# KNOWING SCIENCE LIKE A TEACHER: AN EXPLORATION OF THE CONTENT KNOWLEDGE OF NEW SCIENCE TEACHERS

by

RYAN STEPHEN NIXON

(Under the Direction of Julie A. Luft)

## ABSTRACT

Teacher content knowledge is an important component of science teachers' knowledge as it can influence classroom practice and the development of other forms of knowledge. Despite its importance, content knowledge has been poorly conceptualized in science education. This dissertation is composed of two manuscripts that present and new model of science teacher content knowledge, known as science knowledge for teaching (SKT). The first manuscript reports on a study that sought to characterize the domains of the SKT model using a sample of 13 new teachers from South Africa and the US. Through a qualitative analysis of interviews regarding teachers' knowledge of the conservation of mass, the domains of the SKT model are characterized. Findings suggest the presence of unique domains of teacher content knowledge used in the work of teaching science and that it is possible for new teachers to have knowledge in these domains. The second manuscript reports on a study that explored the development of SKT in new teachers in the US. This cross-sectional sample included teachers in their first, second, and third years. Though all of teachers taught chemistry, half of them held a degree in chemistry and half held a degree in biology. Results of the inductive qualitative analysis indicated that the development of SKT is influenced by both holding a degree in the subject area and classroom experience. These two factors may be tied to SKT development by influencing teacher identity and opportunities for reflection. This dissertation suggests that the SKT model is a viable way of conceptualizing the content knowledge of science teachers, emphasizing the unique knowledge needed for teaching. Further, this dissertation clarifies the SKT model and suggests future directions for research related to teacher content knowledge.

INDEX WORDS: content knowledge, new teachers, science education

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B.S., Weber State University, 2009

M.A., Brigham Young University, 2012

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILSOPHY

ATHENS, GEORGIA

2015

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# DEDICATION

For Liz.

"Part of the tragedy you must avoid is to discover too late that you missed an opportunity to prepare for a future only God could see for you."

Henry B. Eyring

# ACKNOWLEDGEMENTS

I would like to acknowledge all of the assistance I received from my advisor, Julie Luft. This would not have been possible without the opportunities and assistance you provided. Thank you for the invitation to apply to UGA at that fateful NARST conference, for the opportunities to be involved with many great projects, and especially the opportunity to visit and be involved with South Africa. You've broadened and enhanced my view of education, educational research and the world. I appreciate the many hours you devoted to meeting with me and reading my work. Thank you for the feedback—for consistently pushing me to find something "more meaty" and to write with greater clarity.

I would also like to acknowledge the assistance from my doctoral committee: Julie Kittleson, Steve Oliver, and Hamsa Venkat. Thank you for your feedback and mentorship, both formal and informal. A particular thank you to Hamsa, for your expertise in an unknown field, for your insightful guidance, and for dealing with the inconvenience of time zones.

This work would not have been possible without the assistance and friendship of my amazing collaborators and coauthors, Ben Campbell and Rene Toerien. Thank you for devoting far more time to this project than you ever should have. It would not have been the same without you. Thank you, also, to Shannon Dubois, for your friendship and collaboration. Thanks for blazing the trail and showing me the way. And, to the grad students at UGA— Ann, Baha, Bo, Heather, Jackie, James, Laura, Logan, Melissa and all the others—thanks for the fun times and good conversations.

Thank you to my parents. For all the things you’ve taught me and done for me throughout my life. And to Brent and Julie, for your constant support of Liz and I.

Last of all, many thanks to Liz. Thank you for your love, willingness, and support. For being willing to consider this possibility because I was excited about it. For moving all the way across the country. For being alone while I was at conferences, South Africa, night classes, and writing my comps and dissertation. For so kindly enduring years of dinner conversation about SKT. You probably should be listed as a coauthor for your intellectual and financial contributions. I am so grateful for you.

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# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

The purpose of this chapter is to provide background and structural information regarding this dissertation. The first section will describe the larger project from which these papers were derived. The second section will then present the purpose of this dissertation, drawing on research related to new science teachers, content knowledge and cross-national research. The concluding section will be an outline of the following chapters.

## Background Information

The two manuscripts that comprise this dissertation were part of a larger National Science Foundation funded project called “Persistent, Enthusiastic, Relentless: Study of Induction Science Teachers” (PERSIST) #1247096 and #0918697. The purpose of this project was to understand the knowledge, beliefs, and practices of new science teachers during their first five years in the classroom. Previous research from this project highlighted the importance of new teachers’ content knowledge (e.g., Luft et al., 2011) and instigated the development of the SKT model. Initial pilot studies suggested the model was productive and in need of further development (Luft, Hill, Weeks, Raven, & Nixon, 2013). For this purpose, and other purposes related to the larger project, the project expanded to include researchers and participants from South Africa. Additional funding from the National Association for Research in Science Teaching (NARST) and the Sasol Inzalo Foundation supported the addition of researchers and participants.

## Purpose of the Studies

New teachers, those with less than five years of experience, are a concern of educational systems worldwide (Jensen, Sandoval-Hernádez, Knoll, & Gonzalez, 2012). In the United States (US), new teachers constitute a significant portion of the teaching force (Feistritzer, 2011; Ingersoll, Merrill, & Stuckey, 2014 2014; Rushton et al., 2014). During the 2011-2012 school year, the most common US teacher had five years of experience. The prevalence of new teachers is tied to the overall growth of the teaching force (Ingersoll et al., 2014; Rushton et al., 2014) and the finding that 41% of US teachers leave within their first five years of teaching (Ingersoll et al., 2014). Even in nations where there are not currently a large proportion of new teachers, there is a concern about new teachers. In South Africa, for example, two thirds of the teachers are over 40 years of age (Center for Development and Enterprise, 2011). Anticipating the upcoming retirement of these teachers, recommendations have been made to recruit, prepare, and support new teachers entering the profession.

New teachers also occupy an important space at the transition from teacher preparation to classroom teaching. In this space, new teachers have been influenced more by their teacher preparation program than their school context (e.g., Kleickmann et al., 2013). As such, they make an ideal sample for studying the effects of teacher preparation programs. Furthermore, an understanding of the knowledge and skills of new teachers entering the classroom can be informative for those desiring to support new teachers during the particularly challenging early years (Davis, Petish, & Smithey, 2006; Luft, Dubois, Nixon, & Campbell, 2015).

One of the challenges faced by new teachers is developing knowledge of the subject area they are responsible for teaching (Davis et al., 2006; Luft et al., 2015). For a science teacher, this knowledge, known as content knowledge, includes an understanding of the facts, laws, theories, and practices of science. Research has repeatedly demonstrated the importance of content knowledge (Abell, 2007; Kind, 2009, 2014; van Driel, Berry, & Meirink, 2014). For one, content knowledge influences the development of pedagogical content knowledge (PCK; van Driel et al., 2014). PCK can be understood as teacher specific knowledge that blends knowledge of content and pedagogy in ways that enable the teaching of science content. Content knowledge is often seen as the "source or basis for the development of PCK" (van Driel et al., 2014, p. 861). For example, Halim and Meerah (2002) found that when Malaysian elementary teachers demonstrated incorrect scientific understandings they were less likely to identify students' misconceptions, an important aspect of PCK. In another study, the content knowledge of South African chemistry teachers was found to be an essential component of their knowledge for teaching (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). The content knowledge of teachers in this study influenced their subject matter representations, assessments, and instructional strategies. Strong content knowledge coincided with strong PCK.

Likewise, extant research shows that content knowledge is essential because it influences teacher practice (Abell, 2007; van Driel et al., 2014). In a study of science teacher noticing, for example, Kang (2014) suggested that teachers' ability to determine the accuracy of students' responses, especially partially correct responses, depended on their content knowledge. Similarly, Hanuscin and Lee (2015) discovered that teachers struggled to develop sequences of instruction that coherently built concepts. After finding that differences did not depend on teachers' PCK, these researchers surmised that content knowledge might have constrained teachers' lesson planning. Other research has shown that teachers struggle to develop conceptually coherent lesson sequences (Park Rogers & McCormack, 2015) and identify the most important concepts (Bertram & Loughran, 2014; Davis, Petish, & Smithey, 2006).

Furthermore, research on the structure of teachers' content knowledge has predicted that coherent content knowledge held by the teacher leads to a more coherent presentation of knowledge to students (Bartos & Lederman, 2014; Gess-Newsome & Lederman, 1993). Though the connection is complex, the coherence of a teacher's content knowledge does seem to influence their practice (Bartos, Lederman, & Lederman, 2014). Researchers have contended that difficulties in practice may be due to limited content knowledge, rather than deficiencies in other forms of knowledge as is often assumed (Diamond, Maerten-Rivera, Rohrer, & Lee, 2013; Rollnick et al., 2008).

While content knowledge is recognized as important, it is a construct that has been poorly conceptualized. Wilson and colleagues (2001) identified this as a gap in the research on teacher preparation: "We need to know more about *how much* subject matter knowledge, and of *what type*, prospective teachers need in order to ensure student learning" (p. 11, emphasis added). In order to further our understanding of the important area, we need models of teacher content knowledge that push beyond our current conceptualizations (Loughran, 2014; van Driel et al., 2014). We need a more thorough understanding of what and how teachers need to know the content, and how that knowledge develops in order to better prepare and support all teachers, especially new teachers.

In this dissertation I explore the content knowledge of new science teachers using a new model called science knowledge for teaching (SKT; Luft et al., 2013). In an increasingly globalized world it is important that researchers develop models that are relevant in multiple nations (König, Blömeke, Paine, Schmidt, & Hsieh, 2011). Constructs that would have previously existed in a single nation now influence a global audience (see Askew, 2014; Rollnick & Mavhunga, 2015; Stylianides & Delaney, 2011). Thus, this dissertation draws on a sample of teachers from two nations—South Africa and the US—to strengthen the development of the SKT model. The overarching question for this dissertation is: “What are the characteristics of science knowledge for teaching and how does this knowledge develop in new teachers?”

## Overview of the Chapters

The two manuscripts that comprise this dissertation approach this purpose in different ways. Chapter 2 is the manuscript titled, “Characterizing Science knowledge for teaching: An Exploration with New Teachers in South Africa and the US.” In this manuscript, interviews from 13 new chemistry teachers from South Africa and the US were analyzed to characterize the domains of the SKT model. The characterization that follows includes topics within the SKT model and a discussion of the attributes of teacher content knowledge. From this analysis, there are suggestions about how to conceptualize SKT and what additional research is needed in this area.

Chapter 3 is the manuscript titled, “Exploring the Development of Science knowledge for teaching: The Combined Impact of Degree and Experience.” This chapter is focused on the development of SKT, specifically with regard to holding a degree in the subject area and years of classroom experience. This study used a cross-sectional sample of six US teachers assigned to teach chemistry. These teachers had either one, two or three years of classroom experience. One of the teachers in each year had a degree in chemistry, while the other had a degree in biology. The content knowledge of these teachers was compared and contrasted to understand the potential impact of these two factors. The analysis of the data suggested that both factors influence the development of SKT in new teachers.

Chapter 4 concludes this dissertation by summarizing major contributions from the two studies in order to synthesize what was learned about the nature and development of content knowledge. Ideas for future research are also presented.

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# CHAPTER 2

# CHARACTERIZING SCIENCE KNOWLEDGE FOR TEACHING: AN EXPLORATION WITH NEW TEACHERS IN SOUTH AFRICA AND THE US[1]

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[1] Nixon, R. S., Toerien, R. & Luft, J. A. To be submitted to *Science Education*.

# Abstract

Content knowledge is an important component of science teachers' knowledge as it can influence the development of other forms of knowledge and classroom practice. Despite its importance, content knowledge has been poorly conceptualized in science education. This study seeks to characterize teacher content knowledge through the science knowledge for teaching (SKT) model, using a sample of new chemistry teachers from sites in South Africa and the US. Through a qualitative analysis of interviews regarding teachers' knowledge of the conservation of mass, the domains of the SKT model are characterized. Findings suggest the presence of unique domains of content knowledge used in the work of teaching and that it is possible for new teachers to have knowledge in these domains. This empirically based characterization of the SKT model adds further nuance to our understanding of teacher content knowledge that has potential for use in the international conversation on teacher quality.

# Introduction

The content knowledge of teachers is a major theme in the global conversation on teacher quality. Many nations include requirements for teacher content knowledge in their standards for new teachers (Luft, Dubois, Nixon, & Campbell, 2015) and express concerns about the content knowledge of their teachers in national reports (e.g., Spaull, 2013; Wilson, Floden, & Ferrini-Mundy, 2001). Furthermore, research across the globe often includes content knowledge as an important component of teacher knowledge (Munby, Russell, & Martin, 2001).

Research on the content knowledge of science teachers has found that teachers' content knowledge often contains misconceptions and misunderstandings (Abell, 2007; Kind, 2014; van Driel, Berry, & Meirink, 2014). These findings have been consistent across all science disciplines and many topics. Beyond this point, our understanding of science teachers' content knowledge has not made significant progress over the last decade (van Driel et al., 2014).

This lack of progress may be related to limited conceptualizations of teacher content knowledge. Reports in the United States (US) have indicated that little is known about the nature of teacher content knowledge (National Research Council [NRC], 2013; Wilson et al., 2001). In one report, scholars called for research investigating "how much [content] knowledge, and of what type prospective teachers need in order to ensure student learning" (Wilson et al., 2001, p. 11). Researchers in science education are rarely explicit about the model of content knowledge they are utilizing and often use an implicit model that suggests science teachers need to only understand the content they are responsible for teaching. Further, characterizing a model of teacher content knowledge is important for the improvement of research and teacher education (Loughran, 2014).

This paper seeks to challenge current formulations of teacher content knowledge and adds to the global conversation on teacher quality by characterizing an emerging model of the content knowledge of science teachers. This model, called science knowledge for teaching (SKT, Luft, Hill, Weeks, Raven, & Nixon, 2013), is strongly influenced by the model of mathematical knowledge for teaching (MKT; Ball, Thames, & Phelps, 2008). The SKT model conceptualizes three domains of content knowledge used by teachers in the work of teaching.

This study seeks to characterize the SKT model through the use of a cross-national sample of new secondary science teachers. Teachers from South Africa (SA) and the US are used in order to strengthen the elaboration of a model that transcends national boundaries. In addition, new teachers, rather than experienced teachers, are utilized because of the importance many nations place on recruiting, preparing, and retaining new teachers. A model that is particularly sensitive to new teachers knowledge will better guide teacher preparation programs. In characterizing SKT, this study seeks to address the following research question: How are the SKT domains characterized in the area of conservation of mass?

## Literature Review

Content knowledge is an essential component of science teachers' knowledge (Abell, 2007; Kind, 2014; van Driel et al., 2014). For one, content knowledge influences the development of pedagogical content knowledge (PCK; van Driel et al., 2014). PCK can be understood as teacher specific knowledge that blends knowledge of content and pedagogy in ways that enable the teaching of science content. Content knowledge is often seen as the "source or basis for the development of PCK" (van Driel et al., 2014, p. 861). For example, Halim and Meerah (2002) found that when Malaysian elementary teachers demonstrated incorrect scientific understandings they were less likely to identify students' misconceptions, an important aspect of

PCK. In another study, the content knowledge of South African chemistry teachers was found to be an essential component of their knowledge for teaching (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). Strong content knowledge coincided with strong PCK.

Likewise, extant research shows that content knowledge is essential because it influences teacher practice (Abell, 2007; van Driel et al., 2014). In a study of science teacher noticing, for example, Kang (2014) suggested that teachers' ability to determine the accuracy of students' responses, especially partially correct responses, depended on their content knowledge. Similarly, Hanuscin and Lee (2015) discovered that teachers struggled to develop sequences of instruction that coherently built concepts. After finding that differences did not depend on teachers' PCK, these researchers surmised that content knowledge might have constrained teachers' lesson planning. Other research has shown that teachers struggle to develop conceptually coherent lesson sequences (Park Rogers & McCormack, 2015) and identify the most important concepts (Bertram & Loughran, 2014; Davis, Petish, & Smithey, 2006). Furthermore, research on the structure of teachers' content knowledge has predicted that coherent content knowledge held by the teacher leads to a more coherent presentation of knowledge to students (Bartos & Lederman, 2014; Gess-Newsome & Lederman, 1993). Though the connection is complex, the coherence of a teacher's content knowledge does seem to influence their practice (Bartos, Lederman, & Lederman, 2014). Researchers have contended that difficulties in practice may be due to limited content knowledge, rather than deficiencies in other forms of knowledge as is often assumed (Diamond, Maerten-Rivera, Rohrer, & Lee, 2013; Rollnick et al., 2008).

The content knowledge of science teachers has been studied for many years, primarily finding that teachers have misconceptions and misunderstandings in various science topics

(Kind, 2014; van Driel et al., 2014). However, research in this area is still “at an early stage” (NRC, 2013, p. 23). Scholars have noted major gaps in the understanding of teacher content knowledge, indicating that it is still not known what, and in what ways, teachers need to understand the content (NRC, 2007, 2013; van Driel et al., 2014; Wilson et al., 2001). Indeed, van Driel et al., (2014) asserted that the research in this area had not made progress over the last decade. Progress, Loughran (2014) argued, will require “challenging current formulations” of teacher knowledge (p. 201).

The prevailing formulation, or model, of content knowledge in science education reflects the assumption that teachers primarily need understand the content they are responsible for teaching (see Ball & Bass, 2000). Though rarely articulated, this model can be inferred from assessments of teacher content knowledge (see Hill, Sleep, Lewis, & Ball, 2007). For example, one study assessed the science content knowledge of fifth grade teachers using items appropriate for fifth graders (Diamond, Maerten-Rivera, Rohrer, & Lee, 2014; Maerten-Rivera, Huggins-Manley, Adamson, Lee, & Llosa, 2015). Another study assessed teacher content knowledge by administering the same test to both teachers and their students (Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). This restricted conceptualization of teacher content knowledge may have contributed to a limited understanding of teacher content knowledge.

Scholars have argued that the content knowledge of teachers is not limited to the content knowledge students are expected to learn. In his influential paper, Shulman (1986) posited that teacher content knowledge includes understanding “that something is so…why it is so [and] why a given topic is particularly central to a discipline” (p. 9). Deng (2001, 2007) has similarly argued that the scientific knowledge needed to teach science is unique, distinct from the knowledge that students are expected to learn in order to be scientists or scientifically literate citizens.

## Conceptual Framework

### Mathematical Knowledge for Teaching

The field of mathematics education has more articulated models of teacher content knowledge than science education (Rowland, 2014). One productive characterization, known as mathematical knowledge for teaching (MKT), emphasizes the mathematical knowledge used in the work of teaching (Ball et al., 2008). A salient feature of the MKT model is that it clarifies the content knowledge of teachers by distinguishing three domains of content knowledge. The first domain is *common content knowledge*. Common content knowledge has been defined as the mathematical knowledge of a well-educated adult (not a teacher) or “the mathematical knowledge teachers are responsible for developing in students” (Hill et al., 2007, p. 132). *Specialized content knowledge*, the second domain, includes mathematical understandings that are unique to the work of teaching (Ball et al., 2008). This includes, for example, the content knowledge used in analyzing student work to see if a nonstandard approach can be generalized (Hill, Rowan, & Ball, 2005). The third domain of content knowledge in the MKT model, *horizon content knowledge*, includes mathematical understandings that allow a teacher to orient the content in a specific lesson to the rest of the discipline and judge what is mathematically important (Mosvold, Jakobsen, & Jankvist, 2013). This model also includes domains of PCK.

The MKT model has provided useful insights into the unique ways that teachers need to understand their content (Adler & Ball, 2009). For example, Mitchell, Charalambous, and Hill (2014) identified knowledge used in teaching integer addition and subtraction using representations by closely examining two mathematics teachers’ practice. The MKT model allowed researchers to understand that teachers needed specialized content knowledge to understand the purposes, limitations and affordances of different mathematical representations. Additionally, the MKT model enabled researchers to connect teacher knowledge with instructional practice (Hill et al., 2008) and student achievement (Hill et al., 2005). In short, the MKT model is tied to a productive body of research highlighting the unique content knowledge needed to teach mathematics.

## Science Knowledge for Teaching

Several researchers have suggested building on the strengths of the MKT model and applying the ideas to other disciplines, including science education (NRC, 2013; Settlage, 2013; van Driel et al., 2014). In line with this recommendation and the need to better understand and conceptualize the content knowledge of science teachers, the science knowledge for teaching (SKT) model is presented below (Luft et al., 2013). This model has been adapted from the MKT model to reflect differences in the nature of knowledge in mathematics and science, and the state of the fields of mathematics education and science education.

As with the MKT model, SKT includes three domains of content knowledge. The first domain is *core content knowledge* (CCK). This domain is similar to common content knowledge in the MKT model. CCK comprises knowledge of the fundamental science concepts, theories, laws, facts, and processes of science. It is this knowledge that well-educated adults (who are not teachers) might reasonably know. This includes the knowledge that students are expected to learn. As such, much of this knowledge is reflected in documents that detail the most fundamental science ideas for students to learn and know (e.g., NRC, 2012). Current research on teacher content knowledge investigates this domain of knowledge (see Kind, 2014; van Driel et al., 2014).

The second domain, *specialized content knowledge* (SCK), is scientific knowledge that is used to accomplish various tasks of teaching. SCK is analogous to the domain of specialized content knowledge in the MKT model, though the content and tasks of teaching differ. In science teaching, a teacher must determine if a student who responds to a question using non-scientific vocabulary is correct. This task requires the use of SCK. A science teacher must also understand the science well enough to be able to select, for example, a chemical reaction to illustrate a particular concept in class. Teachers must understand the concept and the reaction well enough to understand that they are connected and that the reaction does not introduce additional complicating details. While knowledgeable teachers would be able to complete these tasks, a well-educated adult who is not a teacher would likely struggle. This is therefore considered "pedagogically useful" scientific knowledge (Ball & Bass, 2000, p. 89). This form of content knowledge has rarely been distinguished in science education.

The third domain is *linked content knowledge* (LCK) and is comprised of an understanding of the logical connections between science concepts. This includes knowledge of which concepts are central and which are peripheral in the scientific disciplines. Furthermore, LCK involves understanding which concepts are prerequisite for other ideas. LCK is similar to the MKT domain of horizon content knowledge. As with SCK, LCK has rarely been distinguished in the science education literature.

While the MKT model includes domains of PCK, the SKT model includes only domains of content knowledge. This reflects the state of research in science education, in which there is a significant body of models for PCK, with a more limited focus on models of content knowledge (van Driel et al., 2014). Considering the significance of content knowledge, it is important to further conceptualize the content knowledge of teachers, putting aside for now the connection of this knowledge with PCK or other components of teacher knowledge.

Although the SKT model is based off of the productive MKT model, there is need to empirically explore this model. Initial research using the SKT model has found that teachers' SKT is more developed when teachers have more classroom experience and a degree in the subject area (Nixon, Campbell, & Luft, in review). While CCK was apparent in content interviews with new teachers, the domain of SCK did not arise as salient themes. More targeted analysis is needed to determine if there is evidence of these knowledge domains in practicing teachers.

Chemistry knowledge is the focus of this study. Chemistry knowledge is comprised of three layers of knowledge: macro, submicro, and symbolic (Johnstone, 1991; Taber, 2013). The macro layer includes tangible and visible objects and phenomena, while the submicro layer relates to substances and phenomenon happening at very small scales (e.g., molecules, ions). The symbolic layer includes the methods of communicating the other two layers. The coordination of these three layers distinguishes chemistry knowledge from knowledge in other science disciplines.

## Methods

### Participants

Participants for this qualitative study included 13 teachers, all of who were assigned to teach chemistry to high school students (see Table 2.1). Five of the teachers in the sample were from sites in SA. This included one teacher in her post graduate certificate in education (PGCE) year (Rita), one in his first year (Daniel), two in their second year (Albert, Brenda), and one in his third year (Richard). Two were female and three were male. In SA, chemistry is a portion of the physical sciences curriculum. As students take physical science each year in high school, there is a different curriculum for each course. Teachers were assigned to teach physical science to multiple grades (10, 11, and 12). Daniel and Brenda were also assigned to teach mathematics.

The remaining eight teachers in the sample were from sites in the US. This included two student teachers (Rhonda, Stephanie), two first year teachers (Aaron, Addie), two second year teachers (Marisa, Aubrey), and two third year teachers (Heidi, Madison). Seven of the teachers were female and one was male. In contrast with SA, high school chemistry in the US is generally taught as a single course, though multiple levels are offered (e.g., Advanced Placement). Most of the US teachers taught multiple levels of chemistry. Aaron and Marisa were also assigned to teach biology, while Heidi was assigned to teach astronomy.

In seeking to characterize the content knowledge of science teachers, this study draws on a cross-national sample of new chemistry teachers. Teachers were drawn from sites in two nations because it is important in a globalized world that models can be utilized across nations (König, Blömeke, Paine, Schmidt, & Hsieh, 2011; Stylianides & Delaney, 2011). Researchers have used cross-national samples in other studies to better understand teacher knowledge (Delaney, Ball, Hill, Schilling, & Zopf, 2008; König et al., 2011). While this study utilizes a cross-national sample, it is not an international comparative study (Phillips & Schweisfurth, 2006). Using participants from sites in two nations will ensure that the model can transcend national boundaries.

New teachers are especially appropriate for participation in this study as efforts to understand how to best prepare and support new teachers are underway across the globe (Jensen, Sandoval-Hernádez, Knoll, & Gonzalez, 2012). Teacher educators and policymakers in SA and the US, in particular, are concerned with preparing and supporting high quality teachers (Center for Development and Enterprise, 2011; Ingersoll, Merrill, & Stuckey, 2014; Luft, 2007). Models attuned to the needs of new teachers will better guide teacher preparation and induction. It is also important to study new teachers because they are more influenced by their preparation programs than experienced teachers (Kleickmann et al., 2013). Better understanding the content knowledge of new teachers provides insights in the quality of their preparation and their needs for future support. Furthermore, new teachers are more likely to have been prepared within the current reform paradigm. This is especially relevant in SA, where new teachers have been prepared post-apartheid. Major changes in the education of teachers accompanied this political and social shift resulting in higher quality preparation (Ogunniyi & Rollnick, 2015; Rollnick & Mavhunga, 2015).

Participants for this study were purposefully selected to help "generate or discover a theory or specific concepts within the theory" (Creswell, 2008, p. 216). As this sample is not representative of teachers in SA, the US, or new teachers as a whole, generalizations about these populations would be inappropriate. As the purpose was to characterize the SKT domains among new science teachers in a way that would be cross-nationally relevant, this sample is appropriate (Hill et al., 2007).

## Data Source

Data for this study included an interview regarding the conservation of mass. The conservation of mass is a fundamental topic in chemistry (Caldin, 2002) as well as the high school curriculum in both SA and the US (Department of Basic Education [DBE], 2011; NGSS Lead States, 2013). Despite the importance of this topic, research has shown that both students (Hesse & Anderson, 1992; Özmen & Ayas, 2003; Salta & Tzougraki, 2011) and teachers

(Haidar, 1997; Kruse & Roehrig, 2005) do not have a solid understanding of the conservation of mass.

One of the challenges with understanding the conservation of mass, and chemistry concepts generally, is that understanding chemistry requires the coordination of three layers of knowledge: the macro, submicro, and symbolic (Johnstone, 1991, 2000; Taber, 2013). The macro layer involves what is directly accessible through the senses while the submicro layer involves the atomic and molecular level of the phenomenon. The symbolic layer includes how these other two levels are communicated (e.g., chemical equations or diagrams of the molecules reacting).

Interview questions aligned with the domains of the SKT model (see Figure 2.1). The first question probed teachers' CCK by asking teachers to explain the conservation of mass removed from the context of teaching. Teachers were then given a classroom scenario in which students demonstrated an error in understanding the topic. To elicit SCK, teachers were next asked to discuss the content related to students' error. Teachers were then asked what they would do to help remediate this error. The final question, intended to elicit LCK, asked teachers what concepts students should learn before and after the conservation of mass.

Interviews involving classroom scenarios have been used to effectively elicit teacher knowledge in previous studies (e.g., Ball, 1990; McDiarmid, 1995; Phelps, 2009). An advantage of this type of interview is that it allows a researcher to elicit teachers' knowledge related to teaching, with the opportunity to follow up on points that are unclear (Hill et al., 2007). It has been argued that interviews like these are an effective way to explore a domain of knowledge, the purpose of this study (Hill et al., 2007).

The validity of these data was supported by the use of multiple interviewers (Miles, Huberman, & Saldaña, 2014; Seidman, 2013). Each participant was interviewed by a researcher from his or her own nation. Interviewers used a semi-structured protocol, which allowed interviewers to adapt to and follow up on participants' responses (Bogdan & Biklen, 2006; Kirk & Miller, 1986). Interview protocols were developed by researchers from both nations, with minor modifications for national context (e.g., "learners" in SA, "students" in the US).

These data were a part of a larger study that explored new teachers in SA and the US. The analyzed portion of the interview lasted approximately 20 minutes and was part of a longer interview aligned with other research purposes. Each interview was recorded and transcribed.

## Data Analysis

In the first phase of data analysis, two researchers read through each participant's interview multiple times and used structural codes to identify segments which provided evidence of each SKT domain (e.g., a paragraph that provided evidence of the teacher's CCK, was coded as CCK). Structural codes are derived from a preexisting framework and are used to identify sections of the data that represent categories from the framework (Saldaña, 2013). Some segments were assigned multiple structural codes.

Using structural codes, researchers then complied all interview segments that provided evidence of each SKT domain. These segments were then reread to generate statements that summarized the teacher's knowledge in each SKT domain. These content statements were not direct quotes, but reflected the participants' words. Content statements were refined throughout the remainder of the analysis process as our understanding of the domains was refined.

Content statements were then placed in a construct table (Miles et al., 2014) to allow researchers to analyze the content statements as a whole. Using this construct table, researchers independently looked across participants for common topics in each of the SKT domains. The researchers then reached consensus on a few salient topics per domain.

The validity of this analysis process was strengthened through the consideration of alternative explanations (Miles et al., 2014). After determining salient topics, researchers compiled the content statements not included in these topics to explore potential themes in the remaining content statements. No additional salient themes were identified. While some of the teachers expressed scientifically inaccurate statements, these were idiosyncratic and, as such, do not appear in the findings. Furthermore, the use of multiple researchers strengthened the analysis process (Miles et al., 2014). One researcher was a native of SA and the other a native of the US. Each had attended schools and taught in their respective nations. During the research process, researchers visited the other nation, spent time together face-to-face and online. The insights each researcher brought about his or her context made valuable contributions to the analysis process.

In addition to the sample selection limitations noted above, there are two additional limitations of this study. First, interview data is not representative of the whole of teacher knowledge (Hill et al., 2007). While claims can be made about what teachers do know and find relevant, claims cannot be related to whole of their knowledge. Second, while these interviews provide some information about what teachers do know, these data do not allow claims to be made about what the teacher does in class or how it affects students.

## Findings

The purpose of this study was to characterize the SKT domains using this sample of new teachers from sites in two nations. The knowledge teachers demonstrated for each domain is presented by salient topics in each domain (see Table 2.3).

### Finding 1. Teachers demonstrated CCK related to the law of conservation of mass, reactants and products of burning paper, the particulate nature of matter, and the energetic composition of a flame.

**Law of conservation of mass.** All teachers provided evidence of understanding the law of conservation of mass. For example, Stephanie stated: “Mass is neither created nor destroyed meaning that whatever the amount of what you started with, the atoms, the specific elements, they are the same for your reactants or your products” (759-761). Here Stephanie demonstrated her understanding that the number of atoms is conserved in a chemical reaction. Similarly, Albert explained, “Law of conservation of mass…comes about in your conservation of number of atoms for each type of element…you see that at a macroscopic level as mass being conserved” (129-134). The knowledge these teachers demonstrated, that mass (macro layer) is conserved because the number of atoms (submicro layer) remains the same, is important for students to learn. The *NGSS*, for instance, states that students should know that: “Matter is conserved because atoms are conserved in physical and chemical processes” (NGSS Lead States, 2013, p. 213).

Not all of the teachers were explicit about the connection between the macro and submicro layers in the law of conservation of mass. For example, Rhonda stated, “The law of conservation of mass says that…if I put one gram of a reactant and one gram of another reactant in a beaker, I will get two grams of product” (581-581). Here she focused on the macro layer, since one can measure mass. In another example, Madison stated, “The total mass of the reactants must equal the total mass of the products” (483-484). Though these teachers did not demonstrate knowledge of the involvement of atoms in the law of conservation of mass, they did correctly state the law of conservation of mass.

**Reactants and products of burning paper.** Many of the teachers in this sample displayed knowledge of the reactants and products of burning paper. Several participants demonstrated the understanding that atoms interact with each other as paper burns. Albert, for instance, described burning paper in this way: “And then, when your paper burns, some of the carbon atoms react with the oxygen in the air to form carbon dioxide” (153-154). Here he explicitly identified the type of atoms that interacted with each other while paper burns. Aubrey described burning paper similarly: “what paper is made of…which is the cellulose organic compound—carbon, hydrogen, and oxygen mainly [reacted with oxygen, to form] carbon dioxide and water” (250-253). While Aubrey was more explicit about the elements that interact during burning, both of these quotations are representative of teachers who demonstrated knowledge that atoms (submicro layer) interacted with each other while paper burned (macro layer). This concept is important for students to understand (DBE, 2011; NGSS Lead States, 2013).

**Particulate nature of matter.** Another topic that was salient among the data for CCK was the particulate nature of matter. A quotation from Albert demonstrates this knowledge: the “mass of substances comes from an atomic level…the atom itself having mass” (181-183). Here he demonstrated the understanding that matter is made of atoms and, furthermore, that the mass (macro layer) is due to the presence of atoms (submicro layer). Though not as detailed, Madison displayed a similar understanding that matter, even air, is made up of particles. She stated, “air is not empty space…there’s actually molecules in there that move around that you can’t see” (Madison, 518-519). According to the CAPS and *NGSS*, this is knowledge that students should learn (DBE, 2011; NGSS Lead States, 2013).

**Energetic composition of a flame.** The last salient topic in the domain of CCK was knowledge regarding the energetic composition of a flame. Only a few teachers demonstrated this knowledge. For instance, Aubrey emphasized the light emitted from the flame. "We will talk about…what actually is the flame. That it is…light" (247-249). Richard emphasized that a flame is heat energy. Richard said, "that [a flame is] heat energy being released" (637). Energy is a particularly important topic for students to understand and is emphasized repeatedly in standards documents (DBE, 2011; NGSS Lead States, 2013).

**Finding 2. Teachers demonstrated SCK related to the gaseous products of combustion, reactions similar to burning paper, and the material composition of a flame.**

**Gaseous products of combustion.** Many teachers provided evidence of their knowledge of the properties of the gaseous products in a combustion reaction. For instance, some teachers expressed their knowledge that the gaseous products of combustion are invisible. When explaining the cause of student difficulty with this scenario, Madison explained that students had difficulty because "they can't see the products of the reaction" (488). Stephanie also identified the invisibility of the gaseous products as a source of student difficulty: "[Students struggle because] they…can't see the gases being produced. The mass that's being released is not visible" (Stephanie, 767-768).

Other teachers demonstrated their understanding that the gaseous products of combustion are challenging to measure. As Heidi described the conservation of mass, she clarified that "some may be lost as a gas so you may not be able to weigh it" (418-419). Richard indicated that the products of burning paper are challenging to measure because they are "released because it's not in a closed container" (665).

In this topic, teachers demonstrated knowledge that the gaseous products of combustion are invisible and challenging to measure. Based on the standards documents, this is not knowledge students should explicitly learn (DBE, 2011; NGSS Lead States, 2013). However, this knowledge is useful for the work of teaching. Knowing that burning paper creates invisible gases assists the teacher in understanding how mass is conserved, even though one cannot see the products of the reaction. Likewise, knowing that burning paper creates gases that are challenging to measure enables a teacher to understand that the mass of the reactants are conserved despite the decrease in the reading on the scale.

**Similar reactions.** Another salient topic in the SCK domain is knowledge of reactions that are similar to burning paper. Albert and Richard expressed knowledge of reactions of a metal and an acid. Albert indicated that when a metal reacts with an acid, “a gas is released, [one] can actually see the bubbling…[while] having a mass decrease” (167-172). In this quotation we see Albert knew that as a metal reacts with an acid, bubbles are formed and the mass decreases. Richard was more specific, identifying the reaction of zinc in hydrochloric acid. In this reaction, one can “see [a gas] being released” (Richard, 660). He explicitly indicated that while there would be a decrease in mass, but that this decrease would be “very little” (Richard, 663). As with Albert, Richard demonstrated his knowledge that as a metal reacts with an acid (specifically zinc and hydrochloric acid) there is a visible reaction and a (minimal) loss of mass. Madison also demonstrated knowledge of a reaction that was similar to burning paper—the reaction of copper in a silver nitrate solution. In this reaction, one can “have all the pieces and show mass before equals mass after” (Madison, 509-510). Here, she demonstrated her knowledge that all of the reactants and products in this reaction are available for measurement.

These teachers demonstrated knowledge of features of reactions that were similar to burning paper.

The knowledge demonstrated by teachers in this topic is not knowledge that students are expected to learn. For example, while the CAPS (DBE, 2011) states that students should be able to identify different reaction types, predict products of reactions, and identify the movement of electrons in these reactions, it does not state that students are to understand features that relate chemical reactions. This knowledge is, however, useful for the work of teaching. Teachers drew on this knowledge as they considered how to address student misunderstandings with another reaction that could make the conservation of mass more apparent.

**Material composition of a flame.** The last salient topic in the SCK domain is related to the material composition of a flame. All of the teachers expressed the understanding that as paper burns the matter does not turn into flame. Stephanie stated this directly: “Paper’s not turning into the flame” (769). Similarly, after hearing students’ response in the scenario, Brenda exclaimed, “No, but that’s completely wrong” (297). A few participants provided further detail. Richard, for example, expressed that fire is not an element and Madison stated that fire is not a state of matter.

The CAPS and *NGSS* documents emphasize that students should be able to classify a chemical reaction as combustion, be able to balance the chemical equation for combustion, and understand the mechanism (e.g., valence electrons, energy) of a combustion reaction. This does not include an understanding of the composition of a flame. However, teachers drew on the knowledge that a flame is not matter as they evaluated students’ responses. Because they knew that paper is not turning into flame as it burns, they were able to determine that the students in the scenario were incorrect.

### Finding 3. Teachers demonstrated LCK regarding concepts linked to the conservation of mass.

All teachers provided evidence of their knowledge related to the connection of the conservation of mass with other concepts. A few of these teachers demonstrated understanding of the centrality of specific topics. For instance, Heidi expressed her understanding that the atomic model is central in chemistry: “The big fundamental would be matter and everything is composed of atoms” (447-448). The majority of the teachers demonstrated knowledge of topics that were connected to the conservation of mass, such as balancing equations. Addie stated, “I think balancing would be a good topic to do with the law of conservation” (120). Others identified links with the mole concept, limiting reactants, stoichiometry and others.

# Discussion & Conclusion

The purpose of this study was to characterize the domains of knowledge within the SKT model using a cross-national sample of new teachers. This discussion will begin with a characterization of the SKT domains based on the findings. These characterizations will be linked to the extant literature. Findings will then be discussed in relation to the literature on new teachers and cross-national studies.

## Core Content Knowledge

CCK is the scientific knowledge of well-educated adults who are not teachers. This knowledge is encapsulated in documents detailing the knowledge students should learn in their K-12 science education (DBE, 2011; NGSS Lead States, 2013). The four salient topics that teachers discussed in this domain are included in the curriculum documents and are foundational to the discipline of chemistry (Caldin, 2002), supporting this characterization.

As the interview focused on the conservation of mass, it is not surprising that teachers demonstrated knowledge regarding the law of conservation of mass. This is in agreement with the body of research on teacher content knowledge in science education, which suggests that teachers need to understand the content that students are to learn (van Driel et al., 2014). One would expect that teaching the conservation of mass would require knowledge of this concept.

These findings also indicate that teachers drew on concepts beyond the conservation of mass when responding to this teaching scenario. This suggests teacher content knowledge must extend beyond the specific topic being taught. Knowledge of multiple related topics is coordinated when teaching. Having well structured, coherent content knowledge may enable teachers to efficiently draw on related topics to support the complex content demands of teaching (Bartos & Lederman, 2014; Gess-Newsome & Lederman, 1993). While further research is needed to investigate how CCK influences classroom practice, this supports research that suggests the coherence of content knowledge influences classroom practice (Bartos et al., 2014).

Another characteristic feature of the CCK demonstrated in this data is the variation in teachers' explicitness regarding the layers of chemistry knowledge (Taber, 2013). Some teachers were explicit about the relationship between both macro and submicro layers, indicating that properties of the submicro layer lead to properties observed at the macro layer. Others were only explicit about the macro or submicro and did not relate the two. That CCK shares this feature with chemistry knowledge suggests that this knowledge is not unique to the work of teaching.

## Specialized Content Knowledge

SCK is scientific knowledge that is unique to teachers and is used in the work of teaching. These findings support both characteristic features of SCK. First, these teachers demonstrated knowledge that is not necessary for students to learn. Each of the salient topics presented in the findings above are topics that are not included in the curriculum documents and are not foundational to the discipline of chemistry. Second, the knowledge represented in each of the salient topics aligns with a different task of teaching. The first topic, knowledge of the gaseous products of combustion, was used to determine why students in the scenario made the error. The second topic, knowledge of similar chemical reactions, was used to consider other labs or demonstrations that the students should experience to help them understand the content. Knowledge of the material nature of the flame, the last topic, was used to determine whether students were correct or incorrect. This supports the assertion that teachers use unique understandings of the content to accomplish the work of teaching.

Differences in the SCK among the teachers demonstrated that this content knowledge is unique to the work of teaching. The scientific knowledge expressed by teachers in this domain differed primarily in terms of how explicit teachers were with regard to the visibility and measurability of chemical phenomena. While the visibility and measurability of chemical phenomena are significant concerns for the work of teaching, they are not fundamental characteristics of chemistry knowledge (unlike the layers of chemistry knowledge).

These findings bring additional nuance to prior research that suggests content knowledge is related to some of the tasks of teaching. For example, prior research on teacher noticing in science has indicated the importance of content knowledge (Kang, 2014). Content knowledge used to do this work is likely SCK. Based on these initial findings and work in mathematics education (Ball, Lubienski, & Mewborn, 2001), it is likely that many of the tasks of teaching science require unique understandings of the content.

## Linked Content Knowledge

LCK is knowledge of the connection between scientific concepts and principles. These findings suggest that teachers do draw on this form of knowledge. However, very few teachers provided evidence that they understood how the concept (i.e., conservation of mass) fit into the broader discipline. Rather, most of the teachers simply provided related topics, largely linked by location in the curriculum. Thus, while this seems to be a viable domain of teacher content knowledge, this domain of knowledge appeared the least developed among this sample of new teachers.

Past research has indicated that teachers struggle to identify the most important concepts in a discipline (Bertram & Loughran, 2014; Davis et al., 2006) and to develop conceptually coherent units (Hanuscin & Lee, 2015; Park Rogers & McCormack, 2015). This difficulty has been tied to limited PCK. However, this study, in agreement with Hanuscin and Lee (2015), suggests that teachers' difficulties in conceptually linking topics may be due to limited LCK.

## New Teachers

While these findings cannot be generalized to all new teachers, observations regarding this sample provide interesting insights into the knowledge and preparation of new teachers. The first observation is that each domain of knowledge was observed in this sample of new teachers. Though this knowledge was not well developed in new teachers, these findings suggest that it is possible for new teachers to have SKT. Though SKT may develop with classroom experience (Nixon et al., in review), these domains of knowledge are not out of reach for new teachers.

The second observation is that this sample of teachers was most knowledgeable in the domain of CCK, as evidenced by the number of teachers who demonstrated knowledge in this domain, and the number of salient topics present in this domain and the complexity of knowledge demonstrated by teachers. This suggests that the preparation of these teachers was most successful at encouraging the development of CCK. As such, new teachers may need the most support in developing SCK and LCK.

**SKT in Both Sites**

The purpose of using a cross-national sample of teachers from sites in two nations was to elaborate on a model that described the content knowledge of teachers in more than one nation. Findings from this analysis suggest that the model did describe the knowledge of these teachers from sites in SA and the US. While not representing the population of either nation, these findings show that the SKT model has the potential for use in both nations. It may be relevant in other nations as well.

**Future Research**

This paper represents one of the earliest attempts to characterize science teacher content knowledge using the SKT model. Many questions remain. As claimed above, past research has primarily emphasized the content knowledge that teachers are responsible for teaching, known as CCK in the SKT model. Further work is needed to understand the domains of SCK and LCK (see Nixon et al., in review). Further conceptualizing SCK may require identifying specific tasks of teaching and the content knowledge needed to enact these tasks. We recommend that investigations in this vein focus on essential, rather than peripheral, tasks of teaching. Work identifying the tasks of teaching should build from MKT-related research (e.g, Ball et al., 2008) and studies identifying high-leverage practices (Kloser, 2014; Windschitl, Thompson, & Braaten, 2012). Understanding LCK to a greater extent may involve investigating how teachers use content knowledge when developing coherent lessons and units of instruction (see Hanuscin & Lee, 2015).

Future research should also consider these domains of knowledge with other samples of teachers including those in other nations and those with varying levels of experience. Rich data from small samples of teachers may be most fruitful as this model continues to be characterized. Furthermore, this same model could be explored in additional science disciplines (e.g., physics) and topics (e.g., acid and bases). These investigations with other samples and topics should consider the interactions between the domains and whether one domain (e.g., CCK) is prerequisite for the others.

Another potentially fruitful line of investigation may involve analyzing the same set of data using multiple models of teacher knowledge. For example, the same set of data could be analyzed using the constructs of PCK and SKT. Such an investigation would require rich qualitative data, such that the demands of each construct could be satisfied. Findings could illuminate the overlap and distinction between the two, allowing for a greater understanding of the strengths of each model.

In all, this paper contributes a model of teacher content knowledge that expands former, often implicit, conceptualizations. The SKT model characterizes three domains of content knowledge needed by science teachers, adding further nuance to our understanding of teacher knowledge and emphasizing the preeminence of content knowledge. It is especially important to understand the nature of teacher content knowledge considering the foundational role of content knowledge in the work of teaching and the development of other forms of teacher knowledge, including PCK. This empirically based characterization of the model is strengthened by the use of a sample from sites in two nations, suggesting the model's potential for use in the international conversation on teacher quality.

# Acknowledgements

The authors would like to acknowledge the teachers in this study for their enthusiastic participation, as well as Ann Brennan, Benjamin K. Campbell, Shannon L. Dubois, Peter W. Hewson, and Melissa A. Jurkiewicz for their assistance throughout the project. This study was made possible by National Science Foundation (NSF) grants 1247096 and 0918697, the National Association for Research in Science Teaching (NARST) and the Sasol Inzalo Foundation. The findings, conclusions, and opinions herein represent the views of the authors and do not necessarily represent the views of personnel affiliated with the NSF, NARST or the Sasol Inzalo Foundation.

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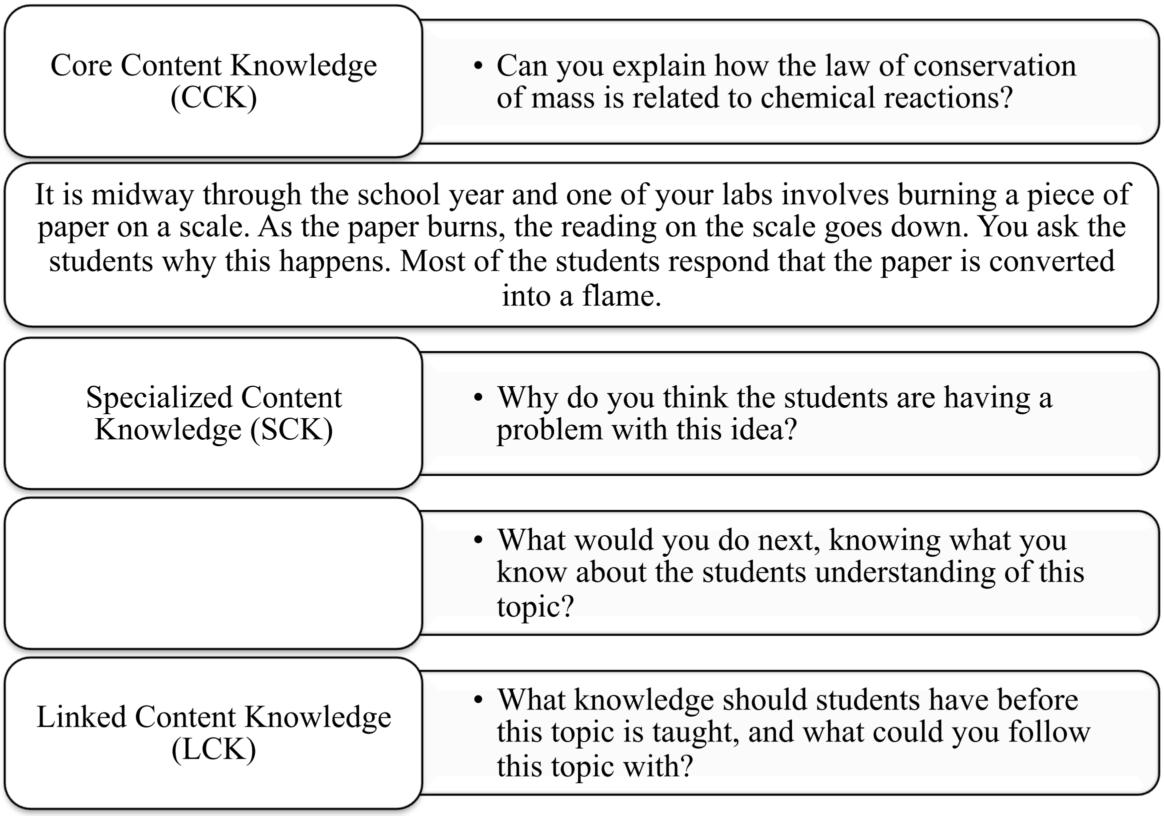

Core Content Knowledge (CCK)

- Can you explain how the law of conservation of mass is related to chemical reactions?

It is midway through the school year and one of your labs involves burning a piece of paper on a scale. As the paper burns, the reading on the scale goes down. You ask the students why this happens. Most of the students respond that the paper is converted into a flame.

Specialized Content Knowledge (SCK)

- Why do you think the students are having a problem with this idea?

- What would you do next, knowing what you know about the students understanding of this topic?

Linked Content Knowledge (LCK)

- What knowledge should students have before this topic is taught, and what could you follow this topic with?

*Figure 2.1.* Alignment of interview questions with SKT domains.

Table 2.1

Teachers in Sample From Each Nation by Year of Classroom Experience

| **Year of Experience** | **South Africa** | **United States** |
|---|---|---|
| PGCE/Student teaching | Rita | Rhonda, Stephanie |
| 1 | Daniel | Aaron, Addie |
| 2 | Albert, Brenda | Aubrey, Marisa |
| 3 | Richard | Heidi, Madison |

Table 2.2

Salient Topics for Each SKT Domain

| **CCK** | **SCK** | **LCK** |
|---|---|---|
| Law of conservation of mass | Gaseous products of a flame | Concepts linked to the conservation of mass |
| Reactants and products of burning paper | Reactions similar to burning paper | |
| Particulate nature of matter | Material composition of flame | |
| Energetic composition of flame | | |

# CHAPTER 3

# EXPLORING THE DEVELOPMENT OF NEW SCIENCE TEACHER CONTENT KNOWLEDGE: THE COMBINED IMPACT OF DEGREE AND EXPERIENCE[2]

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[2] Nixon, R. S., Campbell, B. K., & Luft, J. A. To be submitted to *Teaching and Teacher Education*.

# Abstract

With a workforce dominated by new teachers, it is important to understand the development of teacher content knowledge in the early years. This exploratory study examines the impact of a degree in the subject area and classroom experience on the development of new chemistry teacher content knowledge. In this study content knowledge is conceptualized using the science knowledge for teaching (SKT) framework, which highlights the unique content understandings needed for teaching science. Using a cross sectional sample of six chemistry teachers in their first three years of teaching, analysis suggests that holding a degree in the subject area and classroom experience contribute collectively to the development of teacher content knowledge. These two factors may combine to impact content knowledge development through teacher identity and opportunities for reflection. Analysis further suggests that these two factors promote the development of one domain of SKT, while not impacting the other knowledge domains in the framework.

## Introduction

New teachers constitute a significant portion of the teaching force (Ingersoll, Merrill, & Stuckey, 2014; Rushton et al., 2014). In the 2011-2012 school year the most common teacher had five years of experience. This is in contrast to the 1987-1988 school year, in which the modal teacher had 15 years of experience. The prevalence of new teachers is certainly tied to the overall growth of the teaching force (Ingersoll et al., 2014; Rushton et al., 2014) and the finding that 46% of teachers leave within their first five years of teaching (Ingersoll, 2003).

One of the challenges facing new teachers is developing knowledge of the subject area they are responsible for teaching (Davis, Petish, & Smithey, 2006; Luft, Dubois, Nixon, & Campbell, 2014). This knowledge, known as content knowledge, is an essential component of the knowledge needed for teaching (Abell, 2007; Munby, Russell, & Martin, 2001; van Driel, Berry, & Meirink, 2014). The importance of content knowledge is demonstrated in a study that concluded that content knowledge is one of four fundamental domains of teacher knowledge (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). The content knowledge of teachers in this study influenced their subject matter representations, assessments, and instructional strategies. It has been argued that while "content knowledge alone is not sufficient for effective teachers…without content knowledge, the other types of [teacher] knowledge are also not sufficient for teaching science" (McConnell, Parker, & Eberhardt, 2013, p. 719).

Earning a degree in the subject area one teaches has long been considered an important step in the development of the content knowledge needed for teaching. In the U.S., national policies emphasize that a degree in the subject area is essential for teacher certification (e.g., U.S. Department of Education, 2002). Many non-traditional routes to licensure assume that individuals who hold a degree in the subject area have adequate content knowledge for teaching

(Feiman-Nemser & Parker, 1990). Teacher preparation programs delegate the content preparation of teacher candidates to professors in content departments (Grossman, Wilson, & Shulman, 1989). Researchers have often used a degree in the subject area as a proxy for teacher content knowledge (S. M. Wilson, Floden, & Ferrini-Mundy, 2001).

Another factor that is considered to impact the development of new teacher content knowledge is experience in the classroom. Studies have shown that the content knowledge of experienced teachers is more accurate and coherent than the content knowledge of new teachers (e.g., Barba & Rubba, 1993; Hauslein, Good, & Cummins, 1992). The few studies in this area have led several reviews on teacher knowledge to conclude that teachers' content knowledge improves through classroom experience (Abell, 2007; Cochran & Jones, 1998; Munby et al., 2001; van Driel et al., 2014). Unfortunately, how the content knowledge of new teachers develops is unclear (Luft et al., 2014) and in need of study (National Research Council [NRC], 2013).

Given the prevalence of new teachers and the importance of content knowledge, this study investigates the content knowledge of new science teachers, specifically chemistry teachers, in relation to the subject area of their content degree and years of classroom experience. Specifically, how do degree area and years of experience impact the content knowledge of new chemistry teachers?

## Relevant Literature

Researchers have investigated teacher knowledge over the last thirty years (Ball, Lubienski, & Mewborn, 2001; Cochran-Smith & Fries, 2005; Munby et al., 2001; van Driel et al., 2014). Teacher knowledge is emphasized in this literature because teachers are not simply technicians (Cochran-Smith & Fries, 2005). Rather, teaching is “complex and demanding intellectual work” (Cochran-Smith & Villegas, 2015, p. 10) requiring specialized knowledge.

Content knowledge is recognized as an important aspect of teacher knowledge in many areas of education (Borko & Putnam, 1996; McDiarmid, Ball, & Anderson, 1989; Munby et al., 2001). Researchers in history education, for example, have argued that teachers use content knowledge when noticing student thinking or modifying the curriculum (Bain & Mirel, 2006). In mathematics education, content knowledge has been linked with student achievement (e.g., H. C. Hill, Rowan, & Ball, 2005).

Content knowledge is also recognized as essential in science education. Studies have found that content knowledge influences the classroom practice of science teachers (e.g., Carlsen, 1992; Hashweh, 1987; Sanders, Borko, & Lockard, 1993). For instance, when experienced teachers taught topics for which they had little content knowledge they behaved like novice teachers (Sanders et al., 1993). Content knowledge has also been understood to impact the development of other forms of teacher knowledge (Rollnick et al., 2008; van Driel et al., 2014). One study found that when teachers lacked content knowledge, other forms of knowledge were limited (Rollnick et al., 2008). Additionally, the content knowledge of science teachers has recently been associated with student achievement (Diamond, Maerten-Rivera, Rohrer, & Lee, 2014; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). In one study, middle school teachers’ success in answering a multiple-choice science test was related to student scores on the same test (Sadler et al., 2013).

The content knowledge of science teachers also influences how teachers sequence the content in their courses (Austin, Bloom, Grinnell, & Kirkley, 2011, April; Park Rogers & McCormack; Roth et al., 2011). Teachers struggle to sequence content in conceptually coherent ways. Research has documented that teachers often determine sequence based on connections between activities, rather than the content of those activities (Adams & Phillips, 2015; Hanuscin & Lee, 2015; Park Rogers & McCormack, 2015; Roth et al., 2011). In the TIMSS Video Study (Roth et al., 2006), researchers found that U.S. teachers engaged "students in doing activities without providing the conceptual links that would enable students to have the opportunity to learn science content from these activities" (p. 89). Studies have demonstrated that teachers can learn to sequence topics more conceptually through targeted interventions (e.g., Hanuscin & Lee, 2015; Park Rogers & McCormack, 2015).

Understanding the development of teacher content knowledge is prerequisite to supporting teachers in constructing this knowledge. Research on two factors that are known to impact the development of teacher knowledge, a degree in the subject area and classroom experience, have been an area of interest for many researchers and they are important in this study. These areas are discussed below.

## Degree in the Subject Area

Teacher content knowledge is likely impacted by content coursework and earning a degree in the subject area one teaches. This expectation is apparent in teacher certification policy and teacher preparation programs. To be considered a "highly qualified" teacher in the U.S. one must hold a degree (or equivalent coursework) in the subject area being taught (U.S. Department of Education, 2002). Additionally, teacher preparation programs assume that prospective teachers build the content knowledge they need in content coursework (Ball, 1990; Feiman-Nemser & Parker, 1990; Grossman et al., 1989).

Assuming that teachers develop the content knowledge for teaching from earning a degree in the subject area is problematic for two reasons. First, topics included in content coursework do not align with topics included in the K-12 curriculum (NRC, 2007). The topics that are most important for a college physics course, for example, differ sharply from the topics that are most important in a high school physics course (Deng, 2001).

Second, the nature of the knowledge being taught in content courses is different from the content knowledge needed for teaching. Scholars have long argued that teachers need to understand the content in unique ways, specialized for the distinctive work of teaching (Bullough, 2008; Deng, 2007; Dewey, 1976). Grossman, Wilson, and Shulman (1989) explained:

> While some of what teachers need to know about their subjects overlaps with the knowledge of scholars of the discipline, teachers also need to understand their subject matter in ways that promote learning. Teachers and scholars have different primary goals. Scholars create new knowledge in the discipline. Teachers help students acquire knowledge within a subject area. These differing goals require related but distinct understandings of the subject matter. (p. 24-25)

The differentiation between the content knowledge of teachers and scientists was substantiated by an empirical study demonstrating distinct differences in the cognitive structures of each group (Hauslein et al., 1992). Because of the differences in what teachers need to know and what scientists need to know, it is unlikely that content courses sufficiently prepare teachers with the content knowledge needed for teaching. This distinction leads to the conceptual framework used in this study as described below.

The connection between holding a degree in the subject area and the unique content knowledge needed for teaching is not well understood. Rather than question this link, many studies use a degree in the subject area as a proxy for teacher content knowledge (Abell, 2007). Most studies in this area explore the link between subject area attainment and student achievement (S. M. Wilson et al., 2001). For example, Monk (1994) found that the number of courses science teachers had taken in their field was positively related to student scores on a science test. In another study, however, students of teachers with science degrees performed no better than teachers without science degrees (Goldhaber & Brewer, 2000). Because of contradictory results, scholars have argued for the importance of direct measures of teacher content knowledge (e.g., NRC, 2007; S. M. Wilson et al., 2001). While studies have examined the connection between teacher degree and student learning, no study has examined how a degree in the subject area impacted the unique knowledge of teaching.

Although we do not understand how a degree in the subject area impacts teacher content knowledge, many are concerned that those who teach a subject without a degree will not have sufficient content knowledge (e.g., Ingersoll, 2008). Reports have found that a large portion of teachers in many countries teach subjects for which they do not hold a content degree (e.g., J. G. Hill & Dalton, 2013; Ingersoll, 2008; Ríordáin & Hannigan, 2011). In the U.S., 60% of chemistry teachers report holding a degree outside of chemistry (often biology) (Rushton et al., 2014). This phenomenon occurs more frequently among new teachers than experienced teachers (Ingersoll, 1999).

Concerns about teaching without a degree in the subject area are also related to issues of teacher identity. Identity, or "being recognized by self or others as a certain kind of teacher" (Luehmann, 2007, p. 827), has been recognized as an important factor in teacher development and decision making (Avraamidou, 2014). Research with new elementary teachers has shown that the content knowledge of teachers who identified themselves as science content experts developed over their first few years in the classroom, while the content knowledge of those who did not identify as science experts did not improve (Mulholland & Wallace, 2003; Smith, 2007).

One of the primary factors influencing the identity of secondary science teachers is their content coursework and degree area (Hobbs, 2013).

## Classroom Experience

The increasing number of new teachers is alarming for many who recognize the value of learning through experience in the classroom. Concerns related to new teachers have prompted an increase in research focusing on new teachers and the early years of teaching (Luft et al., 2014). This study defines a new teacher as an individual who is in the first three years of employment as a full-time teacher and does not include prospective teachers. It is important to understand the unique challenges and possibilities of this phase of a teacher's career (Luft, 2007).

Classroom experience is important because it encourages the development of teacher content knowledge. Many teacher educators believe that classroom experience allows prospective teachers to "test the knowledge they have acquired…in the crucible of the classroom" (Grossman, 1990, p. 15). This conjecture has some weight. In their handbook chapter on teacher content knowledge, Cochran and Jones (1998) reported that classroom experience improved prospective science teachers' content knowledge. Other reviews on the knowledge of science teachers have made similar assertions (Abell, 2007; van Driel et al., 2014; van Driel, Verloop, & de Vos, 1998). These conclusions have been used to argue for increased classroom experience during teacher preparation (Cochran & Jones, 1998).

Studies investigating the impact of classroom experience on teacher content knowledge have explored the development of content knowledge during teacher preparation (Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994), compared the content knowledge of expert teachers with novice teachers (Barba & Rubba, 1992, 1993; Hauslein et al., 1992), investigated the content knowledge of experienced teachers with varying levels of experience (Bartos, Lederman, & Lederman, 2014; Gess-Newsome & Lederman, 1995; Hoz, Tomer, & Tamir, 1990; Leite, Mendoza, & Borsese, 2007), and examined the content knowledge of science teachers longitudinally (Arzi & White, 2008). These studies support the assertion the teacher content knowledge develops with classroom experience.

The development of content knowledge with classroom experience is moderated by opportunities to reflect on past classroom experience. Gess-Newsome and Lederman (1995) found that while five experienced (7-26 years) biology teachers reported that their content knowledge developed as a result of classroom experience, the extent of that development was inhibited by limited opportunities to reflect on their practice. The three teachers with weaker content knowledge, though experienced, had taught many different courses during this time. These researchers stated, “the number of years teaching did not seem to directly affect the [teachers’ content knowledge] as much as the quality of this experience or the portion of their careers that they were willing or able to donate to thinking about biology teaching” (p. 313).

Curriculum materials have also been shown to impact the development of teacher content knowledge (Luft et al., 2014). For example, in a study that followed 22 secondary science teachers over 17 years, researchers documented significant changes in teachers’ content knowledge (Arzi & White, 2008). Teachers’ content knowledge became stronger for topics included in the curriculum and weaker for topics not included.

Although research has shown that teacher content knowledge improves with classroom experience, little is known about how this knowledge develops in new teachers. The studies cited above primarily emphasize prospective teachers and teachers with significant classroom experience. Studies emphasizing new teachers have shown that knowledge development in new teachers is uneven (Luft et al., 2014). Some forms of teacher knowledge are developed while others are neglected. For example, Friedrichsen et al., (2009) found that classroom experience led to the development of pedagogical knowledge, but not content knowledge or other forms of teacher knowledge. It is important to understand the content knowledge development of new teachers, as many will leave the classroom prior to gaining significant years of experience.

## Conceptual Framework

The conceptual framework used to guide this study is influenced by the work of Ball and colleagues (e.g., Ball, Thames, & Phelps, 2008) and is related to mathematical knowledge for teaching (MKT). A key assertion of MKT is that the work of teaching mathematics is inherently mathematical, rather than generically pedagogical. This means that mathematics teachers must have mathematical knowledge that is unique to teaching, and is separate and distinct from pedagogical knowledge. MKT is linked to a rich and productive body of research (Adler & Ball, 2009; Rowland & Ruthven, 2011).

MKT posits that the knowledge needed to teach mathematics is composed of two major categories, subject matter knowledge and pedagogical content knowledge (Ball et al., 2008). Though subject matter knowledge is "pedagogically useful mathematical understanding" (Ball & Bass, 2000, p. 89), it is purely knowledge of mathematics and does not include knowledge of pedagogy or students. Pedagogical content knowledge, on the other hand, combines subject matter knowledge with pedagogical knowledge. There are three domains of subject matter knowledge.

The first domain of subject matter knowledge, c*ommon content knowledge*, is mathematical knowledge not unique to teaching. This includes being able to solve and calculate solutions to problems (Ball, Hill, & Bass, 2005; Petrou & Goulding, 2011) and is often aligned with the knowledge students are required to learn in a mathematics class (Ball et al., 2008; Drake, Land, & Tyminski, 2014). It has been said that common content knowledge is the mathematical knowledge of “any well-educated adult” (H. C. Hill, Schilling, & Ball, 2004, p. 27).

The second domain, s*pecialized content knowledge*, is the mathematical knowledge needed for the unique work of teaching (Ball et al., 2008; Mitchell, Charalambous, & Hill, 2014). This knowledge is not useful outside of the work of teaching (Ball et al., 2008; P. H. Wilson, Sztajn, Edgington, & Confrey, 2014). Because the work of teaching requires understanding why a mathematical procedure works, knowing multiple ways of approaching the same problem, or analyzing nonstandard approaches—this knowledge is called “unpacked mathematical knowledge” (Ball et al., 2008; Mitchell et al., 2014). Teachers use this knowledge when analyzing student work to see, for example, if a nonstandard approach can be generalized to other situations (H. C. Hill et al., 2005). This is mathematical knowledge that teachers use in teaching students, but do not intend for students to learn (Drake et al., 2014).

The final domain of content knowledge in MKT, *horizon content knowledge*, is the least discussed knowledge domain in Ball et al.’s (2008) seminal paper. Horizon content knowledge is the knowledge of what lies ahead and behind in the mathematics curriculum (Mosvold, Jakobsen, & Jankvist, 2013). Based on this knowledge of the discipline as a whole, teachers make decisions about what concepts to highlight or omit.

### Science Knowledge for Teaching

Researchers have begun to apply these ideas to science education (Luft, 2012; Luft, Weeks, Hill, Raven, & Nixon, 2013). This conceptual framework, called science knowledge for teaching (SKT), builds off of MKT, focusing on domains of content knowledge in the discipline of science education. As with MKT, there are three domains of content knowledge in the SKT conceptual framework.

The first domain, *core content knowledge (CCK)*, is knowledge of the fundamental understandings of science that a teacher is responsible for teaching or that a well-educated adult (not necessarily a teacher) should know about science. Science knowledge is organized around central concepts that provide a foundation and structure for other concepts (American Association for the Advancement of Science, 1989; NRC, 2012). Rather than knowing all of the concepts in a scientific discipline, a science teacher must thoroughly understand the central concepts of the discipline. As with common content knowledge, core content knowledge aligns with the knowledge students are to learn. This is the domain of content knowledge most commonly studied in the literature (see van Driel et al., 2014).

*Specialized content knowledge (SCK)* is the scientific knowledge a science teacher uses to accomplish his or her work. This domain of knowledge highlights the science-specific thinking required for the tasks of teaching science. Included is knowledge used to size up a student's error, consider the correctness of a student's statement that did not use appropriate vocabulary, or determine the complexities of a specific example to be used in class.

The last domain, *linked content knowledge (LCK),* represents an understanding of the connections among science concepts. As a domain of pedagogically useful content knowledge, LCK is an understanding of the concepts that are prerequisite to learning other topics. This does not imply a specific, correct order of topics; rather, it involves an understanding of the multiple connections linking many concepts. As an example, understanding the particulate nature of matter is prerequisite to comprehending gas laws. Connections between concepts may be within or across science disciplines (NRC, 2012).

While teaching requires also other forms of knowledge, the SKT conceptual framework focuses solely on content knowledge. As the foundation of teacher knowledge, teacher content knowledge is deserving of further scrutiny and explication. This adaptation meets the call from several researchers to apply MKT to science education (Loughran, 2014; Settlage, 2013; van Driel et al., 2014).

## Methods

An exploratory, qualitative design was used to investigate the impact of content degree and classroom experience on the content knowledge of new science teachers using the SKT framework. Such a design is well suited to this purpose, as the construct under scrutiny is not yet well understood by researchers.

### Participants

Participants for this study were a cross-sectional sample of new teachers who had been teaching chemistry as their primary subject during their brief careers. Two of these teachers were in their first year of teaching, two were in their second year, and two were in their third year of teaching. One teacher in each year had earned a degree in chemistry (or equivalent coursework) and one teacher in each year had earned a biology degree. Pseudonyms are used throughout. Abbreviations will accompany each name designating years of experience (e.g., Y1 for first year) and degree area (i.e., B for biology and C for chemistry). All teachers taught in the same southeastern state in the U.S. A brief description of each participant’s background and context is provided below.

**Aaron** was a first year teacher who was hired in January (mid-way through the year) approximately one month prior to our data collection. He had a bachelor’s degree in biology and had worked in banking for seven years. He taught both chemistry and biology courses in a large suburban high school with a large percentage of ethnic minority students. This school had a high pass rate on district and state exams and a high graduation rate.

**Addie**, like Aaron, was hired one month prior to data collection, having begun midway through the school year. She had just completed her bachelor's degree in chemistry and was beginning to work towards her masters of arts in teaching. She was assigned to teach chemistry at a large suburban high school with a majority of African American students and students on free/reduced lunch. This school had a moderate pass rate on district and state exams, and a moderate graduation rate.

**Marisa** was in her second year of teaching, having worked briefly as a microbiologist prior to teaching. She held a bachelor's degree in biology. Marisa taught chemistry (as well as an online biology course) at a suburban alternative school with less than 300 students. Students attended this school for a brief period of time when they are expelled from other schools in the district.

**Aubrey** was also in her second year of teaching. She held a bachelor's degree in agricultural engineering in her native Bulgaria, which included coursework equivalent to a chemistry major, and a masters of arts in teaching. She taught chemistry at a STEM charter school at which 100% of students passed state and district tests and graduated from high school.

**Heidi** was in her third year of teaching and held a bachelor's degree in biology and was working towards a masters of arts in teaching. She taught chemistry and one course of astronomy at a large suburban high school. Eighty percent of the students were ethnic minorities and over one third were on free/reduced lunch. The school had not met federal regulations for student test scores and only 57% of students graduate.

**Madison** was in her third year of teaching as well. She held a masters in chemistry as well as a masters of arts in teaching. Madison taught Honors and Advanced Placement (AP) Chemistry, as well as AP Physics at the same large high school as Aaron.

## Data Sources

Data for this study came from a semi-structured interview probing teachers' SKT. Interviews were conducted by multiple researchers, which contributed to the triangulation of the data (Miles, Huberman, & Saldaña, 2014; Seidman, 1998). The interviews were semi-structured allowing for adjustments to be made to participant responses while maintaining a level of consistency across interviews (Bogdan & Biklen, 2006; Kirk & Miller, 1986). In this way the validity of data was bolstered throughout the data collection process (Silverman, 1993).

During the interview, teachers were asked a set of questions related to the conservation of mass and chemical equilibrium. These are both important topics in chemistry (Ganaras, Dumon, & Larcher, 2008; Özmen & Ayas, 2003) and play an important role in the curriculum of many countries (NRC, 2012; Sahin Pekmez, 2010). Many studies show that students and teachers struggle with these important topics (e.g., Ganaras et al., 2008; Kaya, 2013; Özmen & Ayas, 2003; Quilez, 2004).

The questions in each set were designed to align with the domains of the SKT conceptual framework (see Supplemental Material). Each set began by asking teachers to describe either the conservation of mass or chemical equilibrium. This question was intentionally separate from the context of teaching in order to provide insights into the teachers' CCK. Teachers were then presented with a classroom scenario in which students expressed an error in scientific understanding. The conservation of mass scenario involved a classroom demonstration in which the teacher burned a piece of paper on a scale. When the reading on the scale went down, students explained that it did so because the paper turned into flame. In the chemical equilibrium scenario students expressed the idea that no changes occur when a system is at chemical equilibrium. Related to this scenario, participants were asked to explain the source of the student's error, designed to elicit their SCK. Teachers were also asked to identify concepts that could precede and follow the concept in the scenario (LCK).

The interviews lasted approximately 20 minutes. Each interview was digitally recorded and transcribed. Participants received a small stipend for participation.

## Data Analysis

Transcribed interviews were imported into NVivo 9 (QSR International, 2010)—a qualitative analysis program. Two researchers read through the transcripts together multiple times. As they read through the transcripts, salient features were given a code representing the text (Saldaña, 2013). Using these codes, a profile for each participant was constructed. Each profile included one paragraph on contextual information for each participant and three to four paragraphs describing salient aspects of the participant's content knowledge. For example, Madison's (Y3C) content knowledge was characterized by concise accuracy, inclusion of advanced chemistry concepts, and an understanding of aspects of the content that students find challenging.

Researchers independently inspected these profiles to generate a list of salient codes that were found in all participants' transcripts. Lists of salient codes were compared and condensed into four major salient codes that represented key aspects of the participants' content knowledge: overall response effectiveness (correctness), chemistry focus (depth of chemistry-specific knowledge demonstrated), connections and structure (coherence of responses), and student understanding (how students in the scenario perceived the content).

Using the salient codes, researchers jointly produced a construct table (Miles et al., 2014). In this table, transcript excerpts from each participant were placed in rows for each salient code. In order to determine the validity of the construct table products, researchers completed another review of the transcripts. During this review, the researchers looked for disconfirming evidence and additional salient codes, which would call into question the groups of responses. A subsequent review of the transcripts did not produce additional codes, nor was disconfirming evidence found. The final construct table provided insights into the impact of degree area and years of experience among the teachers in this study.

Validity was strengthened through the use of multiple researchers working both separately and together to engage multiple viewpoints (Miles et al., 2014). Importantly, one researcher was familiar with the data and participants prior to analysis, while the other was new to the data. This difference in familiarity allowed for one researcher to provide contextual background and the other to provide new insights into the data.

## Ladder of Explanations

Oversby's (2002) *ladder of explanations* was adapted to characterize some differences observed in teachers' responses. This ladder is a framework for distinguishing between levels of conceptual understanding in chemistry (see Table 3.1). It has been used to examine elementary students' and prospective teachers' conceptual understanding of dissolving (Oversby, 2000; Subramaniam & Harrell, 2013) and is built on work by Gilbert, Boulter, & Rutherford (1998). There are five levels along this ladder of explanation. At the *definitional* level explanations identify the phenomenon. Such explanations define the phenomenon, but do not provide details about what is occurring. *Descriptive* level explanations move beyond merely identifying and provide observations regarding the phenomenon. Both definitional and descriptive explanations center on tangible and visible objects and phenomena, known as the macro level (Johnstone, 1991). Moving into the *interpretative* level, an explanation must utilize theoretical entities to describe the phenomenon. For example, rather than stating that the mass before and after a chemical reaction must be equal, an interpretative explanation refers to the number of atoms before the reaction equaling the number of atoms after. *Causal* explanations identify the mechanism for the phenomenon, which often requires reference to atoms and molecules. Thus, interpretative and causal explanations refer to substances and phenomena happening at very small scales (e.g., molecules, ions), known as the submicro level (Johnstone, 1991). The final level of explanation, *predictive*, provides a generalizable principle that allows one to predict future phenomena or to predict the same phenomenon in other circumstances.

## Limitations

A few limitations of this study should be acknowledged. For one, this study is exploratory using a small sample of teachers and a limited number of topics. It is possible that the span of experience included in this study is not sufficient to account for changes in teacher knowledge. Nevertheless, this study is a response to calls to focus on new teachers, who make up a large portion of our current teaching force (Ingersoll et al., 2014). Furthermore, we recognize that there may be other factors that contribute to these teachers' knowledge and may account for differences between them (e.g., background, teaching context). While this sampling of participants and content is appropriate for the task of theory building (Flyvbjerg, 2006), findings cannot be expected to generalize to the entire population or the entire curriculum. Furthermore, findings herein rely on the assumption that each participant's knowledge is represented by what was said and how it was said. Though there may be other factors that influenced the teachers' responses, efforts such as ensuring confidentiality and establishing rapport were taken to diminish the effect of these factors. Additionally, the questions required teachers to explain science concepts, a critical task in the work of teaching. Thus, while the findings from this exploratory qualitative study have limitations, these findings provide insights into the nature and development of new science teachers' content knowledge for teaching.

## Findings

The analysis described above led to four findings related to the content knowledge of these new chemistry teachers.

### Finding 1: Level of Explanation Varied with Degree Area and Experience

Explanations provided by Aubrey (Y2C), Heidi (Y3B), and Madison (Y3C) were at a higher level than those provided by Aaron (Y1B), Addie (Y1C) and Marisa (Y2B). Explanations by Aubrey, Heidi, and Madison were (generally) at the interpretative level or higher. Explanations by Aaron, Addie and Marisa were at the interpretative level or lower. Related to the degree and experience of these groups, those teachers who supplied higher-level explanations were either in their third year (Heidi and Madison) or second year with a chemistry degree (Aubrey). Teachers who provided lower-level explanations were either in their first year (Aaron and Addie) or second year with a biology degree (Marisa).

Definitional explanations include Addie's (Y1C) response about chemical equilibrium, which focused on the idea that equilibrium is a "balance" between products and reactants: "It goes to equilibrium by kind of balancing out between the two—the reactants and the products" (243-244). She did not identify any macro (e.g., change of color) or micro properties (e.g., atoms) of equilibrium. Rather, she simply identified the concept of equilibrium as balance.

This sample of teachers also provided explanations at the descriptive level. For instance, Aaron (Y1B) stated, "You start off with 10 grams of A and 10 grams of B, reactant A, reactant

B, you’re going to end up with 20 grams of product. It might be in a different form, but it’s going to be 20 grams of whatever you have” (4-6). Aaron (Y1B) and Marisa’s (Y2B) responses were at this level, focusing on the idea that mass does not change during a chemical reaction.

Teachers in both groups provided interpretative explanations. Addie’s (Y1C) explanation of the conservation of mass relied on the idea that “the molar quantities [in a reaction] have to stay the same” (188-189). Heidi’s explanation of chemical equilibrium referred to the theoretical entities of chemical bonds, “bonds will be broken and come back together” (Heidi Y3B, 521). Though both of these teachers identified the role of theoretical entities (molar quantities, chemical bonds) in the phenomenon, they did not refer to the mechanism that causes equilibrium (i.e., rates of the forward and reverse reaction being equal). These explanations were at the interpretative level.

Teachers with chemistry degrees who had completed their first year of teaching, however, provided predictive level explanations. Both Aubrey (Y2C) and Madison (Y3C) connected the microscopic mechanism with the macroscopic phenomenon while considering student errors. Madison (Y3C) explained that, at equilibrium, the forward and reverse reactions are “just happening at the same rate so you can’t tell from the outside that anything’s going on" (642-643). Similarly, Aubrey (Y2C) explained, “the actual concentration of [the products and reactants] does not change because both reactions are happening with the same rate” (408-411).

### Finding 2: Coherence of Response Varied with Degree Area and Experience

Aubrey (Y2C) and Madison’s (Y3C) responses were distinctly more coherent and structured than the responses of the other teachers. These two teachers are distinguished from the others by holding both a degree in chemistry and having completed their first year of teaching. A representative segment is found when Aubrey (Y2C) described the combustion reaction and how she would help students understand that mass had been conserved:

> We will start with writing a chemical reaction, what the paper is made of. And then what is happening while the paper is burning…And then we will talk about the flame…That is energy that is being released [as] visible light…And then we will talk about the physical state of the…products. For example…water, we say, okay, but water is liquid, why we don't see it? Then we'll talk about the high temperature from the released heat and water vaporizes. (359-372)

In this response, the ideas are well ordered and coherent. It is easy to follow her progression from identifying reactants then products, and then identifying the challenge with observing the product of water. This type of structure is apparent throughout both participants' responses.

Another evidence of their well-structured knowledge is that both Aubrey and Madison answered directly, correctly, and concisely. For example, Madison (Y3C) explained the conservation of mass: "The total mass of the reactants must equal the total mass of the products. The total mass before the reaction must equal the total mass after the reaction" (569-570).

Such a direct and concise answer is a stark contrast to responses from the other teachers. One example is seen when Aaron (Y1B) explained why students made the error in the scenario.

> They're not understanding that heat is actually something that we measure. We don't measure like the flame, a flame doesn't weigh, we're not measuring a flame. They're not considering all the different chemical states of a substance. It can be gas, it can be physical, it can be liquid—they're not thinking about all the states of matter. That's what it seems like. You can always weigh matter. (33-37)

Here Aaron moves between ideas of heat, flame, states of matter, and weight, suggesting that these concepts are not well structured within his knowledge base. While the responses of Aubrey and Madison are easy to follow, it is challenging to follow the logic through much of the other teachers' responses.

### Finding 3: Disciplinary Focus Varied with Degree Area and Experience

In responding to the prompts related to conservation of mass and chemical equilibrium, Aubrey (Y2C) and Madison (Y3C) drew on detailed chemistry knowledge. For example, when discussing chemical equilibrium Madison (Y3C) identified the key concept of reaction rates. Additionally, she cited the advanced concept of energetic favorability: "When [does the reaction] reach [equilibrium]? When it is no longer energetically favorable to continue going in one direction or another" (625-626). While considering a potential teaching strategy for chemical equilibrium, her discussion of radiolabeling products and reactants demonstrated a complex understanding of advanced chemistry concepts. Aubrey's (Y2C) detailed chemistry knowledge is evident in her discussion of acetic acid dissociating in water to explain chemical equilibrium. She explained, "When dissolved in water [acetic acid starts] to ionize and acetate ion is formed. And a hydrogen ion is formed, which we know it is not exactly hydrogen ion, it is attached to a water molecule" (485-487). She went on to describe the process of the forward and reverse reaction rates reaching equilibrium. Throughout their responses, neither drew on concepts outside of the discipline of chemistry.

On the other hand, Aaron (Y1B), Addie (Y1C), Marisa (Y2B), and Heidi (Y3B) did not identify key or advanced chemistry concepts, but rather supported many of their responses with concepts from outside of chemistry. A difference was observed between the knowledge Marisa (Y2B) and Heidi (Y3B) drew on and the knowledge Aaron (Y1B) and Addie (Y1C) drew on.

Marisa and Heidi referred to concepts from biology. For instance, when Heidi (Y3B) discussed chemical equilibrium she primarily drew on the concept of the dynamic balance of population size and genetic equilibrium. She stated that she thought of equilibrium as similar to a situation "where the population isn't growing and it isn't shrinking because of predators or natural selection, it's just at a fixed rate because of births and deaths are equal" (549-555). This is a good approximation of chemical equilibrium, and while just an approximation, it seems to be a productive way to buttress her chemistry knowledge.

Aaron (Y1B) and Addie (Y1C), on the other hand, drew on concepts outside of both chemistry and biology. To illustrate, Aaron (Y1B) identified the concept of the water cycle as a real world example that can be used to help students understand chemical equilibrium. He stated, "So, water's liquid, say we're boiling it off, it's actually vaporizing right? …So if it condenses, like up in the clouds…then it's going to come back down as liquid again" (1-4). Though it seems clear that Aaron was referring to the reversibility of change demonstrated by the water cycle that is inherent in chemical equilibrium, this seems like a distant connection. Likewise, Addie (Y1C) indicated that the cause of students' error about chemical equilibrium is the use of the word in other disciplines. Equilibrium, she said, is the "type of word [that] also shows up in literature or history. They say that things were in a state of equilibrium, so from our content it just means something a little different" (291-294). These concepts do not appear to productively support Aaron and Addie's conceptions of chemistry concepts.

### Finding 4: Teachers Did Not Use Content Knowledge to Determine Sequence

When teachers were asked which topics went before and which topics went after conservation of mass or chemical equilibrium, all teachers spoke about the sequence of their curriculum. Some of the teachers simply talked about the order in which they taught. "It's something we teach toward the beginning of the semester," said Heidi (Y3B, 482). Other teachers, like Aaron, referred directly to the state curriculum. He said, "I honestly don't know the next stage of how I would use this is, I'd just look at what the [state curriculum] says after this," (141-143). The remaining teachers simply provided lists of related topics that came before or after, like Aubrey (Y2C) who supplied chemical reactions, ions, and bonding as topics that come before without any justification or logic.

In all, it is apparent that these teachers did not think deeply about the sequencing of the topics based on the logical connections between concepts. Rather, they seemed to base their sequencing solely on precedence or mandate. Heidi (Y3B) provided a key example of this. She asked if the interviewer wanted her to explain what she actually taught next or what she thought should be taught next. The interview clarified that she meant the latter. Heidi responded, "I don't know why I asked you because I don't really have much of an opinion. After it we teach heat and energy. And then gas law" (561-562). In sum, none of these teachers engaged with the content to determine sequence and, instead, relied on the curriculum.

### Summary

In summary, the first three of these findings showed variation based on both degree area and classroom experience. The content knowledge demonstrated by these teachers was most similar for those with two or three years of experience and a chemistry degree, and for those teachers with one or two years of experience and a biology degree. The last finding was consistent across the sample, with no apparent differences by either degree or experience.

## Discussion

In this exploratory qualitative study, we sought to understand the impact of holding a degree in the subject area and classroom experience on the content knowledge of new chemistry teachers. This analysis provides evidence that having both a degree in the subject area and classroom experience positively impact the development of new teacher content knowledge. Specifically, the content knowledge of teachers who held a degree in the subject area and were no longer in their first year of teaching was more developed in terms of level of explanations provided, coherence, and disciplinary focus than teachers who did not hold a degree in the subject area or were in their first year.

Holding a degree in the subject area and classroom experience impact the development of new teacher content knowledge through teacher identity. A teacher's degree area is the primary factor influencing whether or not the teacher identifies him or herself as an expert in the subject taught (Hobbs, 2013). Those teachers with chemistry degrees were more likely to identify themselves as chemistry experts. To maintain this identity, to both themselves and their students, the teachers with chemistry degrees may have been more likely to pursue the development of their content knowledge over time. For example, as they encountered topics in their planning with which they were unfamiliar they may have taken efforts to learn more about these topics prior to teaching in order to present themselves as chemistry experts. Also, when teachers were asked questions that they did not know the answer to, those with a chemistry degree may have been more inclined to find the answer after class than those who held a biology degree. In this way, teachers holding a degree in the subject area may have learned more from classroom experience because they identified themselves as a chemistry expert.

The factors of degree area and classroom experience may also impact the development of teacher content knowledge by influencing a teacher's opportunities for reflection. Past research has shown that teachers who had to spend time preparing for multiple courses consequently had limited time to reflect on their experiences and, as a result, their content knowledge did not develop as much as those who could reflect more (Gess-Newsome & Lederman, 1995). Teachers who held biology degrees likely had to spend more time, especially in the early years, reviewing and learning the content they were to teach in the coming days. This may have limited the time available to reflect on their experience, how students responded to instruction, and the accuracy of their representations. Because that time was spent on learning the content they were to teach themselves, the impact of classroom experience on their content knowledge development may have been lessened.

Both factors explored here seem to contribute most strongly to the development of core content knowledge. This domain of knowledge is evident in the findings related to the level of explanation, coherence, and disciplinary focus, as each is a characteristic of the knowledge that students are to learn. For example, students should be able to provide high-level explanations of scientific phenomena after instruction. This characteristic is not unique to the content knowledge of teachers. Through earning a degree in the subject area, teachers attend courses in which the instructor seeks to develop an understanding of the main concepts of the discipline. While in these courses, they come to understand the concepts as a student does rather than as a teacher. CCK is also developed through classroom experience. Previous studies have found that over years of experience, teachers' knowledge becomes most developed for topics they teach (e.g., Arzi & White, 2008). As CCK is the knowledge that teachers are responsible for teaching and that they were responsible for learning as students, it is not surprising that both a degree in the subject area and classroom experience contribute to the development of this domain of knowledge.

These findings additionally suggest that neither a degree in the subject area nor classroom experience contribute to the development of linked content knowledge. As an understanding of how topics are connected, LCK should inform decisions about sequencing. It has been hypothesized that this form of content knowledge is used when determining a coherent conceptual sequence (e.g., Hanuscin & Lee, 2015). Instead of using LCK, teachers in this study drew on their knowledge of the curriculum to determine the sequence of topics. This suggests that LCK may not be learned as a result of earning a degree in the subject area or classroom experience. Instructors in content coursework are not likely to be explicit about their reasons for sequencing the topics. While the enacted sequence is apparent, the reasoning behind it is not. As teachers enter the classroom, they may be encouraged to follow the sequencing mandated by administration or predetermined by the department. Rather than considering the connections between topics, new teachers may simply follow others.

The final domain of the SKT conceptual framework, specialized content knowledge, is not apparent in these findings. This may be because teachers in this sample were too new to have developed this domain of knowledge. As this domain of knowledge is most closely tied to the work of teaching, teachers may require more years of classroom experience to develop it. It is also possible that this analysis was not targeted enough to identify evidence of SCK. Perhaps there was not sufficient evidence of this domain from each participant to arise as a salient feature of all participants' content knowledge. A more targeted analysis is likely needed to further examine the nature and development of this important domain of knowledge.

This exploratory study is one of the first to use an adaptation of MKT for science education as recommended by several researchers (Settlage, 2013; van Driel et al., 2014). While this study provides initial information about the development of this knowledge, research regarding the characterization of this knowledge is needed. Further investigating how this knowledge is developed is especially important for understanding how to support the needs of new science teachers. As we come to better understand this conceptualization of teacher content knowledge, it is important to understand how this knowledge impacts teacher practice and student learning. Additional research regarding the connection between a degree in the subject area and the unique content knowledge for teaching is important. We need to understand if this knowledge can be developed in content coursework, if a methods course is sufficient, or if the unique features of teacher content knowledge need to be embedded throughout content coursework. Also, we need to better understand how classroom experience impacts the development of new teachers and how to maximize the learning potential of their often limited years of classroom experience.

## Acknowledgements

The authors would like to acknowledge the teachers in this study for their enthusiastic participation, as well as Ann Brennan, Shannon L. Dubois, Peter W. Hewson, Melissa A. Jurkiewicz, and Rene Toerien for their assistance throughout the project. This study was made possible by National Science Foundation grants 1247096 and 0918697, the National Association for Research in Science Teaching (NARST), and The University of Georgia Presidential Fellowship. The findings, conclusions, and opinions herein represent the views of the authors and do not necessarily represent the views of personnel affiliated with the National Science Foundation, NARST, or The University of Georgia Graduate Program.

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Table 3.1

*Ladder of Explanations for Chemistry*

| Level of Explanation | Description | Example for Conservation of Mass | Example for Chemical Equilibrium |
|---|---|---|---|
| Definitional | Identification of phenomenon | Matter cannot be created or destroyed | Equilibrium is a balance |
| Descriptive | Describe phenomenon | Mass before a reaction is equal to the mass after a reaction | There is no observable change when a system is at equilibrium |
| Interpretative | Refer to theoretical entities | Number of atoms before a reaction are equal to the number of atoms after | At equilibrium, bonds are being broken and formed |
| Causal | Identify mechanism | Atoms are rearranged in a reaction and do not cease to exist | The rate of the forward and reverse reactions are equal at equilibrium |
| Predictive | Generalize to predict other phenomena or the phenomenon in other circumstances | As atoms are rearranged in a reaction, they can create substances that are not easily detectable | Because the forward and reverse reactions are occurring at the same rate at equilibrium, no change is observed |

# Appendix

## Detail on Interview Prompts and Ideal Responses

In order to provide context for the study and additional insights into our thinking regarding SKT, the scenario from each question set, along with key components of what we consider to be essential components of a response, are provided below. These essential components were formulated after reading teacher responses extensively, but prior to completing the analysis.

### Conservation of Mass Question Set

In the conservation of mass question set, participants were asked to first describe how the law of conservation of mass is related to chemical reactions. Next, they were provided with the following scenario:

> It is midway through the school year and one of your labs involves burning a piece of paper on a scale. As the paper burns, the reading on the scale goes down. You ask the students why this happens. Most of the students respond that the paper is converted into a flame.

They were then asked the questions described previously in relation to this scenario.

There are two essential concepts related to a teacher's CCK in this area. The first essential concept is that matter cannot be created or destroyed. As all matter is composed of atoms, atoms must always come from somewhere and go somewhere. In a chemical reaction, the atoms present in the reactants are always present in the products. The second essential concept for this question set is the distinction between mass and weight. While mass is a fundamental property of matter, weight is a force. Because it is a force, weight does not directly vary solely based on the amount of matter present. While the weight of the reactants and products may change, the mass of the reactants and products are the same.

An analysis of the student error (related to SCK) should consider the following. Students in the scenario thought the matter in the paper turned into flame, causing the reading on the scale to go down. This is not the case. The matter in the paper underwent combustion, combining the carbohydrates in the paper with atmospheric oxygen to form carbon dioxide gas and water vapor. Due to incomplete combustion, some ash was left on the scale and some smoke rose into the air. The total mass of the products is equivalent to the mass of the reactants, but the weight of the products is less than the weight of the reactants. These products, both hot, invisible gases, rose off the scale and mixed into the solution of gases present in the room. As such, the scale no longer measured the weight of these products, though their mass was still present. Though one could attribute student error to a variety of sources, a probable cause is that because students cannot see the products, they do not understand that the scale is no longer weighing the products. Though the products are not being weighed, the mass is still present.

In order to understand the conservation of mass (related to LCK) it is essential to understand that matter is composed of atoms. These atoms are combined together and, at times, rearrange their configurations. A detailed knowledge of atomic structure or chemical bonding is not necessary to understand that the total number of atoms is conserved in a reaction. In fact, it is necessary to understand the conservation of mass to understand chemical reactions. This helps provide the reason for balancing equations and provides guidance for predicting the products of chemical reactions. As one of the core concepts inherent in atomic theory, the conservation of mass is foundational for many other concepts in chemistry.

**Chemical equilibrium question set.** The chemical equilibrium question set began by asking participants to describe the process in which a reaction reaches equilibrium. A classroom scenario followed this question:

> You are midway through a unit on chemical reactions and have just finished grading an interim assessment. One of the true or false questions on the assessment asked the following: "When a reversible reaction is in equilibrium, there are no changes occurring." The majority of students answered true.

Additional questions, as described previously, followed.

There is one fundamental feature that we would expect to be present in the teachers' CCK. This is the idea of the dynamic nature of chemical equilibrium. Though the concentrations of the substances stay constant, chemical changes are still occurring. This is possible because the rate of the forward reaction is equal to the rate of the reverse reaction. Thus, while no measurable change is occurring, changes are occurring at the atomic level.

As with the former situation, there are many reasons a student could be in error about this scenario. The content knowledge used to make this determination is SCK. The main possible source of student errors in the scenario is the dynamic nature of a system at chemical equilibrium. To diagnose the student error, participants must recognize that students confounded the concepts of net change with local change. Students likely thought that nothing was happening within the reaction system because the concentrations were constant.

To understand chemical equilibrium (related to LCK), an advanced concept, students need to have a solid foundation in chemical reactions. Balancing chemical equations and understanding concentration are important skills to have before studying equilibrium. Students must also be able to conceptualize the formation and rearrangement of bonds and the reversibility of bonding. To solve equilibrium problems (using equilibrium constants), students need strong mathematical ability. An understanding of equilibrium informs the study of more advanced chemistry topics such as acid-base behavior and electrochemistry. Furthermore, topics in advanced thermochemistry surrounding spontaneity (enthalpy, entropy, free energy) make use of an understanding of equilibrium and the manipulation of equilibrium points for a given reaction.

# CHAPTER 4

# CONCLUSION

This dissertation explored the nature and development of content knowledge among new science teachers. The two different studies comprising this dissertation come from the same larger project and approach the broader question: “What are the characteristics of science knowledge for teaching and how does this knowledge develop in new teachers?” The chapter closes the dissertation by summarizing the major contributions of these studies and directions for future research.

## Major Contributions

The first major contribution made by this dissertation is evidence that the science knowledge for teaching (SKT) model is a viable way of thinking about and researching the content knowledge of science teachers. The initial work in this field pertained to understanding the viability of the model when working with teachers in a content area (Luft, Hill, Weeks, Raven, & Nixon, 2013) The first study extends this work by providing insights into the characteristics of the SKT domains within a specific content area. The other study suggests that holding a degree in the subject area and classroom experience impact the development of SKT in new teachers. These results push beyond current formulations of content knowledge and highlight the need to consider the unique ways teachers may understand content (see Loughran, 2014).

The second major contribution of this dissertation is the presentation and characterization of the SKT model. This model is the first published adaptation of the mathematical knowledge for teaching model for science education (see van Driel, Berry, & Meirink, 2014). This dissertation has helped to elucidate the characteristics and development of this model of content knowledge in two ways.

First, these studies have helped to clarify the definitions of the SKT domains. These studies suggest that *core content knowledge* encompasses knowledge of the fundamental science concepts, theories, laws, facts, and processes of science and primarily includes the scientific knowledge that students are expected to learn. *Specialized content knowledge* is scientific knowledge that is used in the work of teaching, such as considering why a student made an error, similar reactions that could be used to clarify a concept, and determining whether a student is correct or incorrect. *Linked content knowledge* is an understanding of the connections between science concepts. Through the analysis of the data, the definitions of these domains have been clarified and specific examples from teachers have been identified. It has been proposed that these domains work across multiple topics and science disciplines.

Second, these studies contribute to our understanding of the development of SKT. The second study indicates that holding a degree in the subject area and classroom experience contribute to the development of SKT. This study ultimately revealed that new teachers teaching a subject area without a degree in that area may need additional support in the form of identity work and opportunities for reflection in order to develop their SKT.

The final contribution of this dissertation pertains to the international discussion of content knowledge among science teachers. Most studies in the area of teacher content knowledge are restricted to one country. This study explores content knowledge in different countries in order to determine the cross-national potential of the SKT framework. In noting the potential of this framework in both South Africa and the US, there is an opportunity for more cross-national work to explore this construct in other countries.

## Future Research

This dissertation contributes to the discussion of the content knowledge of science teachers by using the SKT model. Further efforts are needed to continue the work begun by these two studies, namely understanding the nature and development of SKT. As the SKT model proposes two new domains of content knowledge for science teachers, these two domains (SCK, LCK) and their connection to one another need further exploration. To accomplish this, there will be more targeted efforts to elicit SCK and LCK. Investigating the content knowledge used in a larger variety of tasks of teaching and more directed interviews might assist in this effort. Also, investigations could broaden to include experienced teachers as well as the knowledge used for other science disciplines and topics. Future research could similarly seek to more fully develop the SKT model by examining the relationships between the SKT domains and other forms of teacher knowledge.

As work with the SKT model progresses, it will be important to understand how this knowledge develops. While we know that a degree and experience promote the development of SKT, it is unclear what experiences in earning a degree and classroom teaching encourage SKT development. Such research could have implications for teacher preparation, induction supports, and policy.

## Conclusion

This chapter expands the fields' conceptualization of teacher content knowledge, offering a model that seeks to understand what, and in what ways, teachers need to know the science that they teach. These studies build off of productive work in other fields and utilize a cross-national collaboration to develop a model that can contribute to the international conversation on teacher quality.

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