts work in everyday life situations. The following everyday life examples are those she identified and shared during our conversations about her teaching of force and motion topics.

***Runners and snowshoes*.** When teaching about friction, Monica said she would ask her students: "Where do you see friction?" Then she used specific everyday examples such as runners and snowshoes, and asks her students, "When do you wear runners [or snowshoes], and why [do you wear these]?" She said, "Runners have certain materials on the bottom . . . that allow them to grip the floor," which provides "enough friction . . . [to] avoid slipping." She concluded, "This is [an example of] good friction."

***Rubbing hands*.** Monica commented that it is possible to demonstrate friction for the students and shared an example. While rubbing her hands together, she said, "[When] you get your hands together, you create friction, which creates heat."

***Winter tires*.** Monica stated that junior high school students need to understand "why [friction] is important," so to do that she uses example of winter tires. She encourages her students to think about friction by asking them, "Why do you need to have good tires on your car in the wintertime?" Monica explained that she expects her students be able to answer, "because there is a resistance to motion."

***Canoe*.** Monica said she asks her students, "What are the forces on the canoe, and why is it able to float?" She then discusses with her students "the pulling force of gravity and the pushing force of the buoyancy of the water . . . [to] give them an idea of how things float."

Monica made the point that she does not remember any examples of "this sort of teaching from her own experience" as a junior high school student and that most of the examples she uses for teaching about friction are the result of her own research, study, and preparation for teaching.

4.10.4 Monica's views, knowledge, and use of teaching resources

Monica shared some teaching resources that she knows of that she has found effective for teaching about force and motion. The following sections present these resources.

4.10.4.1 Inviting guest speakers: A scientist in the classroom

Monica said she invites "guest speakers . . . like engineers . . . from Calgary Science Network (CSN), the scientist in classroom program." CSN is an organization committed to improving science education. They offer professional development workshops to science teachers, but more than that, they also match volunteer scientists and engineers at CSN with the science teachers' requests for classroom presentations that provide engaging activities and talks about science topics for the students. Monica attended some of their professional development workshops, which included the one to prepare for teaching the structures and forces unit in the new science curriculum. She also utilized their scientist in the classroom program for engaging her students' thinking about how science works in the real world when building structures.

4.10.4.2 Using the internet

Monica stated that she finds the Internet an excellent teaching resource and, when necessary, gets immediate help from it to prepare for teaching. She said that she used it for quick help to find an interesting video, PowerPoint, or teaching ideas for teaching force to "grab her students' attention." She also noted that she used Internet searches to understand some of the science topics, which are new for her.

4.10.4.3 Using low-cost materials

Monica communicated that she uses low-cost material resources for her students to build different types of structures. Depending on the nature of the unit, she said, “You can do a lot of stuff . . . with different materials . . . like a carton . . . straws, [and so on].” She said that she collects different materials that they can use to build “different structures . . . everything from a paper tower to a bridge with straws.” She asserts, “You can do different things [with low-cost materials] . . . you can try building [structures] with these. . . . It is quite amazing, if you give [students] an idea and you just let them . . . work, they come up with some quite amazing . . . designs.”

To make this activity more challenging, Monica stated that she “give[s] them specifications or parameters” about what materials they can use, or how much of the materials they can use. In her words, “I will say, you use only thirty centimetres of tape, or you only get five pieces of paper.” She also clarified that she keeps the activity entirely open “in terms of the design [and] they are pretty much allowed to do whatever [they want to]. . . . They have opportunities, within the parameters, to rebuild and . . . they come up some amazing ideas by raising it, [by] supporting it.” She recalled that she also talks about “what is the load and how much [weight] it is supposed to carry, . . . where the deficiency is, and how to make it improve.”

She also stated that she uses low-cost materials in the semi-structured inquiry activity (she previously discussed) to teach about friction, where she used balls, piece of wood, paper and other items.

4.10.5 Monica’s views, knowledge, and use of technology

Monica mentioned above using the Internet, an information technology, for teaching concepts related to force and motion. When further asked for other technologies she uses to teach

about the idea of force, and how she integrates these technologies in her teaching, she shared the following:

4.10.5.1 Using online simulations

She has used an online simulation in her science class to help her students better understand forces and structures. In her words,

> There are a few websites…there is Big Building [http://www.pbs.org/wgbh/buildingbig, which is] . . . on different types of forces. . . . [It] talks about the different types of materials, it talks about loads, it talks about shapes, and all kind of things that you need to know when you are designing something.

4.10.5.2 Using the SMART board

Monica said that she uses a SMART Board for teaching about forces. She said she also "lets them [students] . . . teach the class . . . using the SMART Board." In other words, when they are talking about the design and how they built it, they "actually draw their design on the SMART Board so the other students can look at it and critique the design."

4.10.6 Monica's views and understanding of the science curriculum

During our collegial conversations, Monica presented her views about the current science program of study, the way she uses it for planning, and teaching force and motion ideas, and what criticism she has of this particular unit.

While presenting her opinion about the purpose and value of the science program of study (POS), Monica said that it "basically gives us guidelines of what the students are expected to know." However, as discussed above, Monica takes textbooks as an essential part of the prescribed curriculum, noting that "textbooks also give us ideas, what students are to know." She explained that "based on those [both POS and textbook] we follow the guidelines."

Monica said, “I use the curriculum as a guide but I try to put my own evaluations and my own thinking into it.” She also explained, “There is enough flexibility . . . that we are able to put our own interest into it as well.” In light of this, she spoke about her personal experience, in which she included a session on “the structures of the world.” According to Monica, this “is a small piece in the curriculum [and] in the textbook.” However, she affirmed that she pays attention that her students “explore . . . not only the structures that are here in North America but . . . look beyond North America, and look at all the structures globally.” Monica added, “There are so many amazing structures out there that they can look at.”

During a discussion about the way the units are set up, Monica expressed her opinion that “there is not a lot of continuity” in the Alberta POS. She said that “it is good that we have new things everywhere, because . . . if you repeat a lab, or an activity that they already have seen in grade five or grade two, then . . . some kids . . . [will say] . . . ‘Oh, we have already done that, [or] I already know that.” Monica said that she intentionally tries “not to . . . repeat too much . . . in grade seven, eight and nine.” Monica is aware of the disadvantages of this type of setup, and said, “The way the units are set up, I feel . . . they are like pieces . . . that is one of the downsides of this curriculum.” She clarified the impact of this downside:

> [We] teach them bits and pieces of all these different types of sciences, that they can explore . . . [so they can] . . . differentiate and discover what they want to do in high school. [But] we are not really building on a lot of ideas—like plants is kind of a separate unit. We have ecosystems that is kind of a separate unit. Then structure and forces is a separate unit. But luckily, mechanical systems ties into that. But, in grade nine there is nothing really that links what we have done in grade seven and eight. I mean, we have electricity and they have never seen anything in grade seven and eight [about it] . . . and

> then all of a sudden you have space in grade nine, which [they have] never heard [of] before. So, I find that part of the science curriculum…in the way Alberta Education has set it up . . . I find a bit difficult to understand.

Monica said that if she had an opportunity to design the science curriculum, she would "have more continuity, so that . . . you [can] build on [ideas]." She further expressed her unhappiness with the current science curriculum setup, and said, "I do not understand why we teach [these units] the way we do . . . but that is the mandate."

For Monica, the chief reason to include the topic force in junior high school is the "level of understanding . . . and readiness." She thinks that force is an abstract concept and that it is included at this level because they are able to understand "some of these abstract concepts."

Monica mentioned that there is some continuity between the grade seven unit Structures and Forces and the grade eight unit Mechanical Systems. She talked about how students can build on the ideas of force in grade eight. To highlight continuity as a goal of teaching science, I asked her if there were other topics or units they need to build upon to understand force. Monica recalled the old science curriculum and the unit on force and motion in grade seven, and said,

> I liked the old program. . . . It expanded a little bit more about types of forces . . . buoyancy and gravity, where we do not do that anymore. But I think they need to know some [of these] concepts . . . because when they get into Science 10, they are going to have this whole introductory lesson in physics . . . It would be more challenging if they do not see . . . this abstract stuff beforehand. I think that would be more challenging if they have never seen, they have never heard of Newton's Laws, or force . . . Then in grade ten, I think that will be more challenging. So, at least if we . . . introduce these

> ideas early, and then when they get to high school, at least they will have some notion of what these ideas are about.

Monica expressed her feelings about the lack of focus on the history of science. In her words:

> One of the problems with . . . the curriculum is, it is [so full of] . . . facts and figures, and laws and theories that sometimes we forget the human component, the people and history behind all of these discoveries. So, that is something missing in our curriculum for sure. . . . We never get a chance to get into the historical aspect of how this idea came about . . . I mean, we mention Newton, but do we ever get into any depth about him . . . or James Joule or . . . I mean, other than recognizing that these people came up with some of these concepts. I think that is a problem with our curriculum.

4.10.7 Monica's goals of teaching force and motion

Each curriculum is tied in to individual goals, but teachers also have their own interpretation of the goals of teaching particular topics. During our conversations about her teaching and planning of topics related to force and motion, Monica shared her personal goals of teaching these topics to junior high school students. When asked, "Why it is important for junior high students to understand friction?" she responded that it is important for them to understand "how friction is important in real life." She provided an example:

> If you have a car and if you do not have enough oil in there, then the pieces rub together, they cause heat. So, what's wrong with that? Well . . . your car can get overheated and . . . that heat can damage parts of the car. I think [that] in terms of real-life examples friction is important, and that is pretty much how I will look at it.

When I asked about her critical view on the way the topic gravity is included in the POS, she shared her views and ideas about the goals of teaching this topic to junior high school students. She responded simply:

> Like I said before, it is a concept that needs to be covered; it is in the program of studies. And we need to make the kids aware of this concept as best as we can, even though we do not have a . . . full understanding of it. [We] just need to . . . introduce the idea of gravity and gravitational force . . . so that if that term comes up again they would be able to . . . feel confident that they have enough understanding . . . to apply it.

Our discussion continued on about the concept of gravity, and the way it is included in the science curriculum. Monica said, "Yes, it is not really a concept that is well defined in the curriculum, but it is in the textbook. I think it is important for them to understand." When further asked as to whether sometimes textbooks have variations and may focus on topics not included in the curriculum, Monica offered her opinion, saying, "Yes, and even though it is not in the curriculum, I think they still need to know a little of what gravity is, and that's why I try [to talk about it]". She added that teaching about gravity is important to grade seven and eight students "because they are going to be talking about space science in grade nine, so they need to have some kind of idea [of] what gravity is." Monica further explained that:

> It is important to discuss [gravity with grade seven students], because it is one of the forces, just like magnetism or buoyancy. . . . It is important that they understand that there are different types of forces, and gravity is one of these . . . So, it does fit with what we are doing now, but it also fits with the grade nine science unit as well, and they can talk about gravity and what happens when you travel in space . . . weightlessness and things like that.

Talking about the topic acceleration, Monica said that it is a "more abstract" concept, which is why she suggests that it would be "better taught in a physics class [at senior high school level]."

Monica shared the information that in the old science program, Newton's Laws were included in grade seven science, and she believes "the reason why Newton's Laws are not discussed anymore in the grade seven curriculum right now [is] because the concept is abstract to students. . . I think [that in a] high school physics class they would be able to understand [these laws] . . . because they have a bit more understanding [after] they have taken Mechanical Systems unit." She added, "It could be maturity [as well] . . . because these concepts are so abstract, it is hard for . . . grade seven students to be able to understand some of those ideas."

Monica also commented that Newton's Laws are not part of the current science curriculum, so she does not teach them "because they are not required." She further explained, "We try to stick as close to the curriculum and the textbook as possible".

4.10.8 Monica's views and understanding of considering various teaching contexts

Monica sometimes modifies how she teaches force and motion ideas, depending on the teaching context. Below are some of the variations that have occurred for her.

Schools: Monica had the opportunity to teach in three different junior high schools, and said about her teaching that "it has not changed . . . between the three schools."

***Students*.** She explained that from "year to year, depending on what type of students I have . . . I do not teach the same way. . . I try different activities, [and do these] in different ways, depending on the [group of] students."

***Technology*.** She explained that she "tries to change a bit" every time she teaches a concept. For example, she has a SMART board now in class, and "[does] a lot of virtual labs online." For the same reason, she does not use the overhead anymore.

Experience. Another shift in her teaching has taken her away from teacher-centered teaching towards student-centered teaching. She said about this, "I do not give a lot of notes [now], but [do] more activities" She explained the process of this shift in these terms:

> When you first try to teach something you are not comfortable with, you give a lot of notes. You just basically study and memorize, and then you just lecture and use a lot of notes . . . but with experience you want them to try lots of things, you want them to have fun, you want them to be engaged, you want them to be excited, you want them to come and say "Yes, we got it."

She talked about her past teaching when she would see students getting bored in her class, and said, "That was a different time in my life . . . and now . . . I am totally comfortable about what I am doing, now I am trying different things . . . every year it seems like it is better."

4.10.9 Monica's views and understanding of assessment

One of the aspects of effective teaching is how we make sure that students have learned the intended concepts, and for that teachers use different ways to assess and evaluate their students' understanding. Monica shared some of the formative and summative assessment strategies that she uses to assess her students understanding of force and motion ideas.

Formative. As discussed above, Monica uses various types of questions during her lessons, one purpose of which is formative assessment. Questions at the beginning of the lesson help her to assess her students' prior knowledge of the topic. Questions during the activity help her to make sure her students are on the right track to find answers for themselves, and towards the end, her questions ensure that the desired learning goals are achieved.

Summative. Monica shared her feelings about summative assessment, stating that "unfortunately sometimes we just teach to tests." She added, "There are some topics that we

cover . . . that we are not sure . . . how to make that understanding come across . . . even though we do not have a full understanding of why it is important."

4.10.10 Monica's views and understanding of addressing student diversity

Monica appeared to design inclusive science lessons to include all her science students. She talked about many types of student diversity and the ways in which it has affected her science teaching.

4.10.10.1 Addressing ethnic and cultural diversity

Monica noted that Canada's demographic landscape is changing; Alberta had been welcoming thousands of new immigrants every year. She told that she usually teaches science to a group of students with various ethnic and cultural background. During our conversations, she reflected on her own experiences as a new immigrant child in a Canadian classroom and could recall that she was taught science from a western, particularly European perspectives. She said that she never heard about the contribution of scientists from China or Egypt. Despite doing well in science in high school as well as in university, Monica told that she did not find science interesting and useful. Therefore, as a science teacher one of her aim is to make science interesting and relevant for her students with diverse ethnic and cultural backgrounds. Monica claimed that she embraces a curriculum that recognizes, promotes, and enhance diversity in the science classroom. She shared an activity where she organizes curriculum to help her students become aware of the people and scientists from many different cultures who have made significant contributions in the areas of science.

To include students from various cultural and ethnic backgrounds, Monica tries to "incorporate . . . different types of structures . . . globally." She said, "I push them to . . . research something in Dubai and go and research something in Turkey, or [something] in Asia, or

[something] in China." By using this approach, Monica stated that she wants her students "to recognize that these famous buildings are not just in Europe and Western society, but we have famous structures all over the world, going back to 1000 BC." I think this approach used by Monica is a multicultural approach to teaching science.

In the context of teaching friction, when confronted with an imaginary situation where her students have not had experience with snowshoes or winter tires—which is possible as she always have new immigrant students in her class—Monica quickly reacted, "You are right, a lot of them probably have never seen snowshoes before." Explaining how she will deal with such a situation, she continued, "I will try to ask them, about…what they know and how they define friction. But, I would not do that necessarily until we have done some of the lab work." She explained the reason, and said she does this so "they can understand what the word friction means." She realized that it "maybe friction is not the word that they have used in their language." So, she went on to clarify that "once you do some of the different activities in class then I would say, can you give me a specific example of where friction is used in your home country."

Monica notes that ethnic-minority students bring many talents and knowledge with them in the science classroom, and it is the responsivity of the teacher to find ways to make science learning interesting and attainable so that those students can overcome barriers and success in science-related careers. She says that she helps to build a positive self-concept among her ethnic-minority students so that they can achieve their full potential.

She says that by including students from all cultural background in her science classroom, she also aims at developing scientifically literate population.

4.10.10.2 Addressing diverse learning styles of students

Monica suggested, “I think you have to understand their learning styles and plan accordingly.” She described that she developed gradually as an inclusive science teacher. She said that now she “include[s] diversity in different aspects. [For example] . . . in terms of the students and their learning if they are coded, if they are ESL.” She asserted that as a teacher “you have to take [diversity] into account.” She explained her approach to doing so: “One of the things that . . . [I] try to do is . . . to make sure that . . . [I] have a variety of ways . . . to teach it.” According to her, these variety of ways include: “writ[ing] that [information] on the board . . . giv[ing] them a small example, or . . . show[ing] them . . . so that if there are visual learners you going to try and show them how force works in real life.”

She further said, “You might have a PowerPoint, and then you might have an activity, and then you might get them to draw a diagram and label it.” By doing this, Monica is of the opinion that “you are trying to get all of your different types of learners, whether they are coded, or they are ESL, whether they are gifted, you are giving them all the different opportunities to learn the material.”

A summary of the story of Monica’s teaching is presented in Appendix G, on pages 434 to 448.

PART IV: THE STORY OF DAVE'S TEACHING

4.11 Dave - An Introduction

Dave has been teaching formally for seventeen years, sixteen of which were spent teaching under an Albertan school board, and one year in Australia on a teacher exchange program. Later, he became a science consultant in a school district in Alberta, and at the time of the interview he also had experience as a science consultant for two years.

Dave held two bachelor's degrees—a Bachelor of Science in Biology and a Bachelor of Arts in Sociology—before entering the BEd Program. He had also completed a Graduate Diploma in Environmental Studies from a university in Montreal. Dave did not take any courses in physics during his undergraduate study as all his undergraduate coursework was strictly biology and environmental sciences. After his undergraduate study, he completed a BEd from an Albertan university, qualified for an Alberta Teaching Certificate, and started his career as a high school science teacher.

Dave described his BEd program as "an introduction to inquiry-based learning." He specialized in secondary science curriculum, and practiced planning science lessons in the course on secondary science. Dave stated that he had the option to choose topics from any high school science area, and he always chose biology and chemistry, "falling back on [his] strengths." Dave shared his experience of "getting in touch with physics" when he had one practicum in junior high school during his BEd program. The other practicum was in high school biology, where he "did not teach any of the physics" during the practicum.

Dave has taken a few professional development workshops during his teaching career. He took many workshops in general science and some in physics. In one of these workshops on teaching physics, Dave said the workshop facilitator demonstrated teaching physics through

exploration and inquiry, and used formative assessment to assess the higher-level thinking of the students. The major focus of these workshops was to reduce dependency on worksheets and mathematical calculations in the physics classroom. Dave said that he modified all his exams after attending these workshops to incorporate assessments of higher levels of thinking in his students, rather than simply testing their rote memorization of physics concepts or their mathematical skills.

During his teaching career, he has taught in two senior high schools in Alberta, mainly grades 10 to 12, and one high school in Australia. Most of this time, he has taught for International Baccalaureate (IB) biology and general science (Science 10, Science 20, and Science 24). However, in Australia he had the opportunity to teach students from grades 7 to 12. In addition, Dave also has informal teaching experiences, including tutoring in science mainly to junior high school students during the first seven years of his teaching career, and later, teaching biology to adults who were upgrading their high school in colleges.

Dave, and I briefly reviewed together the science curriculum he teaches (Alberta Science POS) to see where the topics related to force and motion are included. We both noted that these topics are included at the junior and senior high school levels. In junior high, they are included in the grade seven unit Structures and Forces and the grade eight unit Mechanical Systems In senior high school, these topics are discussed in Science 10, Physics 20, Science 20-30, and Science 14-24. Dave has experience in teaching general science, so our conversations about teaching force and motion ideas were predominantly in the context of teaching Science 10, Science 20-30, and Science 14-24.

Dave taught force and motion topics at the junior high school level two to three times at the beginning of his teaching career, and once in Australia on the Exchange Program. At the

senior high school level, he has taught these topics approximately 20 times to grade 10 students in Science 10, and approximately 10 times to grade 11-12 students in Science 24. During his teaching career, Dave also taught Biology 20 and Biology 30 regularly to grade 11 and 12 IB students, and once in Australia during his one-year stay as a science teacher on the exchange program.

Dave did not like the way physics was taught in his school where he was a high school student, and according to him, that was the reason that he never "got into it." However, when asked formally whether he finds himself personally interested in physics or physics teaching, Dave took an interesting stance and responded that in high school, if the science department is large enough, teachers usually specialize in just one science area, biology, physics, or chemistry. Dave had the opportunity to teach in high schools where he worked as a specialist in biology and taught all biology courses. There were teachers who were specialists in physics and chemistry who taught chemistry and physics courses. Dave said that they all "share[d] the commonality of Science 10" and taught it every year. Dave argued that being less familiar with a science area (physics) actually makes him a better teacher because he then "spend[s] more time in finding creative ways" to teach science 10 instead of using "just a worksheet." He claimed he uses "fun activities and lots of inquiry" because he believes that is "a better approach."

4.12 Dave's Orientations to Teaching Science

My conversations with Dave provide opportunities to analyze what he considers effective instructional strategies for teaching force and motion ideas, and these in turn reveal his underlying orientations to teaching these science topics. Comparing his experiences as a science teacher with his experiences as a science learner also brings insight into whether he has followed similar approaches to that of his own teachers, and his identified need and rationale for doing so. Overall, two themes emerged in Dave's orientation to teaching force and motion ideas: (a) an integrated approach to teaching, and (b) a shift from formula-driven physics to exploration.

4.12.1 Integrated approach to teaching

During part of our conversation about the sequence in which he would prefer to discuss force and motion topics, Dave revealed that he approaches teaching these topics, or any other science topics, as interconnected and not as separate, stand-alone ones. Specifically, he said about this,

> I understand what you are doing by trying sequential [topics], but that is not the way I approach science. It is not like one day you show up and say, today we are going to learn about friction. It is trying to teach things that are processes and things that are inter-related. So, it is never static, one day we do this, one day we do that. Each day, we grow from what we have done before, and then hopefully, introduce the new concepts.

This strategy is consistent with an integrated teaching approach (Pigdon and Wooley, 1992) where the focus is on activities, project, and relationships among concepts.

4.12.2 Shifting from math-based to exploration based Physics

Dave experienced a clear shift in his orientations to learning and teaching physics. He explained this transformation, saying: "I think in physics, if I learned anything, [it] is . . . [a

gradual] shift from the formula-driven [approaches] that I was taught, to much more [of] an exploration." Dave revealed that he experienced only mathematics-based physics when he was in high school, with this consequence: "That is why I never went into [physics, because] I thought physics is very boring."

When further probed, Dave described a critical point in his life for this shift, a message from one of his practicum supervisors, who recommended that he ask himself, "Would you want to be a student in this class?" So, when Dave started teaching physics ideas in Science 10 and Science 24, he noted that he wanted to make the class interesting for his students. Remembering how boring the approach based on formulas was for him, he aimed to find other ways to teach physics or chemistry. Dave described what such a boring class would be like: "Welcome today to distance. Here is our formula, here are 20 examples for you to calculate or correct to the end of the class." He insisted that such a class for him is "dead, if no one enjoys them with [him] at all." Therefore, he put in hard work to find better, engaging strategies to teach these topics. In his words: "So, then I worked to find ways, through talking to colleagues and research[ing] how to teach the same curriculum, but in ways that are much more engaging."

Dave recalled the ways he learned science in school, and said, "I was taught very differently, when I was in school." He stated that he experienced these topics as a high school student very differently. He said, "I was taught . . . [with] lots of vehicles moving at a certain speed, and they will fall off a cliff, and [he was asked:] can you calculate how far off the cliff it had landed? Demonstrate what forces are acting upon, and show using vectors? How these forces are resistant? And it is all questions and calculations."

Dave affirmed that he "was very progressive for a teacher in [his] school district" but it took him almost three years to become the teacher he always wanted to be. He admitted: "In my

first and second year, I taught too much from the curriculum, too much by the textbook, and using the worksheets." According to Dave, "When I felt I really mastered what the students need to know, then I began to start playing with different ways to approach the stuff."

Dave also had the opportunity to work with "great mentors to begin a career in [science] teaching." These people provided him with the possibilities of making science (physics) teaching interesting. He particularly appreciated his course instructor for his teacher preparation program in science curriculum, although he said about them all, "I think they were phenomenal."

As a science consultant, one of Dave's responsibilities is to organize PD workshops for science teachers. During these, he tries to help in-service science teachers use more exploration and less calculations. He said that his aim for these workshops is to help science teachers experience a similar "shift from calculations to inquiry and graphs" to that which he went through. Dave acknowledged he is not a physics expert so he does not teach any physics directly as a science consultant. In his words: "What I do is, I bring in either physics teachers or the examiner . . . very professional people to work with physics teachers . . . , and to have them talk about the concepts."

4.13 Profile of Dave's Pedagogical Content Knowledge Related to Force and Motion Ideas

Dave is not a physics specialist, but has seventeen years of experience in teaching science, mostly Biology 20-30, Science 10, and Science 14-24. He also has some experience in teaching junior high school science in Canada and Australia. Most recently, as a science consultant, he has organized many successful PD events for in-service science teachers in his school board. These diverse experiences allowed Dave to integrate his content knowledge and pedagogy on the job in a unique way, to develop his pedagogical content knowledge. As noted, he did not study these topics during his undergraduate degree or in his teacher preparation

program. His PCK for teaching topics related to force and motion appears to be sourced in working with colleagues, getting help from the textbooks and teacher resource manuals, teaching these topics, reflecting on his teaching of these topics, and improving it. His experience of teaching science in general may have also contributed to the development of his PCK of teaching these topics in particular.

In the next ten sections I will reveal various aspects of Dave's PCK for teaching force and motion topics, based on my interpretations of our conversations.

4.13.1 Dave's views and understanding of the force and motion concepts

According to Shulman (1987), one aspect of a teacher's PCK is knowledge of the content to be taught. For science teachers, this topic-specific science knowledge is considered the *most important* aspect of the science teachers' PCK (Abell, 2008; Loughran et al., 2004, 2006, 2008; Magnusson et al., 1998; van Driel, 1999). In Dave's case, he did not formally study any physics after high school. However, he developed an understanding of the topics related to force and motion in an effort to help his students understand these topics. He also developed a unique understanding of how those topics relate to each other and how he should organize them to provide a logical sequence for his students to understand them conceptually.

I presented Dave with the tentative list of force and motion topics I had prepared, and gave him the opportunity to select the topics from this list that he felt comfortable in discussing. He could also add or remove any topic from the list, and then discuss the selected topics in a sequence based on his personal preference. The choices Dave made, first in terms of selecting topics and then choosing a specific order to discuss these topics, reveal something of the breadth of his understanding of these topics. His choices also contribute to understanding the way he

believes these topics should be discussed in high school classes so that students can understand them, especially to cover the curriculum objectives in Science 10 and Science 24.

What follows here are seven sections describing Dave's overall understanding of topics he covers when teaching about force and motion. I will close this inventory by representing his views about organizing these ideas into a teaching sequence to maximize his students' understanding.

4.13.1.1 Force

The concept of force focuses on two underlying sub-concepts: (a) what a force is, and (b) what a force does.

Dave started a discussion about force, in the context of his experience of teaching this topic in Science 10 and Science 24. He stated that in Science 10 he has used explorations, where he introduces graph analysis of motion. He has also used experiments to demonstrate force and uses formulas to calculate it. However, in Science 24, he claimed to discuss force in the context of collisions, using real-life examples of car accidents and having discussion about the forces involved. He also has constructed simulations of car accidents in his classroom, to engage his students' thinking.

When asked how he approached the topic in junior high school, he considered it a "more fun unit" where he had let his students "build simple machines . . . [to] allow them to explore [force] through the simple machines, and demonstrate the forces." For example, he explained that while setting up a pulley he guided his students to understand that "through the use of a pulley, they can reduce the input force."

From our conversations, it seemed that Dave has talked about force in the context of Mechanical Systems unit, which is a grade eight science unit. At no point in our discussions did

Dave define force as a push or pull. Instead, he focused on how he demonstrates force in various contexts to help his students understand that force can affect the motion. However, he did not go into detail about these effects, which may include acceleration.

4.13.1.2 Rest and motion

Rest in the context of the topic of motion is sometimes not discussed specifically in science classes. Dave stated that he does not consider rest and motion as separate topics, but introduces them to his students during discussion about distance, displacement, speed and velocity.

He said he includes a discussion of rest "when [he] talk[s] about distance versus displacement." He further explained, "We could include force, but it was never an emphasis within the curriculum, where you would say, an object at rest will stay at rest, until...there was no force." By saying this, he defined implicitly Newton's first law of motion, which holds that the same for objects in constant motion. So, according to Newton's first law, an object at rest or in motion remains at rest or keeps moving in constant motion until acted on by a force. This discussion revealed that Dave considers rest as a condition of the object, or as a reference point for motion to start—an object at rest will stay at rest if a force is not applied on it—which he said he does not emphasize in his science classes because he believes this is not one of the curriculum objectives.

Dave indicated that he usually discusses the motion along with speed and velocity. He said he wants his students to understand the difference between uniform motion and non-uniform motion. When asked specifically at what point during the teaching of speed versus velocity he introduces these ideas, he briefly said that he presents motion while doing graphs.

4.13.1.3 Friction or Frictional forces

I invited Dave to consider this topic for discussion because this is included in the Alberta Science Program of Studies at many levels. Dave said that he discusses frictional force in "many different ways." He also said that he discusses the topic of friction "often in Bernoulli's Fluids . . . where [he] shows frictional force and viscosity, and in the same lesson show[s] what is happening with different surface types, and how it affects the force," which is the content covered in Science 20. Moreover, Dave discusses the topic of friction in Science 24, in the context of car accidents, where he "talk[s] about tires, different treads, and how . . . [treads] works" to increase or decrease the frictional force between the tires and the road.

4.13.1.4 Gravity

This subject area can include a discussion of reaction force in the context of Newton's third law of motion, specifically including action-reaction force pairs. The topic could be expanded to a discussion on field reaction forces such as gravity, magnetic force and so on. Many teachers are aware of gravity, magnetic force, and Newton's third law of motion, but sometimes they are unaware of the term reaction forces. I think that was the case with Dave, when he reacted to the topic of reaction forces saying that he "never touched" it. Nevertheless, when explaining further, he commented, "It is not a formal term that the curriculum uses. . . . Now you are getting more into the Physics 20 and Physics 30 programs."

When I reminded him that he could exclude any topic from the discussion, he did decide to exclude the reaction forces. However, when I asked him if he would like to talk about gravity, which is a field reaction force, and an interesting and popular topic in high school science, Dave responded that he did discuss gravity briefly in Science 10. He further insisted that the topic of gravity is not an emphasis in the curriculum, however.

4.13.1.5 Acceleration

This topic logically includes a discussion on speed and velocity. In discussing acceleration, Dave stated, “Acceleration and velocity are both very big in Science 10. I explore both through the use of graphs, and [I] really emphasize that students draw and interpret what is happening in each graph” in terms of velocity and acceleration.

4.13.1.1 Additional Topics: Scalars vs. Vectors and Distance vs. Displacement

When invited to add any topics to this list, Dave included scalars vs. vectors, and distance vs. displacement. He believes “both of those are very large concepts in Science 10.” He also said, “it is just easy to explain, one is very static [no direction] and the other one has a dynamic element [to it] including a direction.” Eventually, Dave and I collaboratively finalized our list of topics related to force and motion to initiate conversations about how Dave plans and teach these topics.

4.13.1.2 Newton’s laws of motion

Newton’s three laws of motion can be discussed as topics, or these laws can be presented during a discussion on motion, velocity, or acceleration. Dave confirmed that he covers Newton’s first and second law of motion but he explained that he does not “introduce[s] them...[as] stand-alone concepts . . . Newton’s first and second law would come when you talk about acceleration.” When asked if he would like to discuss about Newton’s third law, Dave said, “Ah, Newton’s 3rd law...I do not formally remember it.” Therefore, he decided not to include Newton’s 3rd law in our list.

4.13.1.3 Sequencing these topics

When given the opportunity, Dave proposed a specific sequence to discuss above topics, which he follows for teaching these topics in order to help his students’ learning in these topics. This

preferred sequence reveals his understanding of how these topics should be organized to help his students most easily understand them. In his words:

> We would put force probably in the middle of the Science 10 course . . . [and] begin with distance and displacement, and then . . . go with speed vs. velocity, and at this point I would introduce force.

He further explained that "once you have introduced the force you can come back and discuss acceleration, and Newton's laws of motion." When asked if he had a preferred sequence to talk about Newton's laws of motion, Dave responded that he discusses Newton's 2nd and 3rd laws of motion "often together."

When asked about the topics rest and motion, Dave answered that he would talk briefly about ideas relating to rest during the discussion of distance, displacement, speed, and velocity. He would ask his students to "identify the difference between uniform motion and an object at rest, using a graphical or data analysis."

4.13.2 Dave's views and understanding of students' alternative ideas

After many years of teaching science, especially force and motion topics, Dave has developed strategies to understand his students' difficulties in learning these topics, especially their alternative ideas, and has come up with ways to help meet their needs so they can better understand them. The sections below describe some of these problems and strategies.

4.13.2.1 "Mathematical background"

In Dave's opinion the major source of his students' learning difficulties when learning about distance and displacement through graphs is "their math background . . . [which he believes] is often the weakest." According to him, "this problem is more evident when teaching Science 10 in the first semester . . . [because these] students are not taking Math 10 . . .

[Therefore, they] struggle more than the ones that are coming in the second semester" who take Science 10 and Math 10 together. Dave further explained: "The more they explore the graphs and the data analysis in Math, [the more] it helps with their understanding of Physics." Dave also believes that students' weak math backgrounds is the main reason for learning difficulties "through the whole physics [course]."

To overcome difficulties of learning due to his students' mathematics experiences, Dave noted that he works "a lot on the SMART Board and the White Board . . . [and uses] a lot of graphing analysis [to] go through with [students]" He stated, "I use a lot of gizmos from the Learn Alberta website." Gizmos are online simulations where students can manipulate variables and see the results. Dave uses computers and laptops to help his students to use gizmos at school and at home.

4.13.2.2 Graph interpretation

Dave realizes that students often find it difficult to interpret graphs, which hinders their learning about speed, velocity and acceleration. He illustrated this with one example: "When [my students] look at the graph, and they see a flat line, they assume that it is an object at rest." Dave explained that "often [students] will assume that . . . if you drew a horizontal line, it means the object would stop." When confronted with this situation, Dave stated that he "explain[s] to them, No, this is uniform motion . . . [this graph with a horizontal line represents] constant velocity."

To help students confront the misconception that a flat line on a graph always means the object is at rest, Dave presents the scenario of driving to Edmonton with cruise control. He said that he shows his students a graph showing the motion of the car to Edmonton, which is represented by a flat line. Dave stated: "The students really look scattered . . . [when they see that] speed does not change but you are still moving" and not at rest.

Dave remarked that when students understand the difference between speed and velocity, this is the time to introduce them to acceleration. He said, “Then you show them a graph that has a change moving up to moving down. So then you start talking about acceleration.”

4.13.3 Dave’s repertoires of instructional strategies

With his years of teaching force and motion, Dave has many teaching strategies he finds effective for these topics. These fall into two teaching approaches, which he compared: the first is a mathematics-based teaching approach to these topics, using worksheets and solving a number of problems with formula sheets provided to the students. Dave indicated that this is not a useful approach, as it fails to engage students and keep them interested in the science class.

In contrast, he said that the second approach involves the use of exploration and inquiry activities. Dave elaborated in this, noting that he uses open-ended inquiry strategies were he avoids telling students about the ideas under study but guides their learning through exploration. He provided an example where he has used ticker tape exploration to teach about velocity and acceleration. He described this in these terms: “I love to do [the ticker tape experiment] without telling students, what the actual dots [made on the tape] mean . . . I have them measure the [distance between the] dots, and see that [the dots are] close together, [then] farther . . . , and then constant.” Dave explained that his students “try to figure out [why], [by] proposing a formula that would explain acceleration.”

Below I review six topic specific strategies that Dave talked about as effective for teaching force and motion concepts to his high school students. I identified these by analyzing our conversations, listening for when he talked about how he taught this material.

4.13.3.1 Mystery walk

Dave stated that he uses an activity he called a "Mystery Walk" at the beginning of the force and motion unit to engage students to make learning "like a mystery. . . . Students had to walk around the school, using the instruction that were given to them" to reach a specific point, using a map. Dave has used this activity repeatedly and has modified it a few times. In one version of this activity he used a city map. In his words,

> I give them a map of a city, and have the students go through the clues. . . . And with the numbers that [I] have given them, [they have to find] distance and displacement. . . The students [can] use the rulers and . . . [do] calculations to figure out [the distance and displacement covered].

Dave said that by engaging in this activity students learn various concepts like distance, displacement, scalars, vectors and so on. He explained that once he gives students the activity sheet, they, "begin to read the clues, and eventually by the end of the period they come up . . . saying, I know exactly [in] which building this event took place based on the clues." At this point, Dave looks at "all their drawings and considers what they have done" to decide if their answer is correct. He said that by looking at the students' drawings and answers he can see if they know "how to calculate a vector" using the given information.

To make this activity interesting for his students, Dave modified it, working collaboratively with a physics specialist in his school, where students have to take the mystery walk inside their school. He explained:

> We [make students] start at a certain point, and [they are] actually meant to get to [a place or a building] where they are supposed to go by using the data. Then I will go to the finish point . . . and watch them through their measurements and calculations.

Dave noted that he uses this activity to talk about multiple concepts: to calculate distance and displacement, then to "calculate speed and velocity, and [then] again . . . for calculating scalars and vectors."

4.13.3.2 Using scenarios

Dave says that the topics of distance and displacement "come with [the topics of] scalars and vectors." He explained how he teaches all the concepts together, so that the students can develop an understanding of these topics. He told me about how he presents a scenario to his students: "[Imagine] you have covered 100 kilometres, 50 kilometres north, and 50 kilometres east. What is the difference between the total distance . . . [and] the total displacement from where you came?" He stated that he lets his students explore these ideas, then has them "calculate [distance and displacement], and show [the results] on graphs, and understand what is happening about those concepts."

4.13.3.3 Using graphs

Dave stated that he "does graphs," where his students either draw graphs based on data provided or use graphs to interpret motion. According to him, "They should be able to calculate, [for example, distance, displacement, speed, and velocity] from the graphs." Dave explained that he provides many examples of motion, and shows various graphs to his students for them to analyze and understand these concepts. After introducing them to graphs, Dave said, "[I] give them a bunch of data for them to sit down in small groups, graph the data, taking a look at them, [and] talk among each other [about] what each section of data means." Then he asks, "Let me know what it means for the area underneath the graph? And what do we learn from each of these pictures [graphs] that we have created?"

Dave noted that the "best part of this [activity] is that [students] do not use formulas." He said, "I do not introduce formulas on sheets [but] I have them figure out these [concepts] through graphs." For example, to facilitate students' understanding about distance and displacement by using graphs, Dave said that his students need to understand, "The total area under this [velocity-time graph] will give me this [distance travelled]." By doing this he "lead[s] the students into creating their own formulas to solve [them] from what they saw." Dave further explained that he does not provide a formula sheet to students: "I do not want them [to] sit there and look at their data sheet, [and] go for the formula for distance." Instead, he uses velocity-time graphs, and leads his students to see that a velocity-time graph represents the distance travelled.

However, he acknowledged that sometimes using graphs is not enough for his students to conceptually understand this material.

4.13.3.4 Simple pendulum setup

One of the demonstrations that Dave uses in his classroom is a simple pendulum. He described his approach:

> Imagine coming in one day, and you see in front of the classroom I have setup a pendulum. Then I just ask then, sit back [and] 'Explain to me what is happening?' And just have students draw what they see and what they think happens here to here [showing with hands an imaginary path of pendulum], and here [highest left] to here [center], [and so on].

He said, "And eventually they get to see acceleration, negative acceleration, [and an] object at rest." Dave noted that during the demonstration of a simple pendulum, it is critical that students carefully observe the motion of the pendulum. Through using guiding questions, he said that he lets students see "what is happening . . . [by] showing the [movement of the pendulum bob] moment to moment."

4.13.3.5 Ticker-tape experiment

Dave has also used ticker-tape experiments, which are popularly used in high school science classrooms to study motion and observe changes in motion in terms of speed, velocity, and acceleration. Dave shared his experience of using this experiment in his classroom:

> When I first taught Science 10, I told [students] to use measurement. But, then I felt I was leading them too much. So then I let them run the vehicle through, and then I turn up and say, "Tell me what those dots means?" And it is great for them to start discussing. They notice that the pattern of [dots is] getting longer and longer and then coming to the same distance. . . . Then I have them present back to me, [saying] "All right, show the difference between section A, which is here and section B, which is here?"

I shared with Dave my experience of using online simulations and virtual labs using a ticker-tape and mentioned using the online teaching resource website "The Physics Classroom." Dave was aware of this resource and said he has also used this website a few times.

4.13.3.6 Dropping a basketball

Dave mentioned teaching students about gravity by demonstrating with a basketball. According to him, "It is lots of play . . . it is just as fun . . . taking a basketball and dropping it from a taller height, and then having them . . . see if they can calculate gravity." Dave said that he focuses on "showing that gravity [acceleration due to gravity] is a form of acceleration, but it is standard [$g=9.8\ m/s^2$]."

4.13.4 Dave's views, knowledge, and use of teaching resources

Dave shared some teaching resources that he knows of and that he has found effective for teaching about force and motion. The following sections present these resources.

4.13.4.1 Textbooks and teacher resource manual

Dave believes textbooks are phenomenal resources and a great starting point. He explained, “The teacher resource manuals have really good teaching ideas . . . [which are recommended] by some qualified teachers.” These teacher resource manuals come with the textbook. He noted that the graphs he uses for teaching force and motion topics are from this manual, which he has “adapted . . . for [his] visual learners” by making it available on SMART board. In addition, Dave noted, “The teacher resource manual has lots of questions [problem solving]” that he also uses in his teaching.

4.13.4.2 Professional development days

Dave finds PD days to be the most important resource for teachers. In his words: “The best would be sitting down [on the] the Professional Development Day and having 15 people talk about what they are doing in their Science 10 [classes], and just take a few ideas that sound really neat, and [then] introducing those in [your] next year teaching program.”

4.13.5 Dave’s views, knowledge, and use of technology

As described above, Dave uses gizmos for teaching ideas about force and motion: “I love using virtual labs [gizmos],” he said. He says that he accesses these from different websites although he could not remember any specific website at the time of our conversation.

When asked specifically which simulations work best for teaching about scalars and vectors, he described how he selects technology tools:

> I will look first within the Learn Alberta website [to] see if there is a gizmo [that I can use]. Then I go to ‘SMART Essentials’ [a SMART Board tool] to see if there is anything that demonstrates [the concept]. . . . And if it is not there, then I am going to Google, [and] find that tool. The ones that I like the most are where I can put the data in, based on what the

> students [observe, and] then we see [the] graph immediately. . . [Then] I ask students . . . what would we see here [in the graph]?

He further stated, "I also have used Vernier equipment, the same idea but it does the calculation for you." These are electronic sensors and probes attached to computer software to represent live data.

In addition to this, Dave said that he uses videos of car accidents while teaching Science 24. He said that he provides his students with the data about the car accidents and helps them "to work backwards to calculate how long [this] . . . person was texting? Or, how long the skid marks are?" Dave noted that using these inquiry questions helps students "figure out" the answer, and helps them understand these concepts better.

In response to a question about other technologies he uses in his classroom, Dave described that he uses "computers, cars, ticker tape, and stop-watches," which are all technologies. Dave also said this about using technology in a science classroom: "There is not one technology that I use as a crutch. It is a combination of many things," along with using inquiry questions to help students figure out answers for themselves.

Dave further mentioned he has learned from his fellow physics teachers about using photo gates. These are part of the Vernier equipment—a type of motion sensors that have the ability to transfer data to the computer. He tried them out in his own science classes where he asked his students "to collect data from movement with photo gates" and then interpret the motion." He explained: "So, we will take a look at an object, and immediately on SMART Board the data would come. Then we graph it and we take a look at what is happening."

4.13.6 Dave's views and understanding of the science curriculum

Like many teachers, Dave believes that the Program of Study is a legal document and that a teacher is obligated to cover its content and objectives. Many times during our conversations, he described that his reason to include or exclude a topic is based on whether it is in the curriculum or not. For example, while having a conversation about teaching scalars and vectors, he said, "It is part of the curriculum, so you have to introduce it." His reasoning for this is as follows: "If I am not teaching from the [science] Program of Study, then I am not offering continuity. If I let the students down in Science 10 without completing the Program of Study, I do not give [students] the skills and knowledge that we hope will help them to succeed."

Dave said that he believes the Alberta Science Program of Studies as "a driving force," and that it is the responsibility of the teacher to "find ways to emphasize that curriculum." Describing how he emphasizes the science curriculum while planning and teaching his lesson, he said that the Alberta Science Program of Studies has "bullet points . . . [which are] the general outcomes . . . , and then underneath [are some points] in italicized [text that] give you suggestions" to achieve these outcomes. In his view these suggestions are "good for creating ideas . . . [and] to explore these topics." Dave explained: "Often I look at those suggestions, and use [them] . . . to develop a lab, [or design] data analysis [problems] for students to look at."

When specifically asked about the curriculum emphasis included in the introduction to the Alberta Science Program of Studies, Dave said, "I will consider" the three curriculum emphases: Science-Technology-Society, Nature of Science, and Social and Environmental Context. However, he continued stressing the bullet points: "The suggestions that [POS] put in italics, is always something that I consider strongly, because this is prepared by teachers, after the curriculum point [objectives are] created."

When teaching in the exchange program, Dave "did not know the Program of Studies in Australia," so he said that he reviewed it before planning and teaching. However, comparing the Alberta science POS with the science curriculum in New South Wales, Australia he found "there are lots of similarities between the two curricula. . . . The science curriculum in Australia is much more hands-on than what we have in Alberta. . . . Alberta has more curriculum content, [while] Australia has more mini labs."

4.13.7 Dave's goals of teaching force and motion

My analysis of our conversations reveals that Dave takes the goals of various science units in the Alberta Program of Studies very seriously. He criticized the science teachers who are specialists in a particular science areas, and went into some detail about what is expected at a certain level to meet curriculum objectives when teaching general science courses as Science 10 and Science 24 in Alberta. In his experience of teaching in high schools, he observed physics specialist teachers "bringing in lots of information" beyond what is expected from Science 10 students. He showed concern for the efforts of these science teachers and raised a genuine question: "Do the students really need to be burdened by the things that are outside the curriculum?"

When asked further about the goals of teaching the topics related to force and motion, Dave highlighted the need to stay exclusively to the topics and concepts in the POS. For example, Dave is not sure whether understanding the topics of Newton's laws for high school is important, or whether these topics should be taught in Science 10, since they are not part of the Science 10 curriculum. He affirmed that these topics are important, but he said, "Science 10 . . . is often over-packed" so there is no time for new topics.

4.13.8 Dave's views and understanding of considering various teaching contexts

Dave has experience of teaching force and motion topics in the context of two science Curricula: (a) Alberta Science Program of Studies and (b) New South Wales Science curriculum. In addition, he also taught at the junior and senior high school levels, and in three different schools. Dave shared his experience of planning and teaching this subject in the context of the Australian curriculum:

> In Australia though, it is different. They have a ledger, so each school has its own way of approaching topics. If there are two science teachers teaching a physics [topic], then at the beginning of the year they put together . . . like a shared parts system, [for example] to cover page 89, do this lab. At the end of each week, I will put my signature that will legally tell me to show to the government that I covered this curricular concept, and this is how I did it.

Dave further explained the equality of educational experiences for Australian high school students. "Each week, the science teachers [teaching the same grade] . . . basically do, the exact same thing. . . . And whatever was planned, was made sure we [all] covered, and put our names besides." Dave called teaching these topics in Australia "very structured." However, he explained that he could change the activities or labs at the end of the year for next year's teaching.

> If I was there for two years, I could modify. So, I could say at the end of the year, well there is another way to teach this [concept/topic], but because I was on Teacher Exchange, I had to use what was already created. So, lots of my lessons were already pre-planned for me. So that, when I went to parent teacher interviews or I was asked by the Head Master,

> "Did you cover this?" I would say yes. Here is my signature . . . and students covered this, this and this in their science notebooks.

Dave emphasized that the legal obligation to cover the program of studies in Australia was much more serious than Alberta, because "each week, I must put [my] signatures to say that I cover this." However, Dave also admitted modifying some of the lesson plans he was provided with there, in order to make his teaching interesting and engaging. He shared this experience:

> Often I would do it different . . . and I would still put my signature knowing that I covered all that material but in a very different way. And the students really enjoyed it, because we went from a worksheet-based to then much more technology and creativity. And . . . yes at the end of the year the students really have now pushed the teachers that I worked with to embrace the new style rather than the traditional work.

4.13.9 Dave's views and understanding of assessment

Dave was asked to describe the assessment strategies for these topics that he uses with his students. He responded:

> It could be anything, from putting up [examples] on the SMART Board, [and asking] which one is the distance and which one is the displacement? Having students use the clickers to rating their answers? Just talking with the students [about ideas] . . . from their lab investigations. . . . and then follow up with formula part of the lab, [and] having a quiz at some point. So, lots of formative assessment, or what we call assessment for learning.

Formative: The assessments Dave noted above fall into the formative category. He provided further examples, saying that he has used questions during the inquiry activities. He

added, “When I had them [students] walk around the hallways, [or] dropping a basketball, I asked. So what is happening?”

For scalars and vectors, Dave described a formative assessment strategy where he assesses his students understanding by have the students draw scalars and vectors during “The Mystery Walk” activity. He stated, “I really love when students draw what they see happening, and from there just by creating their own arrow system, they did not realize they were demonstrating scalar and vector in the same concepts.”

Summative. Dave also affirmed, “There will be a unit exam” at the end of each unit. When asked about which questions will appear on these unit exams, he said that a question about distance and displacement would always be there. He argued, “It is very important, but it is often the easiest concept for the students.” When asked specifically “What do the questions look like on a unit exam that assess students’ understanding of distance and displacement?” Dave said that he has used “analyzing the graphs.”

4.13.10 Dave’s views and understanding of addressing student diversity

Dave is well aware of the diversity in Canadian classrooms. He asserted that he acknowledges the diverse background of students, and considers them when he designs inclusive science lessons. He described how he considers students’ learning styles, their English language ability, and their cultural backgrounds.

4.13.10.1 Considerations of students’ learning styles

Dave said that to address students’ different learning styles, “I try each day to have something for my visual learners, my auditory learners, and my kinaesthetic learners.” To achieve this, he explained, “I always have hands-on activities [for kinaesthetic learners] . . .

something I show to them [for the visual learners], and then I talk them through examples [for auditory learners]."

4.13.10.2 Considerations of students' language backgrounds

Dave is also aware of the learning difficulties of ESL learners. He plans science lessons to address their needs, such as the following specific activities:

***Word bank*.** Dave described activity where his students "have to create their own word bank" that include meanings of the various terms used in his science classes. He said that this activity helps students build their science vocabulary, which helps them describe science concepts better. Therefore, he uses this activity repeatedly in his science classes.

***Kinaesthetic activities*.** Dave uses many "kinaesthetic activities" in his science classes, based on a physical activity, and involving walking, at the minimum. He believes that these activities support learning of all the students, regardless of "how strong their English is." For example, he explained that he asks "two students to stand up . . . [and] walk around the class. [He] gives them different directions, for example, 'you walk five meters' . . . two and a half east and two and a half north', and tell me the difference." He expressed that he believes students explore the difference between distance and displacement through this activity. He stated that the other students in his class "watch these [two] students walk around the classroom" and contribute towards the discussion. According to Dave, "Then we as a class explore the difference between distance and displacement." Dave asserts that he makes sure his students have diverse experiences, visual, kinaesthetic, and auditory.

***Graphs*.** Dave confirmed that he purposely uses graphs for teaching topics related to force and motion, to help ESL students' learning. He said, "What I love about graphs is, it does not

matter how strong your language skills are, it's a tool that demonstrates" learning of ESL and other students.

4.13.10.3 Consideration of students' cultural and ethnic diversity

When further probed about whether he has ever used specific strategies to include students from various ethnic and cultural backgrounds, Dave shared the following two practices. He noted that if he goes back to high school teaching (as compared to being a science consultant) he would like to focus more on cultural and ethnic backgrounds.

Examples of famous scientists. Dave said that to include students from other countries he has used an activity where he "introduces . . . examples of scientists who are famous in that country . . . [and] gives his or her contribution."

***Including First Nations students*.** Dave said that to include First Nations students, he has designed some science lessons. One of these lessons is to explore the concept of friction through snowshoes, and another to explore the topic of projectile motion through an arrow. About an arrow, he said that he asks his students, "What is acting upon [the arrow] in the air? Why [does the arrow] comes down at a certain distance?" According to him, it is "a different approach to the same concept [projectile motion], so lots of them [First Nation students] will speak" because they will be engaged.

A summary of the story of Dave's teaching is presented in Chapter Five, on pages 311 to 321.

Chapter Five: THE STORY OF LEARNING ABOUT PCK

This chapter presents and discusses the findings and implications of the study, as well as the story of learning through this research project. I began the story in Chapter One to develop a study of PCK. Chapter Two builds understanding of topic-specific science PCK in view of the existing literature on this topic, as well as identifying the gaps therein. Missing in the research literature is a consistent conceptual framework that allows examination of science PCK as well as topic-specific science PCK. This led to the development of my own conceptual framework, comprehensive topic-specific science PCK, which I used to frame the research.

I designed a narrative inquiry into the PCK of four participant science teachers and collected narrative data by engaging them in conversations about conceptualizing and teaching force and motion ideas. I developed a narrative configuration for each participant teacher to represent their pedagogical content knowledge that I call "Stories of Teaching Force and Motion."

This narrative inquiry into the pedagogical content knowledge of science teachers is part of my quest to become a more competent science teacher educator. In this chapter, I conclude the story of learning that started in Chapter One as a means to complete this research project and my role as a researcher of science PCK. This thesis is a significant part of this journey, but the journey itself will continue. As the journey never stops, the story never ends. To bring the thesis to a close, however, this phase of the story wraps up my experiences during this important part of the journey.

The story of learning is presented in four sections, leading to the answers to the four research questions used to guide the process of inquiry:

1. How do secondary school science teachers describe their experiences of conceptualizing and teaching topics related to force and motion?
2. How might science teachers' descriptions be organized as stories to reveal aspects of their pedagogical content knowledge (PCK) of science teaching?
3. How might science teachers' descriptions provide a connection between topic-specific science PCK and general science PCK?
4. How might science teachers' descriptions inform the development of teaching, learning and assessment tools to help pre-service science teachers develop their PCK and to assess it?

In section one, I discuss research question one—the thoughtful steps taken to make science teachers share their experiences of conceptualizing and teaching force and motion topics. In section two, I refer to the process of developing stories of teaching force and motion that I presented in Chapter Four, as a review to answer research question two. In section three, the stories of teaching force and motion are analyzed to answer research question three and establish a link between general science PCK and the topic-specific science PCK on a four-level criteria developed for this purpose. In section four, to respond to research question four, I discuss the process of developing teaching and learning, assessment tools based on the findings (the stories of teaching) and describe some examples of these tools. Moreover, I suggest how to present particular segments of the "stories of teaching" as a story or a case that can be used in science methods courses to explore problems of learning and teaching force and motion ideas. Each story or case offers a few discussion questions to guide pre-service teachers' thinking to develop science PCK of force and motion topics.

5.1 Helping Teachers Describe Their Experiences

In this section, I reflect on the steps taken in this research study to attend to research question one:

> *How do secondary school science teachers describe their experiences of conceptualizing and teaching topics related to force and motion?*

This question was important because many researchers in the field claimed PCK to be tacit and implicit knowledge, which is difficult for science teachers to articulate. The aim of this research was to help participant teachers articulate their experiences by describing events and incidents about conceptualizing and teaching science. This was achieved by (a) developing interview and conversation questions systematically, (b) using interview questions appropriately, and (c) ensuring a comfortable space for the interviews.

5.1.1 Developing interview/conversation questions systematically

Designing questions that could engage teachers in conversations about conceptualizing and teaching force and motion, to provide access to their PCK was extremely important in this research study.

To access and study the PCK of science teachers, Abell (2007) recommended that interview questions should be designed around knowledge categories within the PCK construct. The issue I found was that existing PCK models presented different sets of knowledge categories within PCK. Further review of the literature on science PCK showed the research on topic-specific science PCK either used only a few aspects of PCK or ignored the existing PCK models. This led me to develop a conceptual framework that included many of the teacher knowledge categories, and a few more taken from my own understanding of this field. Together, these can explain general PCK as well as topic-specific science PCK. I call this conceptual framework

Comprehensive Topic-Specific Science PCK and described it in Chapter Two at page 47. I used a systematic process of developing the questions in each of the ten teacher knowledge categories using the Long Interview approach suggested by McCracken (1988), described in Chapter Three (p. 95). One of the challenges of developing and using interview questions was to phrase them appropriately to invite stories and descriptions of events or incidents, but to elicit less about the opinions of the participants. This was a continuous process throughout the course of the research study and even after that. The following section provides an evaluation of the interview conversation questions and makes suggestions to improve them for future research.

5.1.2 An evaluation of the interview questions: Reflections on appropriate use

In this section, I describe an evaluation of the interview questions based on my reflections on the responses I received during my interview conversations with participant teachers. This evaluation may help improve questions for future studies that aim to access various components of science teachers' PCK. The following subsections discuss each of the main interview questions used for initiating a discussion about teaching a science topic.

First, I asked simple background questions (shown in with the intention to understand participants' educational and professional preparation to become a science teacher. The questions served the purpose as participants' responses to these questions helped develop an introduction to each participant. The questions asked them to distinguish their science teaching experiences from those of teaching topics related to force and motion, and were effective in providing a clear picture of their engagement with the force and motion topics. This distinction provided a means to understand their general and topic-specific science PCK.

Then, I shared the tentative list of topics and negotiated with teachers to select the topics they wished to discuss. Next, I had rounds of conversations with each individual participant

about each topic selected. I planned to initiate each round, for example about teaching *force*, with the question:

> *Q: Can you share a memorable event or incident of teaching the concept force that stands out for you?*

Sometimes I rephrased it as:

> *Q: Can you share any insight into your experience of teaching the concept force that stands out for you?*

This question was designed to invite a story about teaching the topic *force*, but the response that participants provided was usually limited to teaching science in general, or in some cases a general view of their science teaching. Therefore, the analysis of the participants' responses helped more in identifying their science teaching orientations, and less in understanding their pedagogical content knowledge.

5.1.2.1 Category: Content knowledge

To access participant teachers' content knowledge understanding of force and motion topics I asked the questions:

Q: What does it mean to understand force? Alternatively, *Q: How do you define force?* The question usually elicited a surface level understanding, as responses were limited to textbook definitions. Sometimes, in the moment, teachers were not able to recall specific meanings. These questions caused some slight discomfort for some participants. However, when they were asked the following question about the underlying ideas and concepts they wanted their students to understand, they usually discussed the topic in great detail.

> *Q: If you want your students to understand force, what underlying ideas or concepts do you think your students need to grasp?*

The participants were able to discuss the conceptual understanding they try to achieve in their science classroom about each science topic. Their responses to the above questions helped in the interpretation of important aspects of their PCK, as well as aspects of the broader conceptual understanding of a science topic such as force. During the conversation following these questions, participants discussed the ways they prefer to sequence topics or ideas to help students better understand these topics. After the first interview, I put more emphasis on this question rather than asking for a direct definition of the science topic. I would suggest this strategy for future research.

5.1.2.2 Category: Knowledge of students learning

To gain access to participant teachers' understanding of students' alternative ideas about force and motion topics, I asked the following questions about force, and repeated this formulation for each topic they selected:

Q: What common misconceptions did your students bring into your classroom about the concept, force?

In response to this question, participants reflected on their experiences and described students' alternative ideas in terms of incidents, events, or stories. I further asked:

Q: How did you address, challenge, or try to modify your students' alternative ideas about the concept, force?

This question was effective to access participants' experiences, as they shared their strategies and the techniques they used to help some of their students modify their alternative ideas. Sometimes, the discussion expanded because of my use of prompt questions so that participants shared their experiences regarding which science topics were particularly difficult to teach because of students' alternative ideas. In the future, I would like to add a question to

researching this aspect of science teaching to invite further details of science teachers' experience:

Q: Which force and motion topic did you find most difficult to teach, and why?

5.1.2.3 Category: Knowledge of instructional strategies

To collect information about each participant teachers' repertoire of instructional strategies used for teaching force and motion topics, I asked:

Q: Which teaching strategies usually helped your students understand the concept of force?

This question was the most effective in helping teachers talk about how they teach science. They often shared their stories of teaching with passion. However, a challenging issue was that most of the time they ignored the science topic, especially in the first round of our conversations. Allowing participants to select from multiple topics related to force and motion helped them to be more precise in the following rounds of discussion about other topics. Probing questions asked on the spot were important, and gave further information about how they developed conceptual understanding of their students through these instructional strategies.

The following questions also helped me collect information about how teachers conceptualized using real-world problems in ways that helped them teach a science topic to students so that the students can see applications of the concept in the real world.

Q: How did you relate the concept of force with the real world? Please describe examples.

5.1.2.4 Category: Knowledge of teaching resources

To gain access to each participant's world of planning a science topic, and to collect information about their understanding and use of teaching resources to teach a science topic such as force, I asked them:

Q: What teaching resources did you find helpful for teaching the topic, force?

This question helped participants reflect on their experiences of planning to teach force, and they shared various teaching resources they drew from, to plan and teach the topic. The questions sometimes helped teachers describe how they came to know about these resources. I was interested to know their reasons for selecting a particular teaching resource in the hope of learning if helping students' understanding was their primary goal here. Therefore, I sometimes asked:

Q: Which resources best help your students understand the concept, force?

The responses were not always presented in depth, and sometimes lacked details about how using a particular resource could help students' conceptual understanding. In the future, I would like to add this question:

Q: Why did you select this particular teaching resource?

5.1.2.5 Category: Knowledge of technology

To gain access to participants' understanding and use of technology for teaching a science topic, I asked the following question for the topic, force, and repeated it for other topics selected by the participants:

Q: How did you make use of technology to help your students understand the concept, force?

The question helped teachers reflect on their experiences, and describe the technologies they use in their classroom to teach a science topic, or teach science in general. The responses to this question helped build an understanding of how participant teachers use technology to teach a science topic or teach science in general.

5.1.2.6 Category: Knowledge of science curriculum

To reveal how the participants enact the science curriculum they are obligated to use, I asked the following questions about each topic they selected, such as force:

Q: How do you use your knowledge of the Alberta Science Program of Studies to plan and teach the concept, force?

The questions took participants into their world of planning and how they conceptualize teaching a specific science topic. They described the way the science program is designed and some of the curriculum emphases they were aware of. They also described their opinions and often critical views of the science program. Their responses to this question helped in analyzing their understanding of the Alberta Science Program of Studies. For future research, to access the topic-specific nature of participants' knowledge, I would recommend asking these further questions:

Q: What are the goals and objectives of teaching the topic, force, according to the Alberta Science of Program of Studies?

Q: Please map the Alberta Science Program of Studies for your grade level, and tell me where the topic, force, is discussed in the science program?

5.1.2.7 Category: Knowledge of goals

Teachers hold personal goals of teaching in addition to the curricular goals. To gain access to these goals of the participant about the topic, force, I asked:

Q: Why is it important for high school students to understand the concept of force?

The same question was asked for other topics selected by individual participants. The questions helped participants to reflect on their teaching and reveal why they teach the topic and why they sometimes prefer to teach in more detail. These responses helped develop an understanding of participant teachers' personal goals of teaching force and motion topics.

5.1.2.8 Category: Knowledge of assessment

To access the participants' knowledge of assessing students' understanding of force and motion topics, I asked the following question about the topic, force, and repeated the same question for other topics:

Q: How do you assess your students' knowledge to make sure that they understand the concept, force?

The question, despite being topic-specific, resulted mostly in responses that gave insight into their ideas about assessment in general. This question was asked in the last few minutes of our meeting so it might be a reason why some teachers to shortened their response. In the future, I would like to use the same questions in a research study focused on this particular PCK component, to test these interview conversation questions and develop questions to access details about the way science teachers use assessment.

5.1.2.9 Category: Knowledge of teaching context

To collect information about participants' understanding of teaching a science topic in various teaching contexts, I developed the following questions:

Q: Do you think that you teach the concept of force the same way you were taught?

If yes—what do you like about the way you were taught?

If no—what did you change? Why and how did you change it?

The questions contributed less to accessing participants' knowledge of contextual factors of participants' topic-specific PCK and more about their orientation to teaching science. After realizing the problem after the first interview, I continued using this question because it acted as a tool to help science teachers recall the memories of their own science learning experiences and how they contributed to their ideas about teaching. Their responses uncovered the way they experienced science as learners and the instructional strategies used by their science teachers, which helped them decide whether or not to use the same strategies. These responses helped me understand their orientation to teaching science. Therefore, I recommend using these questions in the category of teaching orientations for future research. I consider this aspect of a teachers' understanding—themselves as a student or a teacher—to be an important aspect of their orientation to teaching a science topic, or teaching science in general.

Therefore, I asked another question to access teachers' understanding of teaching a science topic in various teaching contexts:

Q: How did the various teaching contexts affect your teaching of the concept, force?

The questions posed some problems in terms of defining "teaching context" by me and by the participants. A conversation about defining teaching contexts usually helped. By the last interview, in addition to coming to a common definition of teaching context, referring to some of the teaching contexts individual participants experienced (for example, teaching a new or different science curriculum, teaching in urban and rural schools, and teaching adults and youth) helped to clarify the questions. The responses helped me to interpret participants' understanding of teaching a science topic in various teaching context.

5.1.2.10 Category: Knowledge of student diversity

To gain access to participants' understanding of addressing student diversity while teaching a science topic, I asked about the topic, force:

Q: How does the range of students' background affect your teaching of the concept, force?

The questions helped teachers reflect on their experiences related to student diversity in their science classroom. They described incidents and approaches to teaching a science topic, such as force, to students from various cultural backgrounds, students with particular disabilities, students with different preparation, and so on. The following probing questions helped in collecting further details about addressing student diversity and the way the teachers created inclusive classroom environments:

Q: How do you help students from various language backgrounds in your class while teaching them about the concept of force?

Q: Do the various cultural backgrounds of students in your classroom affect your planning about how to teach about force? If yes, how?

The analysis and interpretation of participants' responses helped to develop an understanding of the way they are addressing student diversity when teaching a science topic.

5.1.3 Creating a comfortable space for the interview

I attempted to make the interview flexible to meet the needs of the participant teachers. I also let them choose the force and motion topics they were interested in talking about from a list of related topics I developed to initiate these conversations. Participants were even allowed to suggest topics that were not on the list to provide them with more flexibility, and to encourage longer and deeper conversations. All conversations on topics related to force and motion were

audio-taped with participants' permission and transcribed verbatim. The interview conversation transcripts provided narrative research data and descriptions of the participant science teachers' personal experiences of engagement with a specific science curriculum, thus revealing aspects of their science PCK.

5.2 Developing Stories of Teaching that Reveal PCK

Research question two focused on developing stories about teaching to reveal science PCK:

How might teachers' descriptions of their experiences of teaching be organized as stories to reveal aspects of their pedagogical content knowledge (PCK) of science teaching?

I considered appropriate approaches to analyze the narrative data in Chapter Three, to develop the four stories of teaching force and motion presented in Chapter Four that answer this question based on participants' descriptions of their experiences of conceptualizing and teaching force and motion topics. I developed a systematic approach to analyze the narrative data, using the *Narrative Analysis* technique suggested by Polkinghorne (1995). The process of developing topic-stories and stories of teaching has been described in detail in Chapter Three. The conceptual framework, comprehensive topic-specific science PCK, provided a structure in which to organize the PCK of the individual participant teachers and develop the story of their teaching.

5.3 General Science PCK and Topic-Specific Science PCK

In this section, the research findings are highlighted and discussed, beginning with a review of research question three:

How might teachers' description of their experiences of teaching inform a connection between topic-specific science PCK and general PCK?

I discuss the approach I used to analyze the stories of teaching in my attempt to answer research question three, which is aimed at establishing a connection between, or placing, topic-specific science PCK in the broader PCK construct. To demonstrate the process, I present an analysis of Dave's story of teaching force and motion ideas, to locate his general science PCK and topic-specific science PCK. I selected Dave's story since he was teaching out of his area of specialization, which created the possibility that distinct general and topic-specific science PCK related to force and motion topics would be identifiable. I also present an overall analysis of other three stories of teaching.

5.3.1 The analysis process

I identified a gap in the existing literature, described in Chapter Two, the literature review. Prior serious efforts to study science PCK have not considered as an important question the connection between the topic-specific PCK and general science PCK. Thus, no research efforts established a link between general science PCK (the construct) and topic-specific science PCK as it is currently represented in science teachers' practices of teaching various science topics. The only related discussion, available in the literature, is by Veel and Makinster (1999). They proposed a general taxonomy of PCK by viewing it at three hierarchal levels: (a) general PCK, (b) domain-specific PCK, and (c) topic-specific PCK. They noted, "Categorization and sequencing the epistemological attributes related to the development of science PCK is inherently problematic" (p. 10). They argued, "These taxonomies will provide a foundation for future research and ways of organizing science teacher development" (p. 9). Making a point about topic-specific science PCK, Veel and Makinster considered that "a teacher who has knowledge at this level of PCK could have a solid repertoire of skills and abilities" (p. 13).

To answer research question three, I carefully reviewed the stories of teaching outlined in Chapter Four to find ways of establishing a connection between participant teachers' topic-specific science PCK and their general science PCK. Using Veel and Makinster's (1999) general taxonomy of PCK, I considered the continuum of science PCK, from general to topic-specific science PCK. On one end of the continuum, I place general science PCK (the domain in which I have been working) as the domain-specific PCK. On the other end of the continuum is topic-specific science PCK, which, in this case, is the science PCK related to force and motion topics. Figure 5.1 shows the continuum, conceptualized to locate the ten knowledge aspects of participant teachers' PCK as identified in my conceptual framework (comprehensive topic-specific science PCK). Here, these are related to force and motion ideas by using a four-level criteria, which I call the four-level *PCK continuum*. The four-level criteria was used to consider and classify teachers' ideas in the ten knowledge aspects:

- ***Level one*** is assigned to an idea a teacher presents about teaching force and motion topics, in which they do not make any reference to the content related to force and motion.
- ***Level two*** is assigned to an idea with mention of a topic related to force and motion.
- ***Level three*** is assigned to an idea with mention of a concept related to force and motion.
- ***Level four*** is assigned to an idea with a mention of conceptual understanding of topics related to force and motion.

The stories of teaching of the four participant science teachers reveal that all ten components of science PCK identified in the conceptual framework comprehensive topic-specific science PCK were *present* in their PCK discussions with me regarding teaching topics related to force and motion. Moreover, their topic-stories show that the ten components of PCK are amalgamated or unified to varying degrees and are central to science teachers' work. The conceptual framework

helped organize the individual ten components of each science teachers' PCK related to force and motion ideas. Each PCK component consists of various knowledge aspects a teacher used to describe his or her knowledge of teaching a topic or a concept related to force and motion.

General – – – – – – – – – –	– – – – – – – – – –	– – – – – – – – – –	**Specific**
Level One	Level Two	Level Three	Level Four
			Mention of conceptual understanding of topics related to force and motion
		Mention of a concept related to force and motion	
	Mention of a topic related to force and motion		
No mention of content related to force and motion			

Figure 5.1: Four-Level PCK Continuum—General Science PCK to Topic-Specific Science PCK

A further analysis of each of these ten knowledge components of PCK helped to place each PCK component on the *PCK continuum* mentioned above, from general to specific science PCK. This analysis reveals that some components of PCK are topic-specific in nature, while some are of a general nature. The general nature of a PCK component suggests a lack of integration between pedagogy and the science content—force and motion ideas, in this case. On the other hand, the specific nature of a PCK component proposes that the science content is integrated well with the pedagogy to make it comprehensible for students, and is transformed into a distinct combination of content and pedagogy. This analysis considered the in-between situations where, within a PCK component, the specific science content (force and motion ideas) is still in the process of integration or somewhat integrated with the pedagogy.

The analysis of four stories of teaching resulted in four detailed tables while each teable shows each participant teacher's PCK related to force and motion topics, from general to topic-specific science PCK. This represents all ten PCK components, and the related PCK aspects/elements that are assessed on the four-level criteria. I have included three tables as Appendices: E, F, and G.

In the section below, I first present an analysis of Dave's story of teaching, followed by an analysis of all four stories of teaching.

5.3.2 Dave's PCK: From general science PCK to topic-specific science PCK

Using the four-level criteria (shown in Figure 5.1), I analyzed Dave's story using each of the ten components of science PCK to reveal his views and thoughts about teaching force and motion ideas. For example, when Dave shared an idea, with no mention of the content related to force and motion, I considered this general science PCK, that is, level one. Similarly, ideas that included a topic related to force and motion (such as force, gravity, or acceleration) were assigned to level two; ideas with some description of concepts related to force and motion were assigned to level three; and an idea with details about the conceptual understanding of a topic related to force and motion was assigned to level four. Level four represents Dave's topic-specific science (force and motion) PCK. The following sections show placement of Dave's science PCK, in each of the ten knowledge categories, from general to topic-specific PCK related to force and motion topics.

5.3.2.1 Category one: Content knowledge

In the analysis of the story of Dave's teaching, his content knowledge ideas about force and motion topics are scattered on the PCK continuum. Some of them are far from the topic-specific understanding of force and motion ideas. Research on PCK has identified that science

teachers teaching out of their area of specialization tend to provide more general explanations compared with those who work within their areas of specialization (Hashweh, 1987). In light of this tendency, it is noteworthy that Dave is a specialist biology teacher, and a non-specialist when it comes to physics, even though he has been teaching general science for more than 17 years. Dave's story supports Hashweh's findings that science teachers who are teaching out of their area tend to be less specific and less detail-oriented when describing the science content.

Table 5.1: Dave's Content Knowledge—General to Topic-Specific Science PCK

Knowledge Aspects/Elements	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Force			Input force is reduced using a pulley.	
Rest and Motion Newton's First Law			An object at rest remains at rest until a force is applied.	
Frictional Forces				
Gravity				
Velocity and Acceleration	are explained through graphs			
Scalars vs. Vectors Distance vs. displacement				One is very static [no direction] and the other has a dynamic element [to it] including a direction.

5.3.2.2 Category Two: Knowledge of student learning

The analysis reveals that in the story of Dave's teaching, and in the knowledge of student learning category, Dave identified two PCK aspects—two student learning difficulties he has experienced in his science classes on force and motion topics. One difficulty is related to students' mathematics background, which is often weak and hinders their learning. Dave himself generalized this difficulty across physics, revealing his understanding that this difficulty is not connected with force and motion topics only. This suggests that this idea contributes to his general science PCK. However, he mentioned that students who take Math 10 and Science 10

together tend to perform better in numerical problem-solving. This idea represents level two on the PCK continuum. A second learning problem Dave identified is in the realm of an alternative idea. He noted that some students think that a flat line on a graph always represents an object at rest. He also mentioned remedies that he has used to help his students change this idea to a more acceptable scientific view. Thus, his strategies to provide for his students' learning needs are represented on the PCK continuum as topic-specific science PCK.

Table 5.2: Dave's Knowledge of Student Learning and Knowledge—General to Topic-Specific Science PCK

Knowledge Aspects or Elements	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Learning background		Weak math background hinders learning in physics		
Alternative ideas				Interpreting Graphs: Students think a flat line on a graph always represents object at rest.

5.3.2.3 Category Three: Knowledge of instructional strategies

In the analysis of the story of Dave's teaching in the knowledge of instructional strategies category, Dave discussed seven strategies that he has used for teaching topics related to force and motion. In his descriptions, five out of seven instructional strategies reflect his examination of the conceptual understanding he intended to develop in his students; therefore, they represent his topic-specific (force and motion) science PCK. However, for two out of seven instructional strategies, Dave did not reveal details of the conceptual understanding that he intends to develop among his students. So, based on our conversations, these strategies represent his science PCK in between his general and topic-specific PCK on the PCK continuum.

Table 5.3: Dave's Repertoire of Instructional Strategies—General to Topic-Specific Science PCK

Knowledge Aspects/Elements	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Mystery Walk				Students go through the clues and the given map to find distance and displacement, using rulers to measure, and calculations to figure out.
Scenarios				Students imagine moving 100 km, 50 km north, and 50 km east. And then find: What is the difference between the total distance and the total displacement from where you came?
Drawing Graphs				Students draw graphs using the given data. And then find: what each section of a graph means, and what it means for the area underneath the graph?
Interpreting Graphs				Students are presented with different graphs and asked to calculate from the graphs: distance, displacement, speed, and velocity.
Simple Pendulum demonstration			Students observed the simple pendulums set up, and learn about: acceleration, negative acceleration, rest, and energy.	
Ticker-Tape Experiment				Students perform an experiment using the ticker tape equipment. Then they are asked: What do those dots mean?
Dropping a Basket-ball			Students observe a basketball dropped, and are asked to calculate gravity, a form of acceleration and is 9.8 m/s^2	

5.3.2.4 Category four: Knowledge of teaching resources

In the analysis of the story of Dave's teaching, in the category knowledge of resources, Dave identified three teaching resources that he found useful when teaching force and motion ideas: (a) textbooks, (b) teacher guides, and (c) professional development (PD) days. However, he made only one comment that he had used graphs from the teacher guide. He did not refer to

the usefulness of textbooks for teaching other force and motion topics, which suggests that these ideas represent an "in-between" state on the general and topic-specific science PCK on the PCK continuum. Dave provided some details of the PD days, especially one he planned as a science consultant in collaboration with a colleague. They worked with chemistry teachers and had them teach a chemistry topic from Chemistry 20-30. After each topic, there was a rich discussion about other ways to explain a specific concept. Involvement in PD workshops demonstrates Dave's interest in helping science teachers. However, since these workshops are in chemistry, they represent general science PCK on the PCK continuum.

Table 5.4: Dave's Knowledge of Teaching Resources–General to Topic-Specific Science PCK

Knowledge Aspects or Elements	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Textbooks and Teacher Guides	Textbooks and Teacher Guide			
		the graphs are used from the teacher manual		
Professional Development Days	Professional Development workshop series on chemistry teaching			

5.3.2.5 Category five: Knowledge of technology

In the analysis of the story of Dave's teaching in the knowledge of technology category, Dave presented a very good understanding of issues of technology for teaching science. He talked about analogue technologies, computer technology, information technology, learning technologies, and digital media. He presented a broader view of technology, one that is not limited to computer and information technology. He considered that various teaching resources—such as cars, ticker-tape, and stopwatches that he has used to teach force and motion topics—were also technology, just analogue technology. The analogue technology he mentioned

is related to teaching force and motion ideas, so this aspect of his understanding about the use of technology clearly represents features of topic-specific PCK.

Dave mentioned using computers, websites, and Google searches to plan his teaching in general. He did not mention any particular website or Google search related to force and motion topics. This may indicate that Dave used these technologies as a tool for planning science teaching but not topic-specific science teaching related to force and motion. This activity then represents attention to general science PCK. Dave did mention the Learn Alberta website (http://www.learnalberta.ca) and noted that he has found and used online simulations, such as gizmos on this website. However, he could not provide details about the gizmos or how he used them. His general reference to the use of these websites represents a general science PCK perspective.

Dave identified videos and digital media that he had used for teaching force and motion ideas. He provided details of the videos of car accidents that he has used for teaching about collisions (Alberta Program of Studies, Science 20), along with the questions he asked his students. This aspect of technology use for teaching science appears to contribute to Dave's topic-specific science PCK related to force and motion ideas. Dave also mentioned that he has used SMART Board Essential as a search tool to locate teaching ideas. For his visual learners, he modified his graphs to be used on the SMART Board. Dave showed interest in finding technology tools to graph data collected by his students, as a means to engage interest. He described access to the latest classroom technology, "Vernier equipment," to teach various science topics. Dave explained that he used this equipment to analyze motion by graphing data that students collected. This description of using technology represents topic-specific science PCK related to force and motion ideas.

Table 5.5: Dave's Knowledge of Technology—General to Topic-Specific Science PCK

Knowledge Aspect or Elements	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Analogue Technology			Used cars, ticker-tape, and stopwatches for teaching about acceleration.	
Computers	Used computers			
Information Technology	Used websites: Learn Alberta			
	Used online simulations: Gizmos			
	Google searches			
Digital Media and Videos			Students were shown videos of car accidents and asked to use given accident data to calculate: How long was the person texting? How long are the skid marks?	
Learning Technology	Used SMART Essentials tools for teaching ideas, and adopted graphs in SMART Board for visual learners	Used interactive tools to draw graphs using students' data, and then asked them: what that graph represents?		

5.3.2.6 Category six: Knowledge of science curriculum

In analysis of the story of Dave's teaching in the knowledge of science curriculum category, Dave presented a critical view of the Alberta Science Program of Studies and compared it to the Australian science curriculum that he taught when he was in that country. In his view, the Alberta Science Program of Studies has a stronger content focus compared to the Australian science curriculum, which instead contains more science labs. However, he has not examined both the science curricula in terms of force and motion ideas. Dave talked about scalars and vectors as part of the Alberta Science Program of Studies and argued that these topics should be taught by every science teacher in the province. On other occasions, he talked about science topics that are not in the science program of studies at a particular grade or in a particular

unit—such as acceleration in the junior high school science curriculum and Newton's Laws in grade 10 science—but which are taught by some science teachers.

As a parent, he condemned this practice, since it means that sometimes a student is penalized for not doing well on concepts that are not even part of the science curriculum. He also commented on the curriculum emphasis of the Alberta Science Program of Studies: science, technology, society, the nature of science, and the environmental context. Dave noted that the bullet points listed in italics under each curriculum goal were particularly useful for science teachers because these are suggestions about how to teach a specific science topic. The above ideas represent greater attention paid to general science PCK aspects, with one exception—his reflection on the topics of scalars and vectors as part of the Alberta Science Program of Studies and the need to develop a conceptual understanding of these topics—which represent topic-specific science PCK.

Table 5.6: Dave's Knowledge of Curriculum—General to Topic-Specific Science PCK

Knowledge Aspects or Elements	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Comparison of two science curricula	Compared two curricula: Australia's was more hands-on; Alberta's is more content- based			
Alberta Program of Studies	Considered curriculum emphasis: STS, nature of science, social and environment context			
	Followed the bullet points under each goal in science POS about how to teach that topic	Stressed they must teach scalars and vectors, as it is part of POS, and avoid teaching topics that are not there.		

5.3.2.7 Category seven: Knowledge of goals

In the analysis of the story of Dave's teaching in the knowledge of goals category, Dave hesitated to clarify his own goals of teaching force and motion topics. He emphasized the need to follow goals and objectives specified in the Alberta Science Program of Studies because he said they are the only important goals. This perspective underscores the general nature of his PCK.

Table 5.7: Dave's Knowledge of Goals—General to Topic-Specific Science PCK

Knowledge Aspects or Elements	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Goals in Science Program of Studies	Only curricular goals are important			

5.3.2.8 Category eight: Knowledge of teaching context

In the analysis story of Dave's teaching in the category, knowledge of teaching context, Dave had experience of teaching force and motion ideas in the context of two science curricula and shared his experiences of teaching these topics in Australia and Canada. With Dave's experience of teaching this material in two countries, he stated that he is quite conscious of the legal requirement to meet the curricular expectations. If the curriculum specifies particular teaching strategies, then they must be adhered to. He noted that this responsibility exists in Alberta, but the administration puts less emphasis on this. He did not provide details on the particular ways that teaching force and motion are taught in Australia, or the different legal requirements there. In this sense, an understanding about teaching force and motion in the two teaching contexts contributes more towards general science PCK.

Table 5.8: Dave's Knowledge of Teaching Context—General to Topic-Specific Science PCK

Knowledge Aspects or Element	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Context of Australian curriculum	Legally responsible for pre-decided activities and lab			
	Each teacher in a school teaches identical content			

5.3.2.9 Category nine: Knowledge of assessment

In the analysis of the story of Dave's teaching in the category, knowledge of assessment, Dave stated that he has used questions as formative assessment tools during investigations to guide his students' thinking. As already presented in his story of teaching, he described using guiding questions while teaching about distance and displacement, and during the activity, "dropping a basketball." He followed this up with calculations and used quizzes to assess the students' understanding of the topic. He has also used multiple choice questions. He described using the actuvity "Mystery Walk" where he asked students to develop their own arrow system. He emphasized that while drawing their arrow systems the students were drawing the scalars and vectors involved in this activity, which he used for assessing their understanding. Dave's descriptions of the ideas about assessing students' understanding of force and motion using formative assessment strategies is more tuned to a topic-specific science PCK.

In the summative assessment of force and motion topics, Dave told me that he uses a test at the end of the unit. He said that usually he asks one question about distance and displacement, with another about analyzing graphs.The descriptions of these questions on the unit test also represent the topic-specific nature of Dave's PCK.

Table 5.9: Dave's Knowledge of Assessment—from General to Topic-Specific Science PCK

Knowledge Aspects or Elements	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Formative		Asked questions during force and motion investigations to guide students' thinking.		
	Used clickers to answer MCQ to help learning			
	Used short quizzes to ensure learning			
			Used examples of graphs on SMART Board, and asked which one is an example of distance and which one is of displacement.	
				Mystery Walk activity: Students asked to demonstrate their knowledge by drawing their own arrow system to demonstrate scalars and vectors to show their understanding of activity.
Summative	Used quizzes			
	Unit exam	Always included a question about distance and displacement	Qquestion on analyzing the graphs.	

5.3.2.10 Category ten: Knowledge of student diversity

The analysis of the story of Dave's teaching in the category, knowledge of student diversity features Dave's work with students from diverse backgrounds. He spoke about how he considered students' learning styles, their language, cultural and ethnic backgrounds. He said that he had developed an understanding of how to address the diverse learning needs of students in his science classroom, such as by using visual, audio, and kinaesthetic activities. He also

identified some of the ways he includes First Nations students' interests and knowledge in his science classes. For example, he described how he uses snowshoes to teach about friction on a range of surfaces. He also uses an arrow to discuss projectile motion. These aspects of Dave's science PCK are more topic-specific in nature.

One strategy that he found useful when students have a non-English language background that may hinder their learning is to encourage them to develop their own individual science word bank to develop their science vocabulary.

He believes that kinesthetic activities help ESL learners understand science by providing opportunuties to engage with materials other than by talking, since their limited English language background prevent them from participating in classroom dicussion. He described kinaesthetic activities such as the "Mystery Walk" to teach about distance and displacement, which is topic-specific in nature in this knowledge category. He presented information about the accomplishments of scientists from other cultures and ethnic backgrounds in an effort to include students from those cultural and ethnic backgrounds. These ideas about addressing student diversity represent general science PCK.

Table 5.10: Dave's Knowledge of Student Diversity—General to Topic-Science Specific

Knowledge Aspects or Elements	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Addressing Learning Styles	Provided students with diverse learning experiences: visual, kinaesthetic, and auditory			
Addressing language diversity	Had students develop word bank of science words			
	Used kinaesthetic activities to make students move instead of talk		Used example of students walking different directions	Students explore the difference between distance and

			and figuring out the difference	displacement through this activity
Address cultural and ethnic diversity	Used examples of scientist from other countries			
Including First Nation students		Explored the topic of friction through snowshoes and the topic of projectile motion through an arrow	Used an arrow to explore: What is acting upon [the arrow] in the air?	

5.3.3 An overall analysis of the other three stories of teaching

The analysis of the other three participants' stories of teaching is presented in Appendices E, F, and G Each Appendix presents individual participants' PCK on this four-level PCK continuum, revealing knowledge aspects and elements reflecting either topic-specific science PCK or general science PCK. This analysis shows that knowledge aspects that are well integrated have become part of topic-specific science PCK (level 4), while those knowledge aspects that are not integrated with content knowledge become part of general science PCK (level 1). Those knowledge aspects that are in the process of integration are placed in-between topic-science PCK and general PCK on the PCK continuum (levels 2 and 3).

This analysis, based on situating the ten PCK components on the four-level PCK continuum, presents a heuristic method to identify the topic-specific science PCK of individual teachers. This analysis may point to the need for individual science teachers to develop topic-specific science PCK within the ten teacher knowledge components of general science PCK.

For example, as described above, Dave pointed out two difficulties of learning force and motion topics: students' mathematics background and interruption of graphs. He revealed his understanding about an important alternative idea when he observed that some students have difficulty interpreting graphs. This particular alternative idea has been discussed in the literature

on students' misconceptions, where students think that a flat line on a graph always represents an object at rest. The literature highlights that teachers need to have an understanding of this alternative idea to help students understand motion and graphs. That shows that Dave has developed an understanding of this well-known alternative idea through his experience of teaching, which suggests that his general PCK is well-integrated and transformed into topic-specific PCK.

This analytic process may be used to consider and compare the topic-specific science PCK of teachers. For example, Dave identified two learning difficulties related to force and motion ideas, as compared to the other three participant teachers who identified many alternative ideas that their students bring to their science classroom. This suggests that Dave has not experienced those alternative ideas in his science classes. This points to the potential value of helping teachers learn more about the literature on alternative ideas that students may have about force and motion. This might aid them identify the alternative ideas of their students to better help them modify these ideas and improve their understanding.

Another interesting point to note is that among the ten knowledge categories, few tend to be more of a topic-specific nature in terms of teachers' PCK, while others tend to be more general. This is the case in all four science teachers' PCK. It is noteworthy that the knowledge components of the *instructional strategies* category reveal a topic-specific nature for all four science teachers, and that the *knowledge of assessment* category reveals a more general nature. This trend points to the value of researchers deepening their understanding about practicing teachers' topic-specific science PCK.

5.4 Development of Teaching, Learning, and Assessment Tools

In this section, research findings are discussed, beginning with a review of the research question four:

> *How might teachers' descriptions of their experiences inform the development of teaching, learning, and assessment tools to help pre-service science teachers develop their PCK, and to assess it PCK?*

The fourth research question turns attention to how the research findings may be used to help pre-service science teachers develop their topic-specific science PCK. As a science teacher educator, this question was important for me because I believe that, to date, there has been insufficient research and development in this area. I have developed teaching and learning tools, based on the study findings, that will engage pre-service science teachers in discussions about effective approaches that have been used by experienced teachers to teach force and motion topics. The purpose is to aid in developing their PCK of teaching these topics.

Veel and Makinster (1998) recommended that we can try to develop the topic-specific science PCK of secondary science teachers during the pre-service phase of their education. Since they typically have some knowledge of science content before entering into the teacher education program, we can help them develop their PCK in various science topics. My own experiences as a science teacher educator support this view. When I worked with secondary science teachers, I was always left feeling the need for better learning tools that will help science teachers build students' understanding of science topics. I have attempted to develop teaching-learning tools that might achieve these goals: (a) PCK formative assessment tools, and (b) PCK cases. The next section describes the procedures used to develop the teaching and learning, and assessment tools based on the stories of teaching, and presents some of these tools.

5.5 Developing PCK Formative Assessment Tools

To develop the PCK formative assessment and/or learning tools, I used the *analysis of narrative* technique suggested by Polkinghorne (1985). As an example of the procedure, a narrative analysis of the story of Jason's teaching is presented to show how his story about teaching force and motion concepts contributed to development of these tools. The analysis allowed me to highlight problems and issues related to challenging concepts Jason identified, and to clarify some of the solutions he suggested. Using these learning difficulties and solutions, I developed some examples that can be used as teaching, learning, or assessment tools. Table 5.11 presents these examples, each with three parts: (a) the learning problem, (b) the possible solution, and (c) a teaching scenario developed around these two elements. These examples were take the shape of eight PCK formative assessment tools, presented in the following sections. The first seven formative assessment tools were developed as a result of my analysis of the story of Jason's teaching; the eighth tool was a result of analyzing a section of the story of Dave's teaching.

Following the presentation of Table 5.11, the process of developing the eight formative assessment tools is described briefly. They are presented as examples to show the process of developing PCK formative assessment tools. These tools are aimed at developing the PCK of pre-service science teachers. I described how some of these formative assessment tools can be used as a learning tool, a diagnostic tool, or an assessment tool.

Table 5.11: Performing Analysis of Narrative to Develop PCK Formative Assessment Tools

Tool	Learning Problem Identified by Experienced Teacher	Possible Solution Suggested By Experienced Teacher	Scenario Developed
1.	Students, unable to identify forces in real life situations, use a proxy (fake name) when they cannot name it. For example, *Force of Motion* or *Thrust Force.*	The three-step criterion can help students understand the concept of force and overcome the problem of using proxy for a force: 1. Force is a vector. 2. It is applied *by* something or someone. 3. It is applied *on* something or someone.	Jason, an experienced science teacher, used a picture of an arrow pointing towards the left. He asked his students to identify the forces on this arrow. One of the students identified a force in the direction of motion, and called it "force of motion." 1A: What misconception is this student holding? 1B: To help the learning of this student, Jason asked a number of questions: Q: What is the direction of this force? Q: This force is applied on what? Q: Who has applied this force? How do these questions help the student understand the concept of force?
2.	Students think that friction is a force that stops motion and, hence, cannot accelerate.	The friction force is a force like any other force. So, it helps the student to use the explanation that "friction stops sliding" instead of "friction stops motion."	Jason, a science teacher who has taught force and motion ideas for many years, is teaching about friction force and says that friction can accelerate things like any other force. One of his students asks that if friction stops motion, how it can accelerate? 2A: What misconception does this student have? 2B: Which of the following explanations might help this student understand that friction is a force like any other force, and can accelerate as well as decelerate? How? a. Friction stops motion. c. Friction is loss of energy b. Friction stops sliding d. Friction is gain of energy 2C: What teachings strategy would you use to develop the scientifically correct idea?

Tool	Learning Problem Identified by Experienced Teacher	Possible Solution Suggested By Experienced Teacher	Scenario Developed
3.	Students are unable to identify Newton's third law force pairs in real-life situations.	Action and reaction forces are the same, equal and opposite in direction. So, helping students identify action-reaction pairs in real-life situations helps. For example man sitting in a chair	Jason asked his students to visualize themselves sitting in a chair. Then he asked them to explain their experience using Newton's third law pair in this situation. One of his students responded: There is a normal force pushing up on me by the chair and a gravitational force pushing down by the earth. 3A: What misconception does this student have? 3B: What learning difficulties does this misconception pose to this student's understanding of Newton's laws?
4.	Students show lack of trust in Newton's third law: • A large object applies a larger force as compared to a small object. • A fast moving object applies a larger force than a stationary object.	**First,** use examples of an interaction between small objects like electrons. **Then,** follow with an example of an interaction between a small and a large object. This can help because they will be able to see that the reason is acceleration caused by large and fast-moving object.	Jason was teaching about Newton's third law of motion by using an example of a boy pushing against a wall. A student said that the force applied by the wall was bigger than the force applied by the boy, so how can they be equal? 4A: What misconception is this student holding? 4B: How you can help this student with his/her understanding about Newton's third law of motion? 4C: Jason used the following two examples to help this student. How may these examples help this student understand Newton's third law of motion better? Example 1: An electron interacts with another electron that is pushing it. Example 2: A freight train hitting a fly

Tool	Learning Problem Identified by Experienced Teacher	Possible Solution Suggested By Experienced Teacher	Scenario Developed
5.	Students often confuse or mix a Newton's second law problem with a Newton's third law problems.	Use a scenario where a train is carrying two cars, A and B. Jason says to **first**, have students try to identify the Newton's third law pairs between Car A and Car B. **Then** ask: What is the force that the engine exerts on car A? Which is a Newton's second law problem?	Jason is concerned that some of his students are still confused about the application of Newton's second and third laws in real-life situations. This hinders their ability to solve a problem related to these two laws because they are unable to identify which law is applied in a certain situation. To help these students, Jason used a scenario where a train is accelerating towards the left and the train engine is pulling two cars A and B. He asked these question: 5A: What force does car A exert on car B? 5B: What is the force exerted by car B on car A? 5C: What force does the engine exert on car A? 5D: How can the above questions help students separate Newton's second law from Newton's third law? Explain. 5E: Can you identify a similar scenario to be used to deal with this problem?
6.	The sequence used for introducing Newton's three laws has impact on students' learning of these laws	Newton's third law should be taught first, which ca help understand Newton's second law Newton's first law can be taught anytime after.	Jason has taught the students about force at the beginning of the unit. Now, he is planning to teach about Newton's laws of motion. 6A: What do you think is the best sequence to build understanding of Newton's laws? Please choose from the following. a. 1st law, 2nd law, 3rd law b. 2nd law, 3rd law, 1st law c. 3rd law, 2nd law, 1st law d. 3rd law, 1st law, 2nd law e. 2nd law, 1st law, 3rd law f. 1st law, 3rd law, 2nd law 6B: Explain: Why did you choose the above sequence?

			What impact this sequence will have on students' understandings of Newton's laws?
Tool	**Learning Problem Identified by Experienced Teacher**	**Possible Solution Suggested By Experienced Teacher**	**Scenario Developed**
7.	Some students think acceleration is a change in speed, and ignore the fact that acceleration is a change in velocity and not in speed.	Demonstrate "if an object is changing direction, it must have acceleration." Similarly, demonstrate that you can accelerate without changing the speed.	Jason demonstrated making a marble move a tape. He asked his students, "What will happen to the marble if I lift the tape?" Then, he slowly lifted the tape. 7A: What point do you think Jason intended to make to his students? 7B: Which Newton's law might he be teaching?
8.	How do we include First Nation students' experiences in science classes?	Use similar objects from their culture to help them participate in the learning process. For example, using snowshoes and arrows in class examples may be an effective way to engage them in science.	Dave has planned an interesting science class to engage students from other cultural backgrounds in his classroom. He brought snowshoes and an arrow. 8A: Which cultural backgrounds might he intend to address by using these? 8B: Which science concepts will he be teaching in his classroom? 8C: What other objects, resource, or approached might be used to engage First Nations students while teaching force and motion ideas? 8D: Please think of other cultural backgrounds that your future students might have. Select one, and explain how you might engage that students group while teaching force and motion ideas.

5.5.1 Formative Assessment Tool One: What is a force, and what is NOT a force?

Jason noted that many of his students used proxy forces when they were asked to identify forces in a real life situation. He identified that many of his students held this alternative idea about force: a moving object has a force. However, when students cannot name this force, they describe it using a "proxy force," a fake name to identify it, which they call *Force of Motion* or *Thrust Force.*

Jason suggested that to understand what a force is, it is important to understand what is *not* a force, and the three-step criteria he devised (described in his story of teaching in Chapter 4) is the way to do this. He suggests testing any force against these criteria, by considering three aspects of force: (a) force is a vector, (b) a force needs to act on something, and (c) every force needs to be applied by something. He finds the third step particularly helps students eliminate many of the non-forces (proxy forces) they usually think are forces. This is because when they have to identify that force is applied by "something," they try to identify what that something is: in other words, what is applying the force to the given body?

Using this problem and solutions, I developed the following scenario and shaped it into a formative assessment tool that can help pre-service science teachers consider the problem and find ways to help their students deal with their alternative ideas. Figure 5.2 illustrates tool one.

Scenario 1:

Jason, an experienced science teacher, presented a graphic of an arrow, and asked his students to identify the forces on the arrow. One of the students identified a force in the direction of motion, and called it "force of motion."

1A: What misconception might this student be demonstrating?

2B: To help this student, Jason the asked a number of questions:

Q: What is the direction of this force?

Q: This force is being applied on what?

Q: Who or what has applied this force?

How will these questions help address the students' alternative idea?

2C: Suggest three more questions that you think can help address the students' ideas.

Figure 5.2: Formative Assessment Tool One

5.5.2 Formative Assessment Tool Two: Friction is a force like any other force

Both Jason and Kevin pointed out an alternative idea that relates to teaching friction force: Students think friction is something that only stops motion. Kevin stated that to have a good understanding of acceleration, his students need help to make predictions about the role of friction in acceleration. Jason noted that many of his students do not believe that friction can accelerate an object—i.e., can speed things up as well as slow them down. Some of his students do not even believe that friction is a force.

According to both Jason and Kevin, the probable reason is an explanation provided to these students from their teachers or from the textbooks that "friction stops motion." Jason argued that teaching friction force as an opposition to motion encourages students to use a proxy force, a fake name, when they are not able to fit friction into the situation of motion, which in turn reinforces the common misconception that friction is not a force, or using a proxy force, "thrust force" when unable to identify friction as a force.

Jason suggested providing students with the better explanation that the friction force "stops sliding." According to him, this explanation helps overcome the alternative idea about friction force. It can also help students understand that friction is a force like any other force, and can be used to do anything that any other force does.

Based on the ideas of Kevin and Jason, I developed Formative Assessment Tool Two, which is aimed at helping pre-service science teachers identify this particular alternative idea of their future students, and to modify this idea so that they can understand friction force better. Figure 5.2 resents formative assessment tool two.

Scenario 2:

Jason, a science teacher with many years' experience of teaching about force and motion, is teaching about friction force and says that friction can accelerate objects like any other force.

One of the students says that friction stops motion, so how can it accelerate?

2A: What misconception might this student be presenting?

2B: Which of the following explanations might help this student understand that friction is a force like any other force, and can cause acceleration as well as deceleration?

1. Friction stops motion.
2. Friction stops sliding.
3. Friction is loss of energy.
4. Friction is a gain of energy.

2C: What teachings strategy would you use to develop the scientifically correct idea?

Figure 5.3: Formative Assessment Tool Two

5.5.3 Formative Assessment Tool Three: Action-reaction pair forces do not act on the same body—Newton's third law pair

Jason noted that his students often find it difficult to identify Newton's third law force pairs in real-life situations, and confuse Newton's third law with his second law. He described a typical scenario he uses in classes where he asks his students to visualize themselves sitting in a chair and identify the forces at play using the language of Newton's third law force pair in this scenario. When a student responds "that there is a normal force, up, **on me,** by the chair and gravitational force, down, **on me** by the earth" and considers this as a Newton's third law action-reaction force pair, he or she is confusing Newton's third law with the second law, and hence is not correctly identifying the Newton's third law force pair. According to Jason, the student's response does not count as Newton's third law pair because it does not act on the same body.

Jason noted the scientifically correct response that he expects from his students: The normal force that the chair exerts on me, up, and the normal force that I exert on the chair, down.

The above statements from the story of Jason's teaching were used to develop Formative Assessment Tool Three, which aims to help student teachers understand the nature of action-reaction force pairs in a Newton's third law problem, specifically, that the forces of action and reaction do not act on the same body.

Scenario 3:

Jason, a science teacher with deep physics knowledge, asked his students to visualize themselves sitting in a chair. Then he asked them to describe their experience using Newton's third law force Pair in this situation.

One of his students responded: There is a normal force being applied, up, on me by the chair and a gravitational force being applied, down, on me by the earth.

A: What misconception might this student be presenting?

3B: What learning difficulties will this misconception pose for this student's understanding of Newton's Laws?

2C: What teaching strategy would you use to develop the scientifically correct idea?

Figure 5.4: Formative Assessment Tool Three

5.5.4 Formative Assessment Tool Four: Action and reaction forces are equal in magnitude— Newton's third law pair

Jason pointed out another challenge that is the basis for Formative Assessment Tool Four. Students do not trust Newton's third law and, in particular, the idea that in a Newtons' third law pair, action and reaction forces are equal in magnitude and opposite in direction. He noted that the reason for this lack of trust in Newton's third law is caused by two alternative ideas held by these students:

- A large object is going to apply a larger force to another object.
- An object that is moving faster will apply a larger force than an object which is stationary.

Jason provided a further explanation that in an interaction between a large object and a small object, students are unable to observe that large objects do not move when a smaller object exerts a force because the acceleration is small. Since, there is a huge difference in terms of their mass, causing a smaller or bigger acceleration, an application of Newton's second law of motion (F=ma), leaves students unable to see the reaction force, as they cannot see the large object moving.

Jason suggested various strategies to help students understand Newton's third law better including two examples used together: (a) the interaction between two atomic particles, such as electrons, and (b) a freight train hitting a fly. He believes that describing the interaction between small particles helps students understand the action and reaction forces are equal. The second example helps them understand that forces are still equal but that acceleration, in this case, is dramatically different due to the difference in mass.

I used Jason's topic-specific science PCK to develop Formative Assessment Tool Four, which aims at engaging pre-service science teachers in deep discussion about Newton's third law

of motion. The example demonstrates that action and reaction forces are equal in magnitude, but sometimes not observable due to the difference of the mass of the objects.

Scenario 4:

Experienced science teacher, Jason is teaching about Newton's 3rd Law of Motion, using the example of a boy pushing against a wall.

A student comments: The force applied by the wall is bigger than the force applied by the boy, so how can they be equal?

4A: What misconception might this student be presenting?

4C: Jason used the following two examples to help this student. How can these examples help this student better understand Newton's Third Law of Motion?

Example 1: A subatomic particle interacts with another subatomic particle.
Example 2: A fast-moving train is hitting a fly

4B: How would you help this student with their understanding of Newton's 3rd Law of Motion?

Figure 5.5: Formative Assessment Tool Four

5.5.5 Formative Assessment Tool Five: Distinguishing Newton's third law of motion from Newton's second law

Jason noted that some of his students were often confused about Newton's second and third law of motion. He could identify this learning problem when his students picked Newton's third law force pair wrongly. To help them distinguish between Newton's third law from his second law, Jason created examples to help students conceptually understand both the laws.

One such example is of a train accelerating towards left while the train engine is pulling two cars A and B. He asks his students, two questions to help them identify Newton's third law pair first. These questions are:

1. What force does car A exert on car B?
2. What force does car B exert on car A?

After having students understand Newton's third law pair in this example, he asks a third question to help them see how Newton's second law is applied in this situation:

3. What force does the train engine exert on car A?

Based on this example described by Jason, I developed Formative Assessment Tool Five.

Scenario 5:

Experienced science teacher, Jason, is concerned that some of his students are still confused about the application of Newton's second and third laws in real-life situations.

To help these students, Jason used a scenario where a train is accelerating and the train engine is pulling two cars, A and B. He asked the questions:

5A: What force does car A exert on car B?

5B: What is the force exerted by car B on car A?

5C: What force does the engine exert on car A?

5D: How can the above two questions help students separate Newton's second law from his third law? Explain.

5E: Can you identify a similar scenario to be used to deal with the problem?

Figure 5.6: Formative Assessment Tool Five

5.5.6 Formative Assessment Tool Six: Sequence for teaching Newton's three laws of motion have an impact on students' learning of these laws

Jason noted that the sequence in which Newton's three laws are presented to students affects students' learning of the laws. Based on his experience of teaching these laws, he suggested that teaching Newton's third law of motion first (before second or third law) helps students' understanding of force and motion. It is interesting to note that Loughran et al. (2006) also found that introducing Newton's third law first helped in understanding force and motion topics.

He achieved this by teaching action and reaction forces as the types of force towards the end of a discussion on force to help his students' understanding of Newton's third law of motion, which says that action and reaction forces are always equal but act in the opposite direction. Jason stated that Newton's third law, the action and reaction force pair, fits well into the discussion about force, and helps students understand Newton's laws better. He then introduced Newton's second law of motion, and later Newton's first law if required.

Based on Jason's idea about effective teaching sequence of Newton's three laws of motion, I developed Formative Assessment Tool Six, aimed at engaging pre-service science teachers in a discussion about choosing a particular sequence for introducing Newton's laws and how it may affect students' learning.

Scenario 6:

Experienced science teacher, Jason has taught his students about force at the beginning of the unit.

Now he plans to teach about Newton's Laws of Motion.

6A: What do you think is the best sequence to build an understanding of Newton's Laws? Please choose from the following.

a. 1st Law, 2nd Law, 3rd Law
b. 2nd Law, 3rd Law, 1st Law
c. 3rd Law, 2nd Law, 1st Law
d. 3rd Law, 1st Law, 2nd Law
e. 2nd Law, 1st Law, 3rd Law
f. 1st Law, 3rd Law, 2nd Law

6B: Explain why you chose the above sequence and what effect the sequence will have on students' understanding of Newton's Laws.

Figure 5.7: Formative Assessment Tool Six

5.5.7 Formative Assessment Tool Seven: An object changing direction always has acceleration

Jason identified an issue where his students appear to miss the point that "if an object is changing direction, it must have acceleration." He showed concern that students may have difficulty solving the numerical problems related to acceleration.

To help students learn that when an object is changing direction, it always has acceleration, Jason uses a popular demonstration in physics, using a Predict—Observe—Explain (POE) format, explained in detail in his story of teaching in Chapter Four at p. 196 . He described demonstrating a marble moving inside the masking tape, using a POE approach to help his students *observe* that when the marble was moving inside the tape it followed a circular path and the direction of acceleration of the marble was inward, towards the center of the circle. He notes that he asks students to:

1. Predict: What direction the marble is going to go if the tape is lifted?
2. Observe: Lift the tape, and let students observe carefully. Then help them articulate their observations.
3. Explain: Engage students in meaningful discussions about the direction of the acceleration of the marble.

Jaso's ideas guided the process of developing the Formative Assessment Tool Seven, which is presented in Figure ?. This tool aims at engaging student teachers to discuss the direction of acceleration of an object moving in a circle, not changing speed but only direction.

Scenario 7:

Experienced science teacher, Jason, uses a demonstration where he spins a marble inside a roll of masking tape.

He asked his students, "What will happen to the marble if I lift the roll of tape?"

Then, he lifted the roll to help his students observe.

7A: What physics concept do you think Jason intends to develop?

7B: Which Newton's law might he be teaching?

7C: Using this demonstration, which concepts will you build for your students?

Figure 5.8: Formative Assessment Tool Seven

5.5.8 Formative Assessment Tool Eight: Engaging First Nations students in culturally relevant science learning

Dave noted that it is difficult to engage First Nations students if educational experiences are not culturally relevant for them. Therefore, he uses particular examples in his science classes to engage them. Since, Dave believes that using specific cultural objects helps students participate when learning experiences are personally and culturally relevant and meaningful.

Dave used snow shoes to teaching about friction in one of his science classes, and an arrow to teach about projectile motion.

I used Dave's ideas to develop Formative Assessment Tool Eight, which aims at engaging pre-service science teachers in discussion about students' cultural background and how they can impact the learning of a specific science topic.

Any diversity issue should be considered in the context of a specific science content to be a part of the pedagogical content knowledge. This formative assessment tool may guide pre-service science teachers to think about the science concepts that Dave tried to teach. The discussion can be deepened with discussion questions towards other cultural backgrounds present in a science classroom, and ways to accommodate these during science lessons.

Summary: The above eight formative assessment are only examples of developing such tools from the stories of teaching. Further, my plan is to combine a set of tools from each of the topic-specific science PCK and present them in the form of an instrument that can be used to diagnose or assess teachers' PCK of teaching force and motion topics. Moreover, these formative assessment tools need to be developed and improved further by studying their impact on pre-service and in-service teachers.

Scenario 8:

Dave, an experienced science teacher, has planned an interesting science class to engage students from other cultural backgrounds.

He brought snowshoes and an arrow.

8A: Which cultural backgrounds might he intend to address by using these?

8B: Which science concepts will he be teaching in his classroom?

8C: What other objects, resource, or approached might be used to engage First Nations students while teaching force and motion ideas?

8D: Please think of other cultural backgrounds that your future students might have. Select one, and explain how you might engage that students group while teaching force and motion ideas.

Figure 5.9: Formative Assessment Tool Eight

5.6 Using the Formative Assessment Tools

In this section, I make some suggestions about how to use the formative assessment tools as a means to engage pre-service science teachers' thinking and thus develop their topic-specific science PCK. I also discuss the possibility of using the tools as diagnostic or assessment tools.

5.6.1 Example One: Using Formative Assessment Tool Four

Formative Assessment Tool Four is designed to help student teachers understand Newton's third law pair, the action and reaction force pair, in a real-life situation. It will also help them to deal with alternative ideas their future students may have about this law, and gather effective ways to teach this law. This formative assessment tool can be used as a learning and teaching tool, as a diagnostic tool, or as an assessment tool.

5.6.1.1 Use as a learning about teaching tool

Step 1: Present the scenario used in the tool to a group of pre-service science teachers.

Experienced science teacher, Jason, is teaching about Newton's third law of motion, and using the example of a boy pushing a wall. A student comments: The force applied by the wall is bigger than the force applied by the boy, so how they can be equal?

Step 2: To explore pre-service science teachers' understanding about their students' alternative ideas in a Newton's third law of motion problem, ask them the following focus questions:

Focus Question A: What misconception might this student be presenting?

Step 3: Let student teachers discuss in small groups and find the correct misconception—that the student in the given scenario thinks that small objects apply a small force, while big objects always apply a big force.

Step 4: Post the second discussion question.

Focus Question B: How would you help this student with his or her understanding about Newton's third law of motion?

Divide them into small groups, let them think of strategies, and note them down.

Step 5: Each group will present their strategies to help the student modify his or her misconception that small objects always apply a small force while big objects apply a big force.

Note: If you think students have not identified really effective strategies, you can think of designing a lesson on this area.

5.6.1.2 Use as a *PCK diagnostic* tool

Formative Assessment Tool Four can help diagnose the knowledge of science teachers in the category of students' alternative ideas, especially the alternative idea that small objects apply a small force while big objects apply a big force. Have pre-service teachers complete the tool (Figure 5.5). Their answers and their reasoning will contribute to an exploration of their understanding of this alternative idea. This process will help them learn how they can help students confront and modify this idea into a more acceptable scientific idea. By diagnosing the learning needs of the pre-service science teachers it will help them in developing PCK in this knowledge category.

5.6.1.3 Use as a PCK assessment tool

Formative Assessment Tool Four can also be used to assess science teachers' PCK and their knowledge of students' alternative ideas about force and motion. Print Formative Assessment Tool Four (Figure 5.5) and provide to the individual science teachers. Their answer and the strategies they offered can be used to explore their unique understanding of how science teacher grapple with their students' alternative idea that small objects apply a small force while

big objects apply a big force. This alternative idea causes a serious learning difficulty in understanding Newton's third law of motion.

5.6.2 Example 2: Using Formative Assessment Tool Six

Formative Assessment Tool Six is designed to engage pre-service science teachers' thinking about organizing content. Specifically, it involves organizing the presentation of Newton's three laws to maximize the students' understanding of these laws. The tool can also be used to assess the science teachers' understanding of using various sequences in introducing Newton's three laws of motion, as well as how their choice of a particular sequence affects their students' learning.

5.6.2.1 Use as a learning about teaching tool

Step 1: Present the scenario used in the tool to a group of pre-service science teachers:

Imagine, you have taught the students about force at the beginning of the unit. Now you are planning to teach about Newton's laws.

Step 2: To explore and guide the thinking of pre-service science teachers about the advantages and disadvantages of introducing Newton's three laws of motion in a partciular sequence, use the following guiding questions to initiate a classroom discussion:

Discussion Question 1: What do you think is the best sequence to build understanding of Newton's three laws? Please choose from the following:

a. 1st Law, 2nd Law, 3rd Law
b. 2nd Law, 3rd Law, 1st Law
c. 3rd Law, 2nd Law, 1st Law
d. 3rd Law, 1st Law, 2nd Law
e. 2nd Law, 1st Law, 3rd Law

f. 1st Law, 3rd Law, 2nd Law

Allow enough time for each student teacher to choose one of the given sequences and write down at least one reason for using this sequence.

Step 3: Divide the class into small groups based on the choices the student teachers made. Use discussion question two for each small group discussion to identify the pros and cons of introducing Newton's three laws in this sequence**.**

Discussion Question 2: Explain briefly why you chose the above sequence and what affect the sequence would have on students' understanding of Newton's laws?

Step 4: Ask each group to present their ideas, and allow equal time for each group. The presentations from each group will help student teachers review their answer and perhaps revise what they think will be the best sequence.

Step 5: Conduct a wrap-up discussion by asking students if they would like to change their choice? Why or why not? This will help students consolidate their thinking about introducing Newton's three laws in a particular sequence. If there is a sequence not selected by anyone in the class, include it during this wrap-up discussion.

5.6.2.2 Use as a PCK diagnostic tool

The formative assessment tool six may help in diagnosing the knowledge of science teachers in the category of subject-matter knowledge. Have pre-service teachers fill out the tool (from Figure 5.7). Their answers and their reasoning can contribute to exploration of their unique understanding about sequencing Newton's three laws of motion for effective teaching, and how

best to teach this material to their students. In diagnosing the learning needs of the pre-service science teachers they can be helped in developing PCK in this particular knowledge category.

5.6.2.3 Use as a PCK Assessment Tool

Have pre-service teachers fill out the tool (from Figure 5.7). Their answers and their reasoning can help explore the unique understanding of a science teacher about introducing Newton's three laws of motion, which can help evaluates their PCK related to organizing a specific science curriculum topics.

5.7 Developing PCK Cases

I have developed cases based on the four stories of teaching force and motion ideas, as these findings can be used to develop the PCK of pre-service and in-service science teachers.

5.7.1 PCK case – Teaching Gravity

For example, I selected particular fragments from Monica's story of teaching force and motion ideas, and shaped these into a teaching case (Figure 5.3) that I call PCK case—Gravity. This case can be used to help pre-service science teachers develop topic-specific science PCK to teach gravity by generating a discussion about teaching this topic. The following section describes some guiding questions to generate rich classroom discussion.

5.7.1.1 Focus Questions for a Discussion on PCK Case

1. Identify a problem of learning that Monica talked about, and analyze her ways of dealing with this problem. If faced with a similar situation in your classroom, how would you respond to the same problem?
2. Identify a teaching approach that Monica used, and analyze how effective this teaching strategy was. If you have used the same strategy, what would you change and why?
3. Identify some of the teaching resources Monica described. Please add at least THREE more resources to this list.

Experienced science teacher Monica selected the topic, gravity, to have a conversation about her science teaching. When asked to describe an event or incident to provide an insight into her teaching of gravity, Monica said, “The kids have a pretty good idea about what gravity is when they come into the classroom.” She further stated, “If you drop something on the floor . . . the kids pretty much know that is gravity…gravitational pull.” She added that “for the most part, it is pretty self-explanatory; all of the kids know, they have a pretty good idea of what it is.”

In response to a query about how she knows they have an understanding of what gravity is, she maintained that “they are able to provide enough examples that . . . [show that they] have this understanding about gravity.” She expressed her concern that “the only difficulty that they [usually] have is . . . when we move away from the earth, the gravitational pull decreases, [and] that is something they cannot conceptualize because they cannot see it.”

Monica explained that “when you just try and tell them . . . the gravitational pull on the moon is less than the earth, [and this] . . . is because the earth has a larger mass than the moon. They do have a little bit of difficulty with that, but the actual gravitational pull on the earth— they can understand it. ”

According to Monica, “Gravitational force is basically a pulling force that pulls objects towards the center of the earth.” She wants her students to understand that concept. Monica explained that she commonly teaches about gravity by having her students drop various objects from a certain height and observe that they all hit the ground at the same time. In her words: “We use different objects and I get [them] . . . to test and see if they fall different[ly] . . . Then they come up with their conclusions. That is . . . a pretty important concept and I let them . . . try and figure it out.” When asked about the kind of objects she usually prefers to use, Monica said, “Anything from lightweight objects to a book, a ball, a piece of wood, a feather, and then they are amazed that they fall at the same time.” Monica has not used any other resources or technologies to teach about gravity because she thinks that “it is a very small portion of the unit” and she does not spend a lot of time on it.

Monica shared her feelings that “unfortunately sometimes we just teach to tests.” She further said that “There are some topics that we cover . . . that we are not sure. . . how to make that understanding come across. . . even though we do not have a full understanding of why it is important.” When asked about her critical view on how the topic of gravity is included in the program of study, Monica kept her response simple, saying,

> Hm…Like I said before, it is a concept that needs to be covered; it is in the program of studies. And we need to make the kids aware of this concept as best as we can, even though we do not have a . . . full understanding of it. Just, to actually introduce the idea of gravity and gravitational force. . . so that if that term comes up again they would be able to . . . feel confident that they have enough understanding . . . [to] . . . apply it.

The discussion continued about the concept of gravity and the way it is included in the science curriculum, and Monica noted, “Yes, it is not really a concept that is well defined in the curriculum, but it is in the textbook, and I think it is important for them to understand.”

When asked if textbooks sometimes have variations and may focus on topics not included in the curriculum, Monica said they did, saying, “Yes, and even though it is not in the curriculum, I think they still

need to know a little of what gravity is, and that's why I try [to talk about it]." She added that teaching about gravity is important to grade seven and eight students because they are going to be talking about space science in grade nine, so they need to have some kind of idea [of] what gravity is. . . . It is important to discuss it [gravity] now, because it is one of the forces, just like magnetism or buoyancy . . . It is important that they understand that there are different types of forces, and so it does fit with what we are doing now. But it also fits with the grade nine science unit as well, and they can talk about gravity and what happens when you travel in space. . . . weightlessness, and things like that.

Monica thinks that if she has to teach about gravity in an altered curriculum context, school, or geographical settings, she will keep it "really simple . . . and [will] use the same activity and demonstration." She asserted: "If I was in a different place, or [in] a different, rural area . . . I will try to use the same ideas."

She mentioned using the real-world example of a canoe, where she asks her students, "What are the forces on the canoe, and why is it able to float?" Then she discussed with her students "the pulling force of gravity and the pushing force of the buoyancy of the water. . . [to] give them an idea of how things float." Monica expressed her feelings about a lack of focus on history of science. In her words:

> One of problems with . . . the curriculum is, it is [so full of] . . . facts and figures and laws and theories that sometimes we forget the human component, the people and history behind all of these discoveries—so that is something missing in our curriculum for sure . . . . We never get a chance to get into the historical aspect of how this idea came about . . . I mean, we mention Newton, but do we ever get into any depth about him . . .or James Joule or . . . I mean other than recognizing that these people came up with some of these concepts. I think that is a problem with our curriculum.

Monica does not remember how she was taught the concept of gravity as a student, and said, "I came up with these ideas after I started teaching; I really do not remember a lot about gravity from my junior high or senior high school. But a lot of this is coming after I got a job and started teaching science."

Figure 5.10: PCK Case—Teaching gravity

5.8 Other Possibilities

In addition providing the PCK Formative Assessment Tools and PCK cases, the stories of teaching presented in Chapter Four can be used to develop other teaching, learning, assessment tools that can be added to pre-service science teacher education curriculum. The value of the use of these tools lies in the fact that they are based on descriptions of the experiences of real classroom teachers. For example:

1. Any one of the topic-story can be provided to the pre-service science teachers, and they can be asked to analyze the PCK using the conceptual framework, Comprehensive topic-specific science PCK. This exercise can help them organize their knowledge of teaching science.
2. Any one of the four stories of teaching can be provided to the pre-service science teachers, so they can analyze the science teaching presented in the story and make recommendations to improve it.

Personally, I continue to think about possibilities for developing teaching, learning, and assessment tools from the narrative data, and ways to use these tools in science-teacher education, whether as pre-service or in-service tools.

5.9 Summary

This research has attempted to highlight the importance of studying topic-specific science PCK to understand science-teacher thinking and practices more deeply, and to contribute to the development and understanding of the PCK construct. Studying teaching in various content areas can help reveal how experienced teachers transform their knowledge of a specific science content to make it comprehensible for their students, and how they use their knowledge of pedagogy to teach that science content. In this work, I have explored the personal and practical knowledge of teaching science. I believe that when documented and used strategically, this information will help pre-service science teachers better prepare for teaching science. It can also help experienced teachers deepen their practice.

Chapter Six: REFLECTIONS, IMPLICATIONS, AND FUTURE RESEARCH

This chapter concludes the research study. In this chapter, I reflect on my experiences of learning about science PCK, the challenges faced during the research, including limitations on the project. I also consider implications of this study and make suggestions for further work research.

6.1 Reflections

6.1.1 Reflections on My Learning about PCK

I discuss the learning in this research study about the PCK of science teachers in light of the existing literature on science PCK. The titles of the following subsections reflect the themes of the discussion and reveal my thoughts and ideas.

6.1.1.1 Explicit PCK and implicit PCK

This study made an effort to use teachers' descriptions of their conceptualizing and teaching of force and motion topics to study their topic-specific science PCK. Previously, others have discussed PCK as tacit knowledge— not transferable, and implicit knowledge—not easy to articulate (Lee, 2005; Loughran et al., 2006). However, this study reveals that science teachers may, in fact, be able to articulate some or all the components of their PCK as explicit knowledge. To be part of their explicit science PCK, science teachers need to be able to provide their reasoning for using a particular approach to teach a science topic in a specific pedagogical situation. For example, a particular teaching strategy used by a science teacher becomes part of his or her explicit PCK only when he or she is able to provide a description and their reasons for using this strategy to develop students' conceptual understanding of the topic. I call this *explicit PCK*, something that science teachers can describe and articulate with clear reasoning.

At the same time, this study corroborates the previous findings noted above, in that it supports the view that science teachers may still have some knowledge components of PCK, even though they did not necessarily provide their reasoning at the time of the interview. The reasons might include lack of clarity in the questions asked, the way questions were phrased, and the time available for discussion. Therefore, they may have PCK that still needs to be explored. This is what I call *implicit PCK*. Here, I present examples of explicit and implicit PCK from Kevin's story of teaching force and motion ideas.

Examples of explicit and implicit PCK. When Kevin teaches about force he is very clear about which concepts he has selected and how he intends to teach them. He uses a variety of manipulatives or objects to ask students to push and pull something and help them see that a push or pull has moved the object. Thus, he demonstrates that force is a push or pull, and it can move objects or stop moving objects when applied. Similarly, when teaching about friction, Kevin has used different manipulatives and is sure that he can teach the concept using a variety of manipulatives. He speaks about creating an open-inquiry environment where students will pull different objects across a surface and observe differences in the subsequent friction forces. These two examples illustrate Kevin's explicit science PCK.

In contrast, while teaching about gravity—to win his students' trust in the idea of gravity—he describes using "classroom discussion" along with using some "video clips on zero gravity . . . or less gravity." Kevin did not explain the conceptual understanding involved in this discussion or the connection between zero gravity and lack of trust in gravity. This strategy is not a part of his explicit science PCK, though it is part of his implicit PCK. In this instance, his PCK can be a tacit form of knowledge that may be hard to articulate. It may often be the case for teachers, where articulating their knowledge of teaching is not part of their job or a regular

expectation (Loughran et al., 2004). When Kevin described his teaching strategy of using graphs to help students distinguish between speed, velocity, and acceleration, he did not explain how he used them, or how they helped the students' learning. At another time, he explained that on a graph, a straight line represents constant velocity as compared to a curved line. This example illustrates the likelihood that Kevin has the explicit PCK about teaching this science topic.

In the literature, one perspective is that for PCK to be useful, it has to be explicit (Kennedy, 1998), which demands that science teachers be able to articulate their PCK. If science teachers can explain the way they teach a specific science topic and can provide reasons for those teaching strategies, this may show the quality of their PCK, i.e., how well-integrated and unified it is. This is what pre-service science teacher education intends to achieve. Engaging student teachers in learning experiences that allow them to make decisions about teaching science content in a hypothetical pedagogical situation, and then having them describe the reasons for their decisions, can lead them to develop explicit topic-specific science PCK. Similarly, involving experienced science teachers in meaningful conversations about the ways they engage with a specific science content to conceptualize it and then teach it, can lead to the development of exemplars, which improves science teacher education.

6.1.1.2 Role of the science curriculum in shaping topic-specific science PCK

My analysis of participant science teachers' stories of teaching force and motion ideas, including plotting their knowledge categories along the continuum from general to specific science PCK, shows that their topic-specific PCK is shaped largely by the science curriculum and the specific grade levels they teach. That my research participants were from various grade levels played a significant role in revealing this aspect of their topic-specific PCK. As Jason teaches at the high school level and Monica primarily at the junior high level, the way they

approach the content must necessarily be different, given the content requirement, and learning capacity and stages of their students.

Jason has taught force and motion topics in the context of the Alberta Program of Studies, Physics 20 and post-secondary courses on introductory physics, both embedded in the area of basic mechanics, covering force and motion ideas. Both course outline largely identified examples, activities, and resources for force and motion ideas.

Monica's current experiences of teaching force and motion topics are in grade seven, but she has some experience of teaching grade eight and nine science. She articulated ideas about force mainly in the context of structures, which appeared to be influenced by the grade seven unit, Structures and Forces, in the Alberta Science Program of Studies. However, while talking about friction, she brought up examples from the grade eight unit, Mechanical Systems. Similarly, while talking about gravity she raised the example of teaching about the solar system, which is in the grade-nine unit, Space Exploration. As Monica had some experience of teaching the old science curriculum (specifically the grade seven unit, Forces and Motion), she spoke briefly about Newton's laws of motion, though she did not provide any examples, activities, or resources that she has used to teach these topics. Interestingly, Monica shifted the focus of our conversation from force and motion to force and structures, even while we engaged in our discussion about force. That suggests that her ideas about what it means to be a science teacher are influenced by the science curriculum she teaches, which in turn may have influenced her topic-specific science PCK related to force and motion ideas.

Kevin's current teaching experiences include teaching grade eight science and mathematics. He has also taught grade seven science in the past. His topic-specific science PCK of teaching force and motion topics appears to be influenced by the grade eight science unit

Mechanical Systems. He defines force both in terms of motion and structure, which might be due to his teaching experience in grades seven and eight science, or influenced by his undergraduate physics study. His discussion about teaching the topic, friction, is mainly in the context of machines and mechanical systems. The details he provided about his teaching activities are in the same context. While talking about acceleration, however, he briefly mentioned the role of friction in motion. Kevin's topic-specific PCK related to force and motion topics appears to be shaped by the science curriculum he was teaching. However, it also appears that it has been influenced by other sources he mentioned, such as his undergraduate physics study, his interest in physics, and a professional development session he attended on force and motion.

Dave works in a different situation from the other three participants, as his current role involves providing curriculum support and workshops for the professional development of science teachers, in addition to some classroom teaching. Since he had no undergraduate training in physics and usually taught other science topics, he relied on searching on his own for teaching ideas or on fellow teachers' ideas and resources when he had to teach force and motion topics. The curriculum context to discuss the force and motion ideas for Dave included predominantly the grade ten unit, Energy Flow in Mechanical Systems, and some discussions in Science 20-30 and Science 14-24. Thus, his topic-specific PCK related to force and motion topics emerges as being significantly influenced by these curriculum contexts. For example, while talking about teaching force, he mentioned the example of a pulley, which he stated could change the input force. This example comes from Science 20-30, taught to grade 11 and 12 students. Similarly, his discussion about car collisions is an example from Science 14-24, also taught to grade 11 and 12 students. He spent considerable time during the interview discussing the topics of scalars

versus. vectors, and distance versus displacement, which are part of Science 10, which he teaches regularly.

In summary, the participants' references to the topic-specific PCK related to teaching force and motion topics appear to be shaped largely by the topics they encountered in the science program of study that they were teaching. This is evident from the diverse selection of related topics they selected for our conversations, as well as from the ways they approached these topics for teaching. This suggests that the ways science methods courses prepare teachers to teach science at junior and senior high schools might best be organized as separate science methods courses for each level, with substantial opportunities specifically related to the science curriculum topics educators are expected to teach.

6.1.1.3 PCK conceptualized as knowledge of practice

The above discussion points to the ways in which the participant teachers developed their topic-specific PCK related to force and motion largely as a result of their practice of teaching these topics. All four participant teachers indicated that they did not learn content knowledge about force and motion topics when learning to teach during their teacher education programs. With the exception of Jason, none of the participants studied physics at an advanced level. Kevin took a physics course during undergraduate study, but Dave and Monica did not study any physics after high school. This suggests that participants' topic-specific science PCK is grounded in their practice of teaching, and is an aspect of their practical knowledge. Therefore, defining PCK as the knowledge that is required by science teachers to teach science content (Shulman, 1987) appears to be problematic.

In light of the findings of this research study, I prefer to take a position and define PCK as knowledge of teaching science content that teachers have, as a result of teaching specific

science topics. Moreover, experienced science teachers' PCK provides a structure for the knowledge that we can hope a science teacher needs to develop in order to become an effective teacher. This suggests the usefulness of exposing pre-service science teachers to examples of documented topic-specific science PCK, and using the frameworks such as Co-Res and Pap-eRS developed by Loughran et al. (2004, 2006) and the teaching, learning and assessment tool that I have developed in the present research. I argue that the comprehensive topic-specific science PCK can provide a useful structure for pre-service science teachers to organize their topic-specific science PCK.

6.1.1.4 New ways of understanding and defining science PCK

The present research contributes to a reconsideration of the ways in which science PCK is defined. Since Shulman (1986) introduced the concept of pedagogical content knowledge, it has gradually been changing. A consensus has been reached that PCK has subsets, constituent parts, or components that combine together to comprise the PCK of a science teacher, but no agreement exists about what these components are (Abell, 2007). The PCK concept has expanded in terms of ideas about the nature of teacher knowledge components included in it.

Some scholars believe that some knowledge categories are *included* in PCK, while some only *influence* it. This distinction is present in the theoretical framework such as the one suggested by Abell (2007), though the distinction is not clarified and, more importantly, has not been reported by researchers who studied the PCK of classroom science teachers.

Few researchers in the field of science education have studied the PCK of science teachers with the sole purpose of understanding the PCK construct and elaborating its concretization (Lee & Luft, 2008; Park & Oliver, 2008). Some researchers have devoted their research to studying topic-specific science PCK of teachers (Loughran et al., 2001; 2004; van

Driel et al., 1998), while some of them documented the topic-specific PCK of science teachers with an aim to use this knowledge to help pre-service science teachers to develop their topic-specific science PCK.

In the context of teaching science, Lee (2008) found seven knowledge components of PCK, shared by her four participant science teachers: (a) science, (b) goals, (c) students, (d) curriculum organization, (e) teaching strategies, (f) assessment strategies, and (g) resources. Knowledge of resources for teaching was a new component that she introduced as a component of science PCK.

The literature on PCK notes that individual knowledge components within science PCK are interrelated and provide various frameworks, popularly called PCK models, to manifest these relationships, which are far from consistent. The attempts to understand general science PCK has added to the complexity of understanding the concept of PCK. The present research attempted to study and understand PCK from the topic-specific standpoint, and through science teachers actually describing their experiences of teaching specific science topics. This research affirmed Lee's (2008) findings that knowledge components are interrelated within the context of science teaching, as presented in participants teachers' topic-stories, and "play as a class of knowledge that is central to science teachers' work" (p. 156). However, this study explored ways to identify these PCK components by employing the comprehensive topic-specific science PCK as a conceptual framework.

Shulman (1986) defined PCK as "the unique knowledge for teaching science (p. 9). Lee (2008) argued that PCK was much more than that. She attempted to define PCK as the application of that knowledge by science teachers in their pedagogical decision and actions to (a) improve students' understanding of scientific concepts, and (b) encourage student scientific

inquiry through using effective instructional strategies, representations, and assessment strategies within diverse teaching situations.

The study expands on the definitions of PCK that are covered in the literature review. I define PCK as a unique form of teacher knowledge that lies (a) in individual teachers' practice of teaching science content, and (b) at the intersection of their conceptual understanding of the science content and the pedagogical knowledge of teaching this content. Science teachers' PCK contains various knowledge components as described before, with the addition of new components. PCK is informed or influenced by ten knowledge categories as I outlined in Chapter Two: (a) knowledge of content, (b) knowledge of student learning and/or knowledge, (c) knowledge of instructional strategies, (d) knowledge of science curriculum, (e) knowledge of goals, (f) knowledge of teaching resources, (g) knowledge of technology, (h) knowledge of teaching contexts, (i) knowledge of assessment, and (j) knowledge of student diversity. I added two knowledge categories: knowledge of technology and knowledge of student diversity. The category, knowledge of technology is inspired by the concept of technological pedagogical content knowledge (TPCK), while I introduced the knowledge of student diversity category based on my own experience as an educator. Each of these ten knowledge categories contributes a specific component to science PCK. Each PCK component lies at the intersection between content knowledge and one of the other nine knowledge categories. Moreover, each PCK component further consists of knowledge elements or aspects that are in the form of events, incidents, or even stories of teaching the science content.

The study helped to situate PCK on a four-level PCK continuum from general science PCK to topic-specific science PCK, which also helped to develop a connection between general

science PCK and the topic-specific science PCK. This led to an operational definition of topic-specific science PCK.

I attempted to define topic-specific science PCK in light of the findings, since I believe defining science PCK at the topic-specific level may help to clarify the composition of science PCK of teachers, which is the core professional knowledge of teaching science. Therefore, I recognize topic-specific science PCK as the application of the nine knowledge components on a single science topic (content knowledge) by science teachers, to improve their students' understanding of this topic by engaging them in meaningful activities and discussions—a way to (re)define PCK as an integration between content knowledge and pedagogy. Moreover, I distinguish topic-specific science PCK as a unified form of knowledge pertaining to the quality of science PCK, as compared to general science PCK of any science topic area—which is useful but is less unified, where unification means to be unified or integrated with a specific science content.

I also find it important to define "topic" in the topic-specific science PCK. The *topic* could be a single concept: for example, "force is a push or a pull." The topic could also be a *set* of related topics as they are presented in science programs of study. I find it helpful to study interrelated science topics as a means to develop a science teacher's spectrum of science PCK. In this, I agree with Loughran et al. (2006). A description of science teachers' knowledge of the related science topics warrants a well-defined PCK related to a number of science topics. This can then be used as an exemplar or prototype for pre-service science teachers. Considering topic-specific science PCK as useful knowledge to guide science teacher education curriculum, I find it valuable to study and document PCK at the topic level.

6.1.2 Hurdles in the study

Not surprisingly, several hurdles were faced during the progression of this research study, as is common with any research project. I find it worthwhile to note these challenges since they have had a significant impact on the research. They can clarify some of the limitations of this research study and provide information to other researchers who study PCK using a narrative inquiry approach.

6.1.2.1 Shifts in the design at the developmental stage

From the outset, the focus of this research study was to examine PCK and develop assessment tools to assess science PCK. However, the approaches proposed for this study were very different from those I actually used. The initial approach was a mixed-method research design, and the assessment tools I sought to develop were similar to conceptual tests. These initial ideas were influenced by the personal experiences and the early supervision I received in this project from my first supervisor, who has since left the university. I believed that these types of assessment tools are required to achieve the goals in pre-service science teacher education. Later, I found that to pursue my area of interest, it was necessary to gain a deep understanding of topic-specific science PCK in various science topic areas.

The first shift happened after looking at the scarcity of the literature on topic-specific science PCK in various topic areas, which resulted in a major new orientation towards studying topic-specific science PCK through descriptions of the experiences of practicing science teachers. A secondary goal then emerged to develop assessment tools from the narrative data. I came to realize that initiating assessment of topic-specific science teaching requires extensive study of teachers' existing topic-specific PCK in the given topic area. I needed to use various methodologies to accomplish this.

6.1.2.2 Finding suitable participants

To study and understand topic-specific PCK of science teachers, suitable participants were required. In particular, I was seeking science teachers with specific training and education to learn how their topic-specific science PCK is shaped by different experiences related to a science topic. However, I discovered that finding science teachers with these specific types of experience was a bigger challenge than I had expected.

Additionally, the research study demanded a detailed discussion about a specific science content field, force and motion, and about how experienced educators teach that content. However, the discussion of this specific content was not always a priority for the participant science teachers who had backgrounds and experiences in other science areas, even though they all taught the topic related to force and motion. To encourage participant science teachers to talk about their science teaching experiences in the context of specific content, and not more generally, was often a challenge. Many times, the participant teachers would cross boundaries to other topics when they did not have a specific example to share in the topic area that was used as the context for this research study.

6.1.2.3 Scheduling interviews

The research study involved a long list of topics, and many questions needed to be asked in each topic to articulate fully the knowledge these teachers had to share. Each interview was longer than an hour, and two to three such interviews were required from each of the participant teachers. To schedule interviews with teachers with extremely busy schedules was not easy, and the intrinsic motivation of the participants was the major factor that kept the interviews going. For future studies, the list of topics could be shortened or an extrinsic motivation factor could be added.

6.1.3 Limitations of the study

The research study aimed at understanding secondary science teachers' topic-specific science PCK associated with teaching force and motion, and the development of assessment tools for the PCK of teaching this topic area. The research does not attempt to encompass all the topics related to force and motion and does not purport to portray the wider PCK of secondary science teachers. Moreover, the assessment tools developed to assess the PCK of secondary science teachers do not cover all the topics related to force and motion at junior and senior high school levels. Validating further the developed assessment tools using various approaches would be a useful endeavour for a future researcher.

The literature on science teachers' PCK shows that PCK is both topic-specific, domain specific, and discipline-specific knowledge, which demands that research in science teachers' PCK be situated in the topic-specific PCK within the specific domain of science. The PCK of science teachers varies from discipline to discipline and more specifically from topic to topic within one discipline. For example, a science teacher's PCK of teaching physics will be different from the PCK of teaching chemistry; moreover, science teachers' PCK for teaching certain topics of mechanics will be different from PCK for teaching topics in electricity. Above all, the PCK of science teachers will vary with the grade levels they teach, so the PCK of elementary science teachers will be different from the PCK of secondary science teachers and so on. Therefore, the PCK of science teachers required some limitations for this particular research study.

The present research focused on understanding the PCK of secondary science teachers and resulted in developing formative assessment tool that can be used to develop and assess secondary school science teachers' PCK of teaching force and motion topics. Refining these

tools further was beyond the scope of this research study. Therefore, further research could improve these tools, which might involve studying the experiences of a large number of science teachers with various backgrounds, using the same approach as in this study or using other methodologies. Moreover, conducting research studies using various methodological frameworks will help to firmly establish the validity and reliability of the assessment tool created here. This research study was limited in this regard due to its small sample size.

Similarly, the research study involved a narrative inquiry and represents the experiences of four specific secondary science teachers. These experiences are only a "slice of [the] narrator's life" (Walker, 2003, p. 18) and do not describe the PCK of participant teachers in other areas or other topics in science. Due to the qualitative nature of the research, the results and findings of the study cannot be generalized or likely explicitly replicated. A small sample size has been used to build understanding of major considerations and categories in the research. It is not proposed that these participants represent all secondary science teachers. The participant science teachers involved in this research study have mostly lived and taught in the same geographic area and thus may not include wider perspectives of science PCK used by teachers in other areas.

As a researcher new to the geographic area, I believe that I brought new dimensions of science teaching to the interview conversations. However, being an outsider also posed a limiting factor on this research study. For example, some examples discussed by the participant teachers were based on the local experiences and were somewhat new for me. I had to ask further questions to clarify and get more information while interpreting these experiences. On the other hand, my experiences of teaching in the BEd program at the University of Calgary as a sessional

instructor helped me to prepare for this research in the field, as I had explored the Alberta Science Program of Studies and related curriculum materials in detail.

Rhodes (1997) noted, "Stories contain interpretations, meanings and informal theories of story tellers" (p. 5). As a researcher, I ascribed my own interpretation to the stories told. Therefore, the issues of interpretation offer certain limitations to the meanings attached to the experiences of the participant science teachers in this research study.

6.2 Implications

The implications of this research are threefold: (a) theoretical, (b) methodological, and (c) practical. In the following section, I present these implications.

6.2.1 Theoretical implications

The theoretical implications of this research lie in the development of a conceptual framework—comprehensive topic-specific science PCK—which can help to organize the PCK of science teachers. The research showed the usefulness of the conceptual framework and *PCK Continuum* to help distinguish participant teachers' general science PCK from their topic-specific science PCK.

Moreover, as discussed above, the research shows that the PCK of the participant teachers is shaped by the prescribed curriculum that they teach. This has implications for teacher education program designed, specifically the way science methods courses are offered for junior and senior high science teachers. This research points to the need for designing *separate* science methods courses for junior and senior high school curriculum.

The PCK teaching, learning and assessment tools that were developed in this research study contribute to the body of knowledge and research on science PCK by adding to the tools

that can be used to develop pre-service teachers' topic-specific science PCK. To date, only Loughran et al.'s (2004, 2006) work on Co-Res and Pap-eRs has engaged this concern.

6.2.2 Methodological implications

The research methods used in this research study are not new, but how they were used here is innovative, in particular with respect to the design of the interview questions and the analysis methods. The interview questions were developed following a systematic process of first creating a conceptual framework and then devising questions in each teacher-knowledge category. Abell (2007) had recommended this approach to access science teachers' PCK.

Polkinghorne's (1995) suggested narrative analysis method was an effective means for working with the raw transcript data to develop stories of the participants' teaching. Further, using the conceptual framework (comprehensive topic-specific science PCK) to identify narrative fragments, which were then woven together to develop a topic-story (that is, a story of teaching a single science topic) offered a unique way of developing stories of teaching that can reveal aspects of PCK. The triangulation of narrative data was also distinctive. Narrative fragments identified in topic-stories were woven together to perform narrative analysis while merging data collected for various force and motion topics.

Developing the teaching and learning tools, especially the formative assessment tools, arose from the exclusive application of the *analysis of narrative* method suggested by Polkinghorne (1995). Polkinghorne proposed this technique of analyzing stories to identify themes and conduct a thematic analysis to find answers to particular research questions. It has not been used as the basis from which to further develop useful or practical tools. In this analysis, instead of identifying themes to look for, as patterns within the stories of teaching, I focused on identifying the problem of learning force and motion topics as described by the participants and the solution

they offered. Then, I used these problems and solutions to develop scenario-based tools. This is what I have called *formative assessment tools*, since they can be used as a learning tools as well as assessment tool for pre-service science teachers, to help them develop their topic-specific science PCK.

The analysis methods used in this study present implications for future research on teachers' PCK, particularly topic-specific science PCK. These methods can certainly be useful for future studies of teachers' knowledge, to triangulate data using multiple stories in a narrative inquiry.

6.2.3 Practical implications

The practical implications of this research lie in transforming the stories of teaching, as described in Chapter Four, into teaching, learning, and assessment tools: (a) formative assessment tools, and (b) the PCK Cases. Both will help to develop topic-specific science PCK of pre-service or in-service science teachers. I developed and presented a few examples of the teaching, learning, and assessment tools in Chapter Five, along with the ways they can be used in pre-service science teacher education or for the professional development of science teachers.

In addition, using the comprehensive topic-specific science PCK conceptual framework to critique the stories of teaching may help science teachers to organize their own PCK related to different science topics. This will help them articulate this knowledge, as well as readily apply it when required in various pedagogical situations.

6.3 Future Research

This work provides a foundation for future research. Similar studies on other science topics will expand the substantive depth and findings of topic-specific PCK, which are required to understand the connection between general PCK and topic-specific science PCK as it appears

in the science teacher's practice of teaching specific science topics. Understanding topic-specific science PCK can lead to a deeper understanding the PCK construct itself, as well as establishing a clearer link between the two. This line of research can add to the literature on PCK by providing rich examples of the documented PCK of individual science teachers in various topic areas, to guide the development of the science teacher education curriculum.

A similar research study with participants who have different backgrounds and experiences could provide deeper insights to elaborate and document topic-specific science PCK examples in force and motion topics. This, in turn, will also lead to better and more relevant teaching, learning, and assessment tools in the topic area. As well, a longitudinal study could follow the teachers over time, especially during their teaching of these topics. A pre-service curriculum based on this research study could be created, one that develops the force and motion PCK of science teachers. Such a curriculum would benefit from further evaluation and study.

By examining the insights gained from these discussions with science teachers who talked about their experiences of teaching force and motion topics, this research both contributes to the literature on topic-specific PCK and extends ongoing scholarly conversations and debates on PCK and methodological practices. It offers a preliminary effort to create materials based on the experiences of real science classrooms teachers that can be used to develop the teaching skills of pre-service science teachers. In generating materials such as these new learning tools, these stories of teaching address an area that has been neglected; that is, listening to science teachers' experience to understand their PCK, and developing exemplars of documented science PCK of individual teachers and curriculum materials for pre-service science teachers.

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Appendices

Note: Read pages 389 to 398 as two-page view

Appendix A: A SUMMARY OF RESEARCH ON PCK

Year	**Researchers** **Year** **Context**	**Subject Area** **Topic Area** **Level**	Aim(s)	Teacher Knowledge Areas addressed
1988	Carpenter, T. P. Fennema, E., Peterson, P. L. & Carey, D. A. USA	Mathematics Addition & Subtraction primary (Grade 1)	Investigating the status of teachers' pedagogical content knowledge (PCK) and the relationship between their knowledge and students achievement.	Knowledge of students understanding (thinking about mathematics) Knowledge of goals of instruction
1990	Marks, R. USA	Mathematics Fractions Primary (Grade 5)	To present a description of PCK in mathematics to suggest modifications in the general conception of PCK.	Subject matter knowledge Knowledge of students' understanding Knowledge of media and materials Knowledge of instructional strategies
1993	Even, R. Israel	Mathematics Functions Secondary	To investigates the interrelations between teachers' content knowledge and PCK related to two essential features of the concept of function, arbitrariness, and ambivalence." (p. 97)	Subject matter knowledge Pedagogical content knowledge

Research Methodology, Participants and Data Collection Method	Analysis & Findings
Quantitative plus Qualitative 40 teachers from 27 schools with approximately 10 years of teaching experience in elementary schools and have average of 5.65 years of teaching grade 1. Test for teachers (writing word problem, identify difficult word problem) Teacher Interview after watching video (student solving problems) Teacher predicting problem solving strategies of students Test for students (Number facts and problem solving)	Item mean scores, standard deviation for each items, Percent correct for teachers' estimates of students' success and for actual students' performance by problem type The correlation between measure of teacher knowledge and students achievement writing word problem test (t was excluded because of ceiling affect) The teachers' ability to predict students' success in solving different problems was significantly correlated with student's performance on both the number-fact and problem solving tasks. 2. Teachers ability to predict the strategies that students would use to solve different problems was not significantly correlated with either measure of student performance.
A qualitative Study Eight teachers (six experienced and two novices). Task based interviews (8 tasks) for 45 and 90 minutes (The tasks used were previously developed for a large research (Teacher Assessment project at Stanford University, 1986-89, directed by Lee Shulman project on alternative forms of teacher assessment) All the tasks focused on fifth grade mathematics teaching and included planning a lesson, analyzing a classroom videotape, and diagnosing and remediating students' errors.	All interviews were transcribed in full (Initially 900 selections were made for texts portions based on single idea and then reduced to two to three line texts. Constant comparison method (Glaser & Strauss, 1967) was used, data as coded which resulted into 12 categories. These were decomposed into FOUR hierarchical levels of categories, and then synthesized into coherent structure that included the Three primary knowledge categories - Knowledge of subject matter, general pedagogy and PCK Pedagogical content knowledge is composed of FOUR areas: subject matter for instructional purposes, students understanding of the subject matter, media for instruction in the subject matter, and instructional processes for the subject matter. A model to represent PCK of 5th grade mathematics equivalence of Fractions was also developed based on the data to define pedagogical content knowledge and identify its sources.
A qualitative Study 62 prospective secondary mathematics teachers in the last stage of their pre-service preparation from nine universities Phase 1: Questionnaire To get a general picture of the prospective teachers SMK and PCK an open ended including items to measured different aspects of teachers' SMK and their students' pre-conceptions about functions. Phase 2: Interview To clarify and adding details to the picture about teacher' knowledge 10 subjects were interviewed. Interview consisted of two parts: items needed more thoughtful responses or flexible structure than those in questionnaire and questions about issues emerged from analysis of phase.	Participants' responses on items in questionnaire were analysed and categorized. Categories were refined through consolation with mathematics educators. Interview data was transcribed, analysed and organized by emerging themes. The subjects' pedagogical content-specific choices are described and a comprehensive analysis of their related SMK is given. "Interpretations of the SMK and consequences to pedagogical content-specific choices are discussed. One immediate conclusion of is that an important step in improving teaching should be better SMK preparation for teachers.

Year	**Researchers** **Year** **Context**	**Subject Area** **Topic Area** **Level**	Aim(s)	Teacher Knowledge Areas addressed
1994	Clermont, C. P., Borko, H. & Krajcik, J. S. USA	Chemistry Density & Air pressure Middle and High school	To examined the PCK of experienced and novice chemistry demonstrators.	Knowledge of instructional strategy (demonstration)
1998	Van Driel, J. H., Verloop, N. & De Vos, W. The Netherlands	Chemistry Chemical Equilibrium upper secondary	To study the development of teachers' PCK with respect to a specific topic. (i.e., chemical equilibrium within the context of an in-service program.)	knowledge of students' understanding knowledge of subject matter knowledge of craft
1999	Van der Valk, T. & Broekman, H. International group of researchers (Oslo Maths Project) Sweden	Mathematics Physics Chemistry Area Temperature and Heat Combustion secondary	To develop a method (lesson preparation) to investigate PCK. And see how this method simulates pre-service teachers to show their ability to develop PCK.	Pedagogical content knowledge (i.e., knowledge of school subject matter and pedagogy related to that subject matter) Pedagogy included knowledge of student's preconception, difficulties of learning, relevant representation, strategies and student activities for the specific topic.
2002	Van Driel, J. H., De Jong, O., & Verlopp, N. The Netherlands	Chemistry Macroscopic phenomenon to Microscopic particles upper secondary	To investigate development of PCK of pre-service teachers during a semester of their post-graduate teacher education program and how this is influence by teaching experience, institutional workshops, and the mentor.	knowledge of students' understanding knowledge of subject matter

Research Methodology, Participants and Data Collection Method	Analysis & Findings
A qualitative Study Seven (7) novice and five (5) experienced chemistry demonstrators (elementary to high school teachers) selected based on mean on a questionnaire (5 point Likert scale) to measure confidence for using chemical demonstration teaching. Clinical Interviews while watching and thinking aloud, two different demonstrations on selected topics followed by semi structured interview questions about demonstrations	Transcribed audio tapped data were analysed using framework for qualitative analysis by Spradely (1979): Taxonomic, componential and theme analyses. The results further supports to the presence of cognitive differences between experienced and novice teachers with respect to their pedagogical content knowledge and pedagogical reasoning.
Qualitative research design, grounded theory approach 12 experienced chemistry teachers (with more than 5 years experience in teaching chemistry in upper secondary) with background in chemistry participated in the study. Data were collected through audio-recorded workshop sessions, written responses of participants on assignments and workshop evaluations.	Systematic analyses of audio tapped data was performed and then and "researcher triangulation was employed. The findings identify teaching experience as the major source of PCK, whereas adequate SMK appears to be prerequisite.
A qualitative Study 5 pre-service maths teachers maths and 5 pre-service physics teachers enrolled in a two week post graduate **orientation to teaching** course in a Dutch university participated in the study. Data were collected though Course assignment (Lesson Planning) Followed by Interview (conducted in two parts: first stimulating discussion followed by question about 5 aspects of PCK)	Interviews were video tapped and then audio part was transcribed and video parts used for deep analysis. The lesson preparation method developed this Oslo Maths Project was considered valid in the sense that it really makes teacher express their PCK. The lesson preparation method was recommended to be useful for other subject including science.
In depth qualitative study and a multi-method approach. 12 pre-service chemistry teachers (all M.Sc.) in a one year postgraduate teacher education program participated in the study. Data was collected at specific moments during first semester of teacher education program including: - written questionnaire to test SMK and PCK as base line - video recordings of all workshop sessions - participant interview (semi structured) at the end of semester - Mentors' interviews about pre-service teachers knowledge - questionnaire to check PCK only at the end of semester.	Data was claimed to be analyzed from an interpretive phenomenological perspectives. Growth in PCK was indicated by increased awareness about, -relating macro and micro levels to each other -consistent use of language. Growth of PCK was influenced by -teaching experience, workshops in university and talking with mentors

Year	**Researchers** **Year** **Context**	**Subject Area** **Topic Area** **Level**	Aim(s)	Teacher Knowledge Areas addressed
2004	Loghran, J., Mulhall, P. & Berry, A. Australia	G. Science Particle Theory High School (grade 7 -12)	To develop a research approach to access and portray PCK of science teachers.	Knowledge of content (includes implicitly curricular knowledge of the topic, knowledge of student's understanding) knowledge of pedagogy (includes knowledge of representations, analgise and teaching strategies)
2005	De Jong, O., Van Driel, J. H. & Verloop, N. Netherlands	Chemistry Relationship between physical and chemical processes secondary	To study development of PCK (use of particle models) in the context of a specific course module within a chemistry teacher education program.	pedagogical content knowledge (using particle model)
2006	Johnstone, J. & Ahtee, M. England & Finland	Physics Air is matter and so it has weight Primary	To explore the connection between teacher's attitudes, subject knowledge and the construction of P CK in initial teaching.	Subject matter knowledge pedagogical content knowledge Attitudes towards science teaching

Research Methodology, Participants and Data Collection Method	**Analysis & Findings**
Qualitative naturalistic inquiry. 24 high school Australian teachers with diverse science background (Physics, Chemistry or Biology), responsible for teaching G. Sc. At grade 7 – 9 as well as for teaching their specific area of science at grade 10-12 participated. Data were collected through individual interviews, weekly classroom observations, small (3 or 4) group workshops for developing content representation (CoRes).	Successfully developed a new approach for accessing and representing PCK of science teachers in the form of Content representations (CoRes) and Professional and pedagogical experience repertoire (Papers).
A qualitative Study 12 pre-service chemistry teachers having Master of Chemistry degrees before entering to teacher education program participating in a 10 weeks course module program participated. Data were collected though written responses to assignments questions followed by plenary discussion (audiotape) during the course and reflective lesson reports written at the end of course.	The data were claimed to be analyzed from an interpretive phenomenological perspective. The findings show that pre-service teachers further develop their PCK of using particle models, although this development of PCK varied from teacher to teacher.
A qualitative study 98 English and 98 Finnish primary science student teachers who had studied physics and chemistry only till high school, who have finished 50 hours lectures, seminars and workshops developing scientific knowledge and PCK over previous 2 years and spent 12 weeks on school placement, participated in this study. Data were collected through Questionnaire about Attitudes (semantic differential bipolar questionnaire with 20 bipolar adjectives pairs) developed by Ahtee & Rikkinen (1995) and Predict - Observe - Explain (POE physics activity (Air is matter so it has weight) designed by Driver (1983) was used to examine SMK. Further questions were asked to analyse PCK (students' difficulties & teachers' difficulties to teach this topic).	Mean values were calculated for Finish and English student teachers' rating for teaching physics as compared to other subjects qualitative analysis of students answers. Student teachers responses were analyses to check their misconceptions in the area. student teacher's responses to questions asked were analysed to find PCK abut difficulties to teach this topic Findings shows a link between these student teachers' attitudes and their confidence in teaching Physics but this confidence is not necessarily well founded and result from, and result in, good SMK and PCK. There is need to develop positive attitudes towards Physics, better understanding about SMK qualitatively and not quantitatively

Year	**Researchers** **Year** **Context**	**Subject Area** **Topic Area** **Level**	Aim(s)	Teacher Knowledge Areas addressed
2008	Drechsler, M. & Van Driel, J. Sweden	Chemistry Acids & Bases Upper Secondary	To investigate teacher' knowledge of student's difficulties in understanding acid-base chemistry and their knowledge of teaching strategies, (especially their use of models of acids and bases) in their teaching practice	Pedagogical content Knowledge knowledge of students understanding knowledge of teaching strategies (models of acid and bases)
2008	Ozden, M. Turkey	Chemistry Phases of Matter Primary	To investigate the effect the amount and quality of content knowledge of student teachers on their PCK in context of preparing lesson plans.	Knowledge of content Knowledge of students' understanding (conceptual difficulties) knowledge of curriculum knowledge of teaching methods (instructional strategies) Orientation towards teaching
2008	Krauss, S., Brunner, M., Kunter, M. & Baumert, J. Germany	Mathematics Not topic specific Secondary	To construct and to establish a test of secondary mathematics teachers' PCK and CK and to use this test to examine the level and the connectedness of the two knowledge types in two groups of teachers with different mathematical expertise.	Content knowledge pedagogical content knowledge

Research Methodology Participants and Data Collection Method	Analysis and Findings
A qualitative study 9 pre-service chemistry teachers enrolled in the specific course under study were interviewed two years after completion of the course. (All pre-service teachers in the course were invited but 9 out of 11 volunteered for interview). Data were collected through semi structured interview (in three phases: briefing and warm up, main phase, debriefing). Interview Questions were about their planning of an acid-base lesson sequence and how they changed their teaching from year to year, about textbooks they used (excerpt from the books discussed), about students difficulties regarding acid and bases (commenting on previously recorded teaching) and about their satisfaction with development for teaching acid-base (as a story line).	Detailed step-by-step qualitative analysis was performed, transcribed data was categorize and presented quantitatively using frequencies occurring for each category in all research questions. Teachers showed some development in PCK for teaching acid-bases. They were categorized into two groups: students-model orientated (who focused more on students' difficulties and explanations) and teacher orientated (who focused more on their teaching strategies and using new activities etc).
A qualitative study with Case Study approach. 28 science student teachers enrolled in department of primary science education participated in this study. Data were collected through lesson preparation task followed by semi-structured interview [developed by Van deer Val & Brokeman, (1999)] and content knowledge test (CKT) developed by researchers for this study based on literature on students' difficulties in learning about phases of matter. Semi structured interview was about difficulties in planning lesson and intended to study content knowledge, PCK, difficulties in lesson planning and anticipated problems in teaching and perceived need to be a successful teacher.	Data from three resources (lesson plan, CKT and semi structured interviewed were categorized in main categories as well as sub categories for analysis of students teachers' content knowledge, their conceptual understanding, knowledge of goals/curriculum, teaching methods and their orientations towards teaching science. Finding shoe that content knowledge has positive effect of PCK.
A qualitative study 198 secondary mathematics teachers in Germany participated in the study. 85 (male) taught at the academic track GY schools while 113 taught in other schools. The participants taught mathematics in 10th grade classes sampled within the framework of a nationally reprehensive student achievement study. So participants are fairly representative the 10th grade mathematics teachers in Germany. Data was collected through administering PCK Test and CK test individually and it took 2 hours to complete the tests (65 minutes for PCK test and 55 minutes for CK test). PCK Test: In line with their theoretical framework, the PCK contained three subscales: knowledge of mathematical tasks (4items on multiple paths to solution), knowledge of student misconceptions and students difficulties (7 scenario-based items) and knowledge of mathematics-specific instructional strategies (10 items to explain mathematics situations). CK Test: 13 items were constructed to cover relevant content areas. (e.g., arithmetic, algebra, and geometry) and to tap conceptual or procedural skills. Note: All items were open ended.	All 34 items were open ended and items with no response or an incorrect response were scored 0 while each correct answer was cored 1(for items requiring multiple answers the sum of correct answers was calculated). Each item was coded by two ratters. Psychometric analysis was performed to check quality of both the measures PCK and CK., confirmatory factor analysis was employed in which two knowledge categories were conceptualized as latent constructs. PCK-CK model was analyzed by investigating the latent correlation between the two knowledge categories. (Mplus 4.2 software package was used to run the analysis). Both measures were found reliable (Cronbach Alpha =.77 for PCK and .83 for CK). PCK and CK are two distinguishable constructs (we estimated a model in which correlation between PCK and CK was constrained to 1, this led to a statistically significant decline in model fit. Hence from inferential statistics perspective it can be concluded that teacher with higher CK also tend to have higher PCK (the latent correlation between PCK and CK was high = 79). GY Teacher and NGY teachers have substantially different mean levels of knowledge.

Year	**Researchers Year Context**	**Subject Area Topic Area Level**	Aim(s)	Teacher Knowledge Areas addressed
2008	Lee, E. & Luft, J. USA	Chemistry Biology Physics Different Topics in relevant subject area	To explore the concept of PCK with experienced mentor teachers	Pedagogical content knowledge which is composed of Knowledge of science, Knowledge of goals Knowledge of students Knowledge of curriculum organization Knowledge of teaching Knowledge of assessment Knowledge of resources
2008	Hence, I., Van Drial, J. H. & Verloop, N. The Netherlands	Earth Sciences Solar System Experienced science teachers	To investigate development (change) of PCK of teachers, over the time of three years after introduction of new curriculum in the context of teaching a chapter on solar system	Subject matter knowledge (of models regarding acid and bases) knowledge of students difficulties and knowledge of using text books
2008	Drechsler, M. & Van Driel, J. Sweden	Chemistry Acids & Bases Upper Secondary	To investigate the variation of ideas Swedish chemistry teachers hold about teaching acids and bases, focusing on the use of various models.	Knowledge of curriculum (regarding sub-microscope models) Knowledge of teaching strategies (concerning these models) knowledge of students' understanding (difficulties in this area) Knowledge of using illustration form textbooks.

Research Methodology, Participants and Data Collection Method	Analysis & Findings
A qualitative study, case study approach 4 experienced teachers participated in this study; they were identified through purposeful sampling. Participants have at least 10 years of teaching experience and 3 years of experience for mentoring. Data were collected through semi-structured interviews, classroom observations, lesson Plans, monthly reflective summaries over (data was collected over 24 months).	Constant comparison method was employed. Three type sequential coding (open, axial and selective) were conducted. Eeach data source was performed; codes were modified and refined during the process of analysis. Seven components (knowledge of science, goals, students, teaching, curriculum organization, assessment and resources) were found common to all four participants with slight variations in specific elements.
A study with both q quantitative and qualitative methods Nine (9) teacher working in 5 different schools, who completed a one year course to teach participated in the study(3 were Physics teachers 3 were Chemistry teachers and 3 were Biology teachers) Data were collected new science semi-structured interviews in three subsequent years. Interview questions were designed based on study of literature on PCK, and Protocol designed models and modelling in Astronomy. Interview questions were pilot tested and revised.	Interview responses were coded and were put together in relevant PCK elements. Combinations of the codes that arose across the different elements were examined. These combinations were compared across the nine participant teachers. According to findings, two types of PCK with regard to Models of the Solar System and the Universe were identified: Type A and Type B. Finally combination of codes applied per teacher were examined over the years to find how different types of PCK developed. BY focusing on the relationship between the different PCK elements, the result indicate that Type A and Type B of PCK developed in qualitatively different way.
A qualitative study 281 upper secondary school science teachers participated in this study. Data were collected trough Questionnaire (sent to 441 upper secondary schools and 281 teachers answered (response rate 51%), and follow up interview (9 teacher were interviewed, 2 from each subgroup) Questionnaire was a Lickert type Scale and was developed in two parts; **Part 1:** Teacher variables (age, sex, experience, academic qualification and what textbook they used, type of employment, other subject they teach) **Part 2**: consisted of 31 items about teaching of acid and bases, covering three issues; i - teachers knowledge of students' difficulties in learning and teaching cid and bases, ii – teachers knowledge of the Bronsted and other models of acid and bases, and their use in teaching, and iii - teachers' views on their textbook focusing on teaching models of acids and bases (Item statements were based on the findings of two interview studies on same topic).	To analyze questionnaire following steps were taken, **1. Descriptive statistics was performed** to analyze composition of demographic data and to calculate frequencies, means scores, SD and missing values for 31 items. **2. Principle Component Analysis (PCA)** was conducted on all 31 items to explore relationships between items which revealed a 5 component solution. **3. Pearson correlations** were calculated to explore relationships between the scales. **4. Analysis of variance (ANOVA)** was performed to investigate whether the teachers' score on the scales differed significantly as a result of the personal characteristics. **5. Cluster analysis** was preformed to investigate if subgroups of teachers could be identified. Results shows that the respondents preferred to use the Bronsted Model and thought that the Bronsted model was clear for students (BM scale). However, their knowledge about how the Bronsted model differs from the Arrhenius model was limited and diverse (CK scale). .

Appendix B: A SUMMARY OF RESEARCH ON STUDENT'S IDEAS ABOUT FORCE AND MOTION

	Pre-Conceptions	Champagne et al. (1980)	Ministrell (1982)	Clement (1982)	McCloskey (1983)	Gilbert and Watts (1983)	diSessa (1983)	Halloun & Hestenes (1985)	Driver et al. (1994)	Trumper and Grosky (1996)	Reiner et al. (2000)	Loannides and Vosniadou
1	A forces is exerted by an agent in direct contact							√				
2	Forces are caused by living or active things							√				
3	Weight, motion , activity, and strength are important in determining an object's force											√
4	Force is a property of a single object, rather than a feature of the interaction between								√		√	
5	A moving object has a force within it, which keeps it going.(impetus)				√			√	√		√	√
6	A force is used up naturally and causes a moving object to stop over time				√			√	√	√		
7	If there is motion, there is a force acting			√								√
8	If there is no motion, then there is no force acting		√			√		√	√			
9	A 'preventer' force is required to keep an object at rest		√									
10	Forces cause motion in the direction of the force.						√		√			
11	If there is a force, then there is motion	√							√			
12	If there is not a force, either there is no motion or the motion is decreasing.	√							√			
13	When an object is moving there is a (net) force in the direction of its motion.		√			√			√	√		
14	Motion is proportional to the force acting	√							√			
15	Objects slows down if there is no net force							√				
16	Constant speed results from a constant force.	√	√			√	√	√	√			
17	A constant changing force gives a constant acceleration	√						√				
18	A force cannot keep accelerating an object indefinitely.							√				
19	If speed is increasing acceleration is also increasing								√			

Appendix C: A SUMMARY OF THE SYNTHESIS OF RESEARCH ON STUDENT'S IDEAS OF FORCE AND MOTION BY HALLOUN AND HESTENES (1985)

	Main idea	Pre-Conception	Influences
Influence on Motion: Forces	**Applied Force**	An applied force is a push or pull exerted by an agent in direct contact with the object. Only living things are recognized as agents of force.	Inertial resistance: A force cannot move an object unless it is greater than the object's weight. Weight is not distinguished from mass.
			A constant force produces a constant velocity, sometimes expressed as F = mv.
			Acceleration is due to increasing force.
			A constant force has a limited effect depending on its magnitude. The limitation may be caused by one of two kinds; The force F accelerates the object until it reaches a critical speed proportional to F, which the object maintains afterwards whether or not the force is still applied. A long-range force must be transmitted by a medium such as a rope connecting object and agent. Therefore, long-range forces cannot act on an object in a vacuum.
	Impetus	An Internal force (or impetus) maintains motion of an object independent of external agents. By this principle students frequently infer the existence of a force in the direction of the object's motion.	An impetus can be imparted by an applied force and transmitted from one object to another
			The impetus of an object is proportional to its mass and velocity, as expressed by the equation F = mv.
			An impetus may wear out or build up in the same way as the effect of an applied force.
	Resistance	Resistance opposes an applied force or consumes the impetus of a moving object. Different kinds of resistance are not always distinguished	Inertia (weight or mass) is an intrinsic resistance of an object to motion.
			Friction due to contact with a solid surface.
			Fluid resistance depends on the density of the fluid as well as the size, shape, and weight of the object.
	Obstacles	Obstacles may redirect or stop motion, but they cannot be agents of an applied force	
	Gravity	Gravity is a tendency of objects to fall down. Gravity is not necessarily a force.	heavier objects fall faster

	Main Idea	Pre-Conceptions	The affect
Principles of Motion	**Complexity of motion**	Description of motion	The concepts of "time interval" and "instant of time' are not differentiated. An "instant" is regarded as a very short time interval.
			Velocity is defined as distance divided by time. Thus average velocity is not differentiated from instantaneous velocity.
			Concepts of distance, velocity, and acceleration are not well differentiated.
	Absence of Force	In the absence of forces, every object remains at rest (with respect to the earth)	
	The causal principle of motion	Every motion has a cause	Motion is started by: (i) A force applied to the object by an external agent; (ii) Gravity, an intrinsic tendency to fall down.
			Motion is sustained by: (i) Continuous action of an applied force or gravity. (ii) An internal force (Impetus) in the object.
			Motion may be opposed by: (i) Intrinsic resistance (weight or mass) of the object, (ii) Resistance of a medium surrounding the object, (iii) Obstacles that "get in the way."
	Resistive media force	The action of a resistive medium or an obstacle is not an active force, because it does not start or sustain motion. It may, however, be called a reactive force, to help students develop a general force concept.	
	Newton`s 3rd Law	Newton's third law is inconsistent with common sense intuitions. Most students characterize the reciprocal interaction between two objects by some sort of dominance principle:	The greater mass exerts the greater force, or more frequently,
			The object which causes motion of the other exerts the greater force, because it overcomes the other's opposition.
	Superposition Principle	The Newtonian superposition principle (Vector addition of forces)	Dominance: Motion is determined by the larger of two competing forces
			Compromise: Motion is determined by a compromise among competing forces

Appendix D: A SUMMARY OF FORCE AND MOTION IDEAS (LOUGHRAN ET AL. 2006)

Sr. NO.	The Idea	What is intended to learn this idea
1	A force is a push or pull	A force is push or pull only
		A force on an object is external to the object.
2	Objects distort when forces are put on them. That causes them to exert a force on the object that distorted them.	Reaction forces (usually occurred because an object distorts (as a result of force acting on it)
		Rigid things do not need as much distortion to exert same (reaction) force as non-rigid things.
		Reaction forces are real (Vs convenient and imaginary).
3	Objects that are stationary always have an equal balance of forces acting on them	If an object is at rest then it must have balanced forces acting on it, i.e., the net force is zero.
4	Frictional forces are caused by distortion of two surfaces sliding over each other	Frictional interactions result in real forces and are due to tiny bumps on surfaces.
5	Reaction forces occur in pairs. Each force in a pair acts on a different object	Reaction forces occur in pairs.
		Each force in a pair acts on a different object.
6	Field reaction forces are forces between objects that are not touching. Field reaction forces are not due to distortion of an object.	Field reaction forces (gravitational, magnetic, and electric) are the exceptions to idea that forces cases distortion.
7	When objects accelerate, they change speed and/or change direction of travel	Constant speed motion differs from accelerated motion.
		Objects traveling at constant speed may change direction.
		During accelerated motion on object's speed changes and/or its direction changes
8	Newton's first law	If something has net force acting on it, it will either be speeding up or slowing down (or reversing).
		The net force on an object is the sum of the (real) forces actually acting on the object.
9	Air resists in the movement of objects	The force of air resistance on an object increases with the object's velocity.
10	Changes in speed are continuous	An object's speed cannot instantaneously jump from say, 60 Km/h to 100 Km/h. i.e., the object's speed must pass through all speeds in between 60 Km/h to 100 Km/h.
		Changes in speed take time.
11	Newton's second la	More mass needs more net force for same acceleration.
		The net force is proportional to the object's acceleration.

Appendix E: PROFILE OF KEVIN'S PCK RELATED TO FORCE AND MOTION: GENERAL TO SPECIFIC

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Category: Content Knowledge				
Understanding Force	z			Aimed to make his students be able to: say that Force is a push or pull demosntrate a force, for example saying "I just applied a force on the pen and made it move' measure a force using approperaite deices and units, or atleast "could see if I apply a big force to a small object I can send it flying"
Understanding Friction				Friction: is a type of force caused by two surfaces rubbing against each other reduces the efficiency of machines due to friction between various parts of the machines So, by decreasing friction they can increase the efficiency of the machine

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Understanding Gravity			Students should know how it is generated, and why we have gravitational force, the interaction of planets, and the centre of mass" as related to gravity	Gravity is a force
			Is a relationship between mass and force	The idea of objects speeding up and slowing down, which is acceleration and de-acceleration.”
2. Category: Knowledge of Students Alternative Ideas				
Everyday meanings of the word "force"			Students made a wrong connection between force as a science concept and the ideas of force in the *Star Wars* films, where it is a mystical power. Students compared force with plasma	
Machines are 100% efficient				Student had trouble with the idea that friction is loss of energy, or transfer of energy into a different form.

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Lack of trust in gravity			students thought gravity "is imaginative or magical,"	
Role of friction in acceleration			Students were unable to make predictions about the role of friction in acceleration	
3. Category: Knowledge of Instructional Strategies				
Questions during discovery process			Used questions: What happens when you push it? What happens when you pull it? What happens when you push it harder? What happens when you pull it harder?	
Classroom discussion	Used thoughtful questions to engage students in classroom discussion			
Accessing students' prior knowledge	Used questions and asked for examples from students in the beginning of his science class			
Using Discovery Labs			To explore a relationship between friction and efficiency made students,	

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
			to move a wooden block across various surfaces. to measure the forces using spring scale /force meter.	
Using Graphs			Used pre-designed graphs to teach about acceleration, by showing them the difference between speed, velocity, and acceleration	
Using real word examples: Different types of machines		Used various types of machines for teaching about friction Rural machinery to make is relevant for students with that background		The bridge surfaces are to increase friction, so there is better traction for drivers.
Using real word examples: Driving a car			Asked students: the difference when driving in the city limits versus on the highway using cruise control. the difference when a car going at a constant speed versus when a car accelerates from a stop light.	

PCK Elements/Aspects	General ----------Specific			
Using real word examples: Riding a bicycle			Rode his bike to the school when to explore topics, acceleration and de-accelerating. Made his students apply force to pedal it and talked about the changing motion and force applied.	
Demonstration: Push my shoulder				Demosntarted a student pushing his shoulder and then enagge students in a discussion: (i) by pushing or pulling you apply a force on the shoulder, (ii) shoulder moves because force is applied.
Demonstration: Rubbing Hands				heat is given off by friction when rubbing hands together.
Using manipulatives		Used wooden block and mini cars for teaching about friction	Made students pull different objects that they are choose and then see what the difference is in the frictional forces	Made student play with mini cars to discover: If you push the car gently it does not go very far The car goes farther than the wooden block
Using video	Bill Nye the Science Guy video series	Used video clips on zero gravity		

4. Category: Knowledge of Resources				
PCK Elements/Aspects	General ---------- Specific			
	Level 1	Level 2	Level 3	Level 4
Using manipulatives			Used manipulative such as miniature cars, wooden blocks, and so forth to use , to demonstrate a force, to measure a force, and display the effect of friction on motion.	
Use of textbooks	Used textbook: to show graphical representation of the ideas to encourage students to read about the idea in the textbook, after doing an activity and having a classroom discussion, Believed that textbook is written at students' level and helps their understanding	Believed that textbooks help to implement curriculum, specifically about force and motion		
Use of textbook teacher guide	Used strategies from this binder to facilitate differentiated learning for his students.	Used the teacher resource binder for Science Focus textbook:		

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
		Because this binder has many useful ideas, which he has used in his class when teaching about force and motion.		
5. Category: Knowledge of Technology				
Analog Technologies	Believed: in a broader sense of technology It does not have to be an electronic device.	Believed that bicycle is a technology which he has used to teach about acceleration.	Made a nice thick line using a pen and a paper and dicuss: Force is appled both when holding a pen to the paper and writing on the paper.	
Use of Active Board	Believed that using technology can engage more students. Kev	Used an Active Board in science and math classes, regularly.	Made a nice thick line on Active Board by moving the pen and asked students: what forces are applied here?	
Digitalizing resources	Wanted to digitalize graphs using a software, "Geo Algebra, a program for Active Board to represent graphs online			
Using Video Clips		Used videos clips to show difficult concepts:	Used *Bill Nye the Science Guy* video for teaching about friction, where he spills marbles	

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
		zero gravity or defying gravity. force and motion	and walks on it to show frictional force.	
Using website and simulations		Used the website www.explorelearning.com to help his students understand frictional force. Used a gizmo from above website, to present real-world situations involving friction	Used an airplane simulators where students could momentarily defy gravity Used one gizmo where students used changing surfaces of an inclined plane and measured friction.	
6. Category: Knowledge of Science Curriculum				
	Used POS to prioritize topics in a unit collaboratively: how important a concept is how long to spend on the topic, what other information have to get across in that unit.			the POS shows: how to design a specific science curriculum so that students: understand a force [knowledge], understand how forces are used [skill] get a general attitude of discovery in science [attitudes]

7. *Category: Knowledge of Goals*				
PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
		The goals of teaching force and motion ideas at junior high school level are to help students: 1. understand forces involved: when riding a bike when playing hockey	Believed that helping students understand the idea that force is push or pull will helps them understand Newton's laws" of motion, and will definitaley help them study high school Physics.	Undersanding force and motion helps students understand safety issues in driving a car. Because when driving they are dealing with a huge velocity and therefore if it hits something there is a massive force applied Understanding the concept friction to grade eight students helps them understand the concepts: efficiency heat transfer.
8. Category: Knowledge of Teaching Context				
Rural and urban school contexts			Believed that his teaching about friction in a rural context would be different because rural students have some prior knowledge of efficiency and simple machines.	Believed that he would teach force the same way by demonstrating push and pull in any context by using relevant examples. For example in a basketball court he will use a basketball to teach about the concept, force.

9. ***Category: Knowledge of Assessment***				
PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Assessing students' understanding				Checked understanding of students at the end of a sciece labs or an activitiy, and looked for explannations: friction affects efficiency, Friction increases, efficiency or decreases it There is a relationship between friction and the amount of effort force to move an object, and the transfer of heat.
Using Questions		Used question to check students understanding of acceleration		
Using MCQs		Used MCQs sometimes to assess his students' understanding of friction		
Using quizzes	Used quizzes in classroom to check students understanidng			
Using units tests	Used unit tests in his classroom to check students understanidng			

10. ***Category: Knowledge of Student Diversity***				
PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Student Background	.	He belived that if he has a student with no experience of driving or even being in a car to experience he use exmaples: aeroplanes by using there experience of feeling the acceleration	Included students from rural background when teaching about friction by using examples of rural machinery	Could include students with no experience of being in an automobile by showing videos of predatory animals like cheetahs, or horse races where they can observe the changing speed, and the acceleration.

Appendix F: JASON'S PCK RELATED TO FORCE AND MOTION: GENERAL TO SPECIFIC

Knowledge Elements Aspect	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
1. Category: Content Knowledge				
What a Force *Is* vs. What a Force *Does*				Force is a push or pull, and it is a useful concept. But there is something more than the push or pull to force. This is particularly important for students in high school. It is better to discuss force as push or pull in the context of an interaction between two things. Force should not be treated as an object, that what it is. But to define force operationally.
Defining Force Operationally			It is critical for high school physics students to be able to define force operationally, by identifying three things about a force: (i) force is a vector (ii) force needs to act on something (iii) every force needs to be applied by something	
What a Force is NOT				A force that fails any of the three-step criteria is not a force.

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Free Body Diagram				Free body diagrams help students: Identify forces in real-life situations Make a transition from the idea of what force is to the idea of what force does Understand net force Understand proxy forces (non-forces) they may have initially identified as forces
Types of Force			Different types of forces are better understood as *examples* of forces in the context of various other topics.	The reaction forces are better understood within the framework of Newton's third law of motion. When two objects interact, with one object applying a force to the other and the second object push back with the same force, this is a reaction force. It is the same in magnitude but opposite in direction. The force of friction is understood better in the context of Newton's second law of motion, where force causes acceleration. Force of gravity can also be understood in the context of Newton's second law of motion,

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
				especially applied to free-falling objects.
Adding Forces and Resolving a Force into Components				To solve numerical problems, high school students need to: Add the forces Divide a force into horizontal and vertical components. Students need to understand: (i) vector addition, (ii) coordinator systems, and (iii) components of a vector. When introduced right after free body diagram helps students' understanding.
Application of Force(s)				The concept of what a force does is a link between the idea of forces and the idea of acceleration, and this can be better understood during the discussion of Newton's second law of motion.
Velocity			Velocity fits in the bigger discussion about "what a force is". The idea, velocity, should be kept separate in order to keep the discussion about Newton's laws of motion "neat".	

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Newton's Third Law of Motion and Reaction Forces				When the object A pushes on object B with a force of any type in some direction, then object B will always push on the object A with a force of the same type in the opposite direction and the same magnitude. Force on the object A due to object B is a reaction force."
Newton's Second Law of Motion and Acceleration			.	Newton's second law of motion is a relationship between the force applied on an object, and the acceleration caused as a result of this force (F=ma). In the context of real-life situations, understanding Newton's second law means understanding: The acceleration caused by a force What force should be applied in order to achieve a certain accelerate, or acceleration in a certain direction In addition, understanding Newton's second law of motion involves applying Newton's second law equation, F=ma, to

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
				solve second law numerical problems.
Acceleration				Acceleration is the rate of change of velocity. The acceleration is not about how speed changes, acceleration is how velocity changes. Acceleration is better understood in the context of Newton's second law. When you can identify the net force, you can find your acceleration using f=ma.
Newton's First Law of Motion				An object at rest stays at rest, and an object in motion stays in motion unless a force is applied.
Circular Motion				The fundamental concept involved in a circular motion is that the object is accelerating throughout, and the direction of acceleration is towards the center of the circle (inward) during the circular motion. Students should understand that Newton's laws of motion apply to circular motion and hence used to solve numerical problems related to circular motion.

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Energy				When an object is moving, it has energy called kinetic energy, and it also has energy due to its position or height from the ground, called potential energy. The topic of energy can be best understood in the context of amusement park physics, such as how roller coasters work.
2. Category: Knowledge of Students' Alternative Ideas				
Everyday meanings of force			Students bring alternative meanings of "force" which they have acquired because of the everyday use of the word force. These ideas are not informed by their prior education but sometimes by a reality show on TV. The same problem exists with the use of the word "energy".	
Force of motion or thrust force			Students repeatedly bring to science classes the idea that a moving object has a force, which his students sometimes call *force of motion* or *thrust force.*	

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Friction force only opposes motion				Students hold the alternative idea that friction force stops motion. "It is very difficult for them to understand that a friction force could be used to accelerate something . . . to speed something up, as well as to slow it down, or to make it turn a corner. A friction force can be used to do anything that any other force can be used for."
Students do not trust in Newton's third law of motion				"Many students show a lack of trust in Newton's third law of motion due to two major naive ideas: (a) a large object is going to apply a larger force than a smaller object, and (b) a fast-moving object is going to apply a larger force than a stationary object."
				Students are unable to observe that larger objects do not move when the other smaller object applies a force because the acceleration is small. The mass is different for both the objects and hence causes smaller or bigger acceleration, an

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
				application of Newton's second law of motion.
Acceleration is a change in speed, not velocity				Many students think that acceleration is caused by a change in speed alone, which is a remarkably wrong idea because acceleration is caused by a change in the velocity. To help his students to change this idea, he uses an example of an object that changes direction but not speed.
Missing the direction			Many students ignore the direction of force and acceleration.	In the case of force, students are unable to identify the direction of net force on an object.
				In the case of acceleration, students ignore that it has to have a direction, which is more evident in the case of an object in circular motion. Therefore, Jason uses the example of circular motion when his students are not clear that when an object changes direction it has acceleration.

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
An object changing direction always has acceleration				Many students miss the point that if an object is changing direction, it must have acceleration, such as an object moving along a circular path.
Error of omission		Students have a wrong image of being an expert who is on a fast track and can skip a step to be more efficient. They think that if they just knew the acceleration for this problem, they could solve the problem.		
Students mix Newton's second law of motion with his third law	Jason asks his students to visualize themselves sitting in a chair, and to identify Newton's third law force pair in this scenario. Therefore, it has often occurred during his classes where a student would say that "there is a normal force up, on me by the chair and gravitational force down on me by the			

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
	Earth," and says, "That is Newton's third law pair." Jason suggested the response shows that the student is confusing Newton's third law with the second.			
3. Category: Knowledge of Instructional Strategies				
Using especially designed criterion				Developed and used this set of three criteria to teach about force: (a) force is a vector, (b) force needs to act on something, and (c) every force needs to be applied by something.
Using free-body diagram and itemizing forces			Jason uses a set of well-defined free body diagram problems which involve different types of forces acting on a body and are designed in a developmental sequence from simple to complex scenarios. He asks students to "itemize forces" on a given body in a given situation. Itemizing forces includes making a list of forces acting on	

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
			the body and then identifying the type of force using the three-step criterion discussed above to evaluate a force.	
Using four-step process for numerical problem-solving			Jason has designed and uses "a four-step process to help students solve numerical problems: Draw a free body diagram. Choose a coordinate system. Develop a table of components. Solve the problem using Newton's laws of motion.	
Predict-observe-explain (POE) activities				Jason used demonstration using POE format where he let a marble move inside the masking tape, and then lifts the tape to show students the direction of acceleration when the marble was moving inside the tape. Predict: Tell me in what direction the marble is going to go. Observe: The direction of motion of the marble.

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
				Explain: Through asking questions led towards the *explanation* that the direction of acceleration of an object moving in a circular path, at any point around the circle is inward, towards the center of the circle.
Conceptual change strategies: Specially designed and sequenced examples		Jason uses two examples together in a logical way to gain his students' trust in Newton's third law of motion:	First an example of interactions between two elementary particles and then an example of a fast-moving train hitting a fly.	He uses this example mainly to clear the alternative idea that large and heavy objects apply a larger force back. He wants his students to understand that "the forces [in this Newton's third law pair] are the same but the acceleration is dramatically different." Jason uses these examples so that his students can see how mass changes the acceleration, which explains the reason why, in an interaction between a small object and a large object they cannot see, the large object moves.
Using collaborative case scenarios: A box on a truck	Jason lets his class work collaboratively on a complex problem.			He presents a scenario where he shows a diagram of a truck accelerating to the left with a box on the back of the truck and asks his students to identify

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
				every Newton's third pair in this problem. Then he invites his students to come to the board and draw these force pairs. Students are able to identify from 4 to 14 Newton law force pairs in this scenario.
Using everyday life examples: A person jumping off a table				Jason used this example to clear the misconceptions students hold about Newton's third law is "a person jumping off the table where [the] force of gravity acts down, towards the Earth . . . the forces involved are the same, but Earth does not move because of its huge mass.
Using everyday life examples: A fast-moving car vs. an open Jeep going around the corner		Jason uses this example to teach about circular motion and to win his students' trust in Newton's third law.	He uses the scenario of a person sitting in a car moving fast around a corner, and asks his students if they would feel a force. Then he uses the scenario of a person sitting in an open Jeep and not wearing a seat belt. He asks students: "If the Jeep is moving really fast, and you are going around the corner,	As a result, students realize that "if they are in a car they feel somehow pulled towards the outside because they are wearing a seat belt He also sometimes expands this discussion by asking additional questions about other forces involved in this scenario, such as the force applied on the seat and the seat applying force back on the person (Newton's third law pair).

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
			is there a force on you? And which direction you will move?"	
Using everyday life examples: A person on a planet	Jason stated that he introduces different types of forces as examples in various scenarios, and then furthers that discussion in other topics.		He uses an example where a person is standing on a planet, and asks students to identify the forces on the person.	His students get that there is a gravitational force by the person on the planet, and there are normal forces by the planet on the person (Newton's third law pair).
Using everyday life examples: Rubbing hands		Jason uses the example of rubbing hands to expand his students' understanding about various types of forces and to introduce frictional forces.		He demonstrates rubbing his hands in front of the class and asks: Which force(s) is involved? What is the direction that I feel on my hand when I do this [action of rubbing hands]? What is the direction of the force on one hand? Which force is applied on the hand, and what is the direction of this force? He focuses on the directions of force involved and identifying Newton's third law force pair.
Using everyday life examples: A hammer hitting a nail			For this purpose, Jason draws on the board a hammer hitting a nail, and asks students to	His students are able to explain: "A hammer is applying a force on the nail, and the nail applies a force back."

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
			identify Newton's third law pair.	
Using everyday life examples: The accelerating train		Uses this example to separate Newton's third law from Newton's second law		He uses an example where a train is accelerating towards the left and the train engine is pulling two cars, A and B. He asks his students: What force does car A exert on car B? What force does car B exert on Car A? After they identify that this is a Newton's third law pair, he asks: Which force does the engine exert on car A? (Newton's second law problem).
Using visualization	Jason draws diagrams on the board to present scenarios.			
Questions, wait-time, and discussion	Jason uses well-thought-out questions to initiate classroom discussion and to explain science ideas to his students.			

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Idea progression: Developmental instructional design	Jason designed and used a combination of instructional strategies in a developmental sequence.			A car Hitting another car from behind at a red light, and A car hitting a truck from behind at a red light
Conceptual change activities	Jason used instructional strategies to facilitate conceptual change	Using the example of a person sitting in a chair he identified the alternative ideas hindering students' learning which is critical to understand Newton's third law.		In this case this particular conceptual change is critical to understand how Newton's third law is distinct from Newton's second law of motion, and can lead students' understanding that "Newton's third law always say this [that forces are equal and opposite]" but " Newton's second law sometimes have force balanced, not always"
4. Category: Knowledge of Teaching Resources				
Use of SMART board and whiteboard	Jason used visual and diagrams Drawing on whiteboard			
Use of Free-body Diagrams worksheet				Used Court's (1993) article to develop these worksheets
Using ideas from Professional development workshops		Used a demonstration about acceleration	He has developed a platform with strings attached, and a cup is sitting on the platform.	

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
			He performed demo and asked student: What forces are accelerating this thing?	
5. Category: Knowledge of Technology				
Using smart phones	Iused n class to engage students	Asked students to use smart phone to find resources to do physics labs.	Used Apps: Accelerometer, Giro, and Compass Needle	
Developed Custom computer program		Jason developed a custom computer programs to generate assignment across physics units.		
Using Xplorer GLXs	Used GLXS to make physics more real			
Calway Park visit		Showed student how physics happens in an amusement park.		
APproperiate use of technology	Believed that technology should be used as a crutch to depend entirely on it.	Students should not think that physics happens only in class or lab, but in real life.		
6. Category: Knowledge of Science Curriculum				
Program of Studies as a guide	Believed that the science POS is a mandate for teachers and is flexible to incorporate new ideas.			Noted that the topic of acceleration is not "in the textbook, and it is not in the curriculum, so we do not discuss it as a separate topic."

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
	The content organization is personal to teachers.			The concept, gravity, is also not well defined in the science POS.
Content Section	POS contains science/physics topics, which most of the teacher would agree to teach			
Content Organization	Curriculum is something personal when it comes to organizing science topics or ideas	He used a particular sequence to teach force and motion ideas that helped his students understand these ideas.		Presented a unique sequence related to force and motion, discussed in Chapter 4.
Planning and improving	Jason used reflections on each lesson, prepared and stored as soft copy. Keep notes to improve in future.			
7. Category: Knowledge of Goals				
POS goals	POS has general and specific goals for force and motion ideas. These goals should be taken seriously, but there are certain ICT goals he disagrees to	Teaching students the grammar of Microsoft Excel should not be a curriculum goal. To use the i- phone in physics class should not be the end goal,		Believed it is important for students to understand how friction is important in real life. For example, to maintain a car they need to know that if you do not have enough oil, then the pieces rub together and cause

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
	be useful for teaching these ideas.	but a means to achieve the curriculum goals.		heat, and can damage parts of the car.
8. Category: Knowledge of Teaching Context				
Teaching Adult and then high students	Jason used more independent learning strategy for university students, but for high school students helps them to become independent learner gradually.			
9. Category: Knowledge of Assessment				
Assessing conceptual Understanding	In physics to pass exam, students need to understand conceptually various inter-related concepts			
Formative: Asking questions	Used questions to assess the level of students understanding, in order to help them better understand these topics.	Used formative assessments strategies to ensure student have developed sufficient understanding of force and motion topic.	Used questions from Force-concept-inventory (FCI) a questionnaire designed to develop and assess conceptual understands of force and motion topics.	
Formative: Interceptive collaborative problem-solving	To strengthen students' understanding of the concepts learned, he uses this strategy in the middle of the unit.	He uses a real life complex scenario involving many types of forces.	Student should be able to demonstrate, type of force, large or small forces, direction of the force, and the Newton's third law force pairs	Used box on a Truck Scenario, explained in Chapter 4.

PCK Elements/Aspects	General ----------Specific			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Summative	Used assignment Each student has a different assigned so they cannot copy but help each other solve the physics problem,			
10. Category: Knowledge of Student Diversity				
Understanding students' level and understanding and their diverse learning styles to plan accordingly	Check the level of students' understanding and their learning styles to plan a lesson o include all his students.			
Helping ESL learners	Helped students understanding meanings of science words.			
	Helped student who have problems with understanding a problem for the reason that a local cultural image is used.			For example, a problem where Evil Knievel have to cross buses, as described in Chapter 4.
Helping students with Physical disabilities	Worked with a student who was hearing impaired.	Not sure how he will help a blind student, but determined to find ways.		

Appendix G: MONICA'S PCK RELATED TO FORCE AND MOTION: GENERAL TO SPECIFIC

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	**Level 2**	**Level 3**	**Level 4**
1. Category: Content Knowledge				
Understanding Force				Force is a push or pull. When you push or pull something that is force.
				Students understand the concept, force when: They can demonstrate it by physically moving something, for example, the desk, and by saying they are pushing it or pulling it. They can use the unit "Newton" when measuring a force.
Types of Forces				Force are four types of force based on the impact of force on an object: (i) compression force (ii) torsion force (iii) tension forces (iv) shear force. In addition, friction and gravity are also specific types of forces. ,

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
				Force is a very general term, and we need to be specific by using terms like compression compressive strength, bending force, or tension. To demonstrate a force, students need to show: (a) what tension forces are, (b) what compression forces are, and so on.
Internal and External Forces				In the context of structures, force are classified as internal and external: compression, tension, and torsion are internal forces, and there are external forces as well which may be responsible for a structural failure.
				In the context of structures, the student should be able to understand: What role forces play in strengthening or weakening a structure, and how to create and test structures for strength
Friction			To understand friction, junior high school students should be able to understand:	She defined friction as two surfaces rubbing against each other.

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
Gravity			What is friction? Where do we see it? Why do we need it?	Friction is needed to slow down motion. Gravity is a force which is a pulling force. Gravity pulls objects towards the centre of the earth.
Acceleration		Acceleration is there when an object is in motion and the speed of the object is changing. So, it is accelerating; it is moving faster or slower depending on the forces exerted on it.	An object has an acceleration when it is not moving at a constant speed, and it is either slowing down or speeding up, depending on the force that is applied.	Students should understand how acceleration is related to friction. Acceleration comes into play when using the example of good tires, needed for speeding up and slowing down the car.
Newton's Laws of Motion				Newton's first law states that an object at rest stays at rest and an object in motion stays in motion unless something counteracts that motion.
2. Category: Knowledge of Student Learning				
Everyday meanings of force		Students sometimes have their own everyday definition of force that is not exactly what the science meaning is.		

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
Students' diverse learning backgrounds	Students' prior understanding about a topic from previous grades is sometimes insufficient.	Students come from a variety of backgrounds, so it is unlikely that everybody will have the same information. To deal with the diverse learning backgrounds of students, it is really important to find out what their prior knowledge is, and then go from there at the beginning of any concept that you are teaching.		
Difficulty of concepts		Gravity is easy to understand if you drop something on the floor . . . The kids pretty much know that is gravity. They are able to provide enough examples of it.	Friction is not as difficult for students to understand as force and weight, because friction is something that they can see in everyday life whether it is tires, or whether it is runners.	
Gravity and diminishing gravitational pull				Students can understand the actual gravitational pull on the Earth, but they have difficulty understanding that when we move away from the earth, the gravitational pull decreases. This is something

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
				they cannot conceptualize because they cannot see it. And when you just try and tell them that the gravitational pull of the moon is less than the Earth, and this is because the Earth has a larger mass than the moon, they do have difficulty with that.
Mass and weight are not the same		Students have problems understanding that mass and weight are two different concepts. They think mass and weight are the same things. In everyday life they do not say, what is your mass, but, how much do you weigh?	Mass and weight in science terms are different. Mass is the amount of matter in an object, which is measured in kilograms. But weight is a gravitational pull, which is measured in "Newtons".	
Cooperative Learning	Believed in and supported cooperative		Using an analogy and the term "weightlessness" helps deal with this learning difficulty. The analogy that if they are traveling in space, their weight changes. Made her students work collaboratively in groups	Used the advance cooperative learning technique Jigsaw, where each group of students

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
3. Category: Knowledge of Instructional Strategies				
	learning in her classroom		to demonstrate different types of force	mastered one type of force and then taught it to other groups
Using Questions	Believed in using questions to engage students	Used question (a) at the beginning of her lesson to identify students' alternative ideas; (b) during an activity to engage her students' thinking; and (c) at the end of an activity to help them formulate their understanding. For example, "What did you find? What worked [and] what did not work?" and "Why did it not work?"		
Hands-On Activities		Believed that Force and Motion or Structures and Forces are hands-on units	- Used a hands-on activity where she makes her students measure the force - Used hands-on activities to explore concepts, force, and structures, e.g.: build a golf ball bridge out of given materials, and build the tallest	Used a hands-on activity to teach about various types of forces, e.g., compression, tension, torsion, and sheer force, by using different objects, including a sponge, a rope, a pair of scissors, and paper.

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
			tower out of the paper given.	
Building Structures	Stated that she believed in using both open-ended and structured inquiry	Stated that the best way to teach the concept, force is through the use of inquiry activities. Used open-ended enquiry by letting students come up with questions and methods to answer these questions and then come up with their own conclusions.	Stated that she used structured enquiry by using a pre-designed activity sheet, which included both open-ended and structured questions on hypothesis, data, observation, etc.	Stated that she used an inquiry activity to teach about friction using various types of ramp surfaces and balls. Students measured the distance and time it takes for balls to go down a ramp. She asked questions to help them conclude how a smooth surface works as compared to a rough surface, and how it affects the motion of the balls.
Exploring Gravity				Stated that she used an activity where she made her students drop various objects from a certain height and observe that all the objects hit the ground at the same time.
			Stated that she used an activity where she made students build a structure such as a bridge or a tower, and then talked about the stability of the structure using the ideas of balance and loads, building on the students'	

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
			ideas about compression, tension, and twisting forces using the concept of internal and external forces. She achieved this by showing them real-life examples of why it is important to study force and how it affects a design and the materials used. Examples of questions used are: What is the weight of the bridge? What objects are going to be traveling on the bridge? What types of forces will impact the bridge?	
Examples of Runners and Snowshoes				Runners and snowshoes: Used real-life examples of runners and snowshoes when teaching about friction, and asked, “When do you wear runners? When do you wear snowshoes? Why do you wear these?" Runners have certain materials on the bottom that

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
Example of Rubbing Hands			Rubbing hands: demonstrated friction by rubbing hands in order to explain that by rubbing your hands together you create friction, which eventually creates heat.	allow them to grip by providing enough friction.
Example of winter Tires			Winter tires: Used the example of winter tires to help students understand the importance of friction by asking, "Why do you need to have good tires on your car in the wintertime?" She expected her students to be able to answer, "because there is a resistance to motion."	
Example of Canoe				Canoe: Used the example of a canoe to teach about the different forces acting in a real-life situation by asking, "What are the forces on the canoe? Why is it able to float?" She expects students to explain the pulling force of gravity and the pushing force

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
				of the buoyancy of the water and give an idea of how things float."
4. Category: Knowledge of Teaching Resources				
Inviting guest speakers, e.g., a scientist, into the classroom			Invited guest speakers from the Calgary Science Network (CSN), the Scientist in the Classroom program. Attended professional development workshops at CSN, including the one to prepare for teaching the structures and forces unit in the new science curriculum.	
Using the Internet	Believed that the Internet is an excellent teaching resource to get immediate help to prepare for teaching.		Used internet searches for quick help to find interesting videos, PowerPoints, and ideas for teaching force in order to understand some of the science topics which were new to her.	
Using low-cost materials	Collected and used low-cost materials to allow her students to build different types of structures she			

PCK Elements/Aspects	General ----------Specific			
	Level 1	Level 2	Level 3	Level 4
	collected. For example, straws			
5. Knowledge and Use of Technology				
Using online simulations	Used online simulations in her science classroom		Used an online simulation lab from the website, http://www.pbs.org "Big Building", to teach about forces and the way they affect the structures. The simulation is about different types of forces, materials, and loads.	
Using the SMART Board		Used SMART Board for teaching about forces	In the above activity about building structures, She allowed the students draw their designs on the SMART Board so that the other students could look at them and critique the designs.	
6. Knowledge of Understanding of Science Curriculum				
	Noted that the science POS is a mandate for teachers and is flexible to incorporate new ideas. It provides guidelines of what the students are expected to know.		Pointed out that Newton's Laws are not part of the junior high science curriculum, and so she does not teach them directly as a topic. There is some continuity between the Grade Seven	Noted that the topic of acceleration is not "in the textbook, and it is not in the curriculum, so we do not discuss it as a separate topic."

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
	The textbooks, as part of the prescribed		unit Structures and Forces and the Grade	The concept of gravity is also not well defined in the science POS.
	curriculum, also give ideas that the students should know. Based on both the POS and textbooks, teachers follow the guidelines.		Eight unit Mechanical Systems.	
	Noted that Alberta POS lacked continuity in terms of the way units are set up, which according to her are stand-alone pieces. The advantage of this setup is that the chances of repeating a lab or an idea are minimal, but the disadvantage is that it does not provide continuity.	Noted that the science POS does not focus on the history of science, especially the human component, i.e., the people behind the discoveries. For example, we discuss Newton's Laws of Motion but hardly discuss the contributions of Newton, the scientist.	Described a session on structures of the world, which is a small piece in the POS and in the textbook. However, she spent more time on it in order to help students explore structures globally, not just structures that are in North America.	

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
7. Category: Knowledge of Goals				
		Noted that Newton's laws were removed from Grade Seven unit because they were too abstract to be understood by Grade Seven students.	Stated that she believed that the topics of gravity and gravitational force are important for Grade Seven and Grade Eight students because they have a discussion about it in Grade nine unit, Space Exploration. Moreover, if these terms show up in high school they have enough understanding to apply it.	Noted that it is important for students to understand how friction is important in real life. For example, to maintain a car they need to know that if there is enough oil, then the pieces rub together and cause heat, and can damage the car.
8. Category: Knowledge of Teaching Context				
Schools	Had the opportunity to teach in three different junior high schools, but her teaching did not change between the three schools.			
Students	She taught differently to different groups of students to address their various learning needs.			
Technology		Using SMART Board has changed her teaching of force by		

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
		including a lot of virtual labs online.		
Experience	Had a shift in her teaching after years of experience, from teacher-centered towards student-centered.			
9. Category: Knowledge of Assessment				
Formative	Used various types of questions during her lesson. Questions during the activity help her to make sure her students are on the right track to finding answers for themselves, and towards the end, her questions ensure that the desired learning goals are achieved	Questions at the beginning of the lesson help her to assess her students' prior knowledge of the topic, force.		
Summative	Used unit tests and subject exams. Noted that sometimes we just teach to the test.			

PCK Elements/Aspects	**General ----------Specific**			
	Level 1	Level 2	Level 3	Level 4
10 Category: Knowledge of Student Diversity				
Understanding students' learning styles and planning accordingly	Used variety of ways to teach a topic to engage the auditory and visual learning styles of students. These ways include: Writing information on the board Describe an example so that they can listen to that information Showing them a diagram	Believed that by giving students different opportunities to learn the material, we can include all the learners in a science class, whether they are coded, ESL, or gifted.	Showed diagrams or drawings on the board to include visual learners. "If there are visual learners, you going to try and show them how the force works in real life."	