Beginning Chemistry Teachers Use of the Triplet Relationship

During their First Three Years in the Classroom

by

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ABSTRACT

Pedagogical content knowledge (PCK) has been described as the knowledge teachers’ use in the process of designing and implementing lessons to a particular group of students. This includes the most effective representations that make the content understandable to students, together with the preconceptions and misconceptions that students hold. For chemistry, students have been found to have difficulty with the discipline due to its reliance upon three levels of representation called the triplet: the macro, the submicro, and the symbolic. This study examines eight beginning chemistry teachers' depiction of the chemistry content through the triplet relationship and modifications as a result of considering students' understanding across the teacher's first three years in the classroom. The data collected included classroom observations, interviews, and artifacts for the purpose of triangulation. The analysis of the data revealed that beginning chemistry teachers utilized the abstract components, submicro and symbolic, primarily in the first year. However, the teachers began to engage more macro representations over time building a more developed instructional repertoire. Additionally, teachers' developed an awareness of and responded to their students' understanding of learning atomic structure during the second and third year teaching. The results of this study call for preservice and induction programs to help novice chemistry teachers build a beginning repertoire that focuses on the triplet relationship. In so doing, the teachers enter the classroom with a repertoire that allows them to address the needs of their students. Finally, the study suggests that the triplet relationship framework should be revisited to

include an additional component that frames learning to account for socioscientific issues and historical contributions.

DEDICATION

To my Lord and Savior, you're the reason I am able to withstand anything.

Mom & Dad, thank you for teaching me it is okay to be myself, to pursue any dream, and to never give up.

Shawnda & Carlos, thank you for taking care of the loose ends.

Nadia, Mikhail, Selenia, & Daniela, thank you for loving me though I was not always around.

Ms. Edith, thank you for all the care packages.

Granny, Papaw, & Mamaw, you are always on my mind.

Stilly, thank you for making me laugh even now.

Ms. D, thank you for always being there.

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I would also like to thank all of the students and professors who worked on this project over the past 6 years. Without their long hours I would never have been able to complete this dissertation. In particular, I would like to thank Charles Weeks and Ira Ortega for helping me see future endeavors from the simple act of coding the data. For Jonah Firestone, thanks for being the wise sage and sounding board throughout the ages. Finally, I would like to thank the NSF for their funding of the grants that supported this study.

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INTRODUCTION

Both the United States government and the American business sector are concerned that the U.S. may be losing its competitive edge to "compete, prosper, and be secure in the global community of the 21st century" (National Academy Committee on Science, Engineering, and Public Policy, 2006, p. 3). In fact, almost one-third of all students in the U.S. graduating with doctoral degrees in chemistry are international students (Long & Kirchhoff, 2008). These students are more likely to leave the U.S. after graduation for increasingly lucrative positions in their home countries .

In order to stimulate domestic K-12 student interest in pursuing careers in the field of chemistry, the American Chemical Society[1] (ACS) has suggested improvements across all levels of education in order to develop students' understanding of chemistry and the role chemistry plays in the global community (American Chemical Society, 2011). One such improvement suggested by the ACS involves the strengthening of pedagogy and appropriate chemistry content in teacher preservice programs. Chemistry teacher educators need to understand how newly certified chemistry teachers integrate teaching strategies and content knowledge in their classroom instruction after leaving their preservice programs.

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[1] The American Chemical Society is a non-profit scientific and educational organization, chartered by Congress, with more than 161,000 chemical scientists and engineers as members. The world's largest scientific society, ACS advances the chemical enterprise, increases public awareness of chemistry, and brings its expertise to state and national matters.

Beginning chemistry teachers need to be cognizant of the areas in the content that cause confusion in students' understanding of chemistry. Students have a difficult time learning the subject due to various issues: its abstract nature (Mayer, 2011; Nakhleh, 1992; Treagust & Chittleborough, 2001; Veal, 2004; Zoller, 1990), the reliance upon mathematical equations to explain phenomenon (Laws, 1996), and confusion caused by teachers moving quickly between macro, submicro, and symbolic representations (Bucat & Mocerino, 2009; Chandrasegaran & Treagust, 2009; Johnstone, 1991; Van Driel, de Jong, & Verloop, 2002). Macro representations are the observable properties of substances, submicro representations are models of atoms, electron density clouds, and molecules, and symbolic representations are the symbols to represent atoms and chemical equations. This triplet relationship (see Figure 1) – of macro, submicro, and symbolic representations – is a key model for chemistry education (Gilbert & Treagust, 2009a).

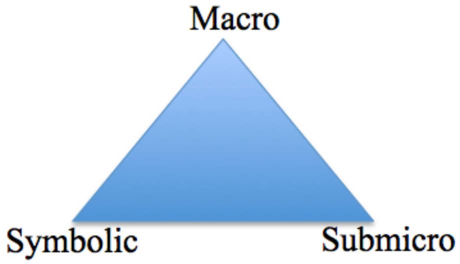

Figure 1. Three levels of representation in chemistry. *Note.* Modified from "The role of submicroscopic and symbolic representations in chemical explanations" by D. F. Treagust, G. Chittleborough, and T. L. Mamiala (2003), *International Journal of Science Education, 25,* p. 1354.

Effective science teachers do many things to promote student learning in the classroom - such as lead discussions, plan inquiry based experiments, and design units (Feiman-Nemser, 2001). For content specialists, especially those in chemistry, teaching strategies that support student understanding should involve both chemistry specific approaches and general pedagogical strategies specific to science (Magnusson, Krajcik, & Borko, 1999; Mulford & Robinson, 2002). This involves the teacher incorporating chemical strategies that may include the use of models of atoms and analogies that make abstract information more concrete and easier to imagine for students in inquiry-based classroom instruction (Bucat & Mocerino, 2009; Treagust & Chittleborough, 2001). The teacher must develop a repertoire of approaches to teaching and learning and the ability to judge when a particular approach is appropriate for a particular situation and when it is not (Clermont, Borko, & Krajcik, 1994; De Jong, Veal, & van Driel, 2002). Content specialists, such as chemistry teachers, must develop both a broad repertoire of discipline-specific approaches and a dynamic and responsive sense of how and when to apply them.

In judging the effectiveness of a representation, it is the experienced teacher who is most cognizant of the complexities of various teaching strategies that cause confusion in their students' learning of science. Experienced teachers have a wide range of experiences and intuitive understandings on which to draw from in making and adapting classroom instruction (Clermont, et al., 1994). On the other hand, novice, preservice and beginning teachers, do not possess such a repertoire. Instead, novice teachers rely on trial-and-error to help them survive the first years in the classroom, regardless of whether or not the practices represent the most effective strategies for student learning (Feiman-Nemser, 2001). In the science classroom, teachers apply multiple knowledge domains in planning and teaching lessons (Magnusson, et al., 1999; Shulman, 1986, 1987). Thirty years ago, Shulman (1986, 1987) first introduced the idea of a teacher creating a new knowledge base through the integration of these domains. In his seminal work, Shulman (1987) identified seven categories of teacher knowledge (italics added):

- content knowledge;
- general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
- curriculum knowledge, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers;
- *pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;*
- knowledge of learners and their characteristics;
- knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
- knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. (p. 8)

Of these categories of teacher knowledge, Shulman described pedagogical content knowledge (PCK) as unique due to the combination of content and pedagogy. PCK represents the knowledge a teacher holds and understands that is distinctive for teaching and learning.

PCK is the knowledge teachers' use in the process of designing and implementing lessons to a particular group of students. In doing so, teachers need to be aware of the students' needs and understandings when planning how to represent the content to them (Friedrichsen et al., 2009; Shulman, 1986, 1987; Van Driel, et al., 2002). This requires the teacher to actively think through the content and anticipate the reaction and the motivations of the learner. The possession of this special knowledge allows teachers to adapt lessons to the needs of the individuals and groups in a classroom. It is this knowledge of teaching and learning that distinguishes a science teacher from a scientist.

Statement of Problem

The teacher's PCK is subject to change as the teacher gains new knowledge and experiences (Lee, Brown, Luft, & Roehrig, 2007; Loughran, Mulhall, & Berry, 2008; Van Driel & de Jong, 1999; Van Driel, et al., 2002). The greatest growth occurs during the first years of teaching as the new teacher moves from "knowing about teaching through formal study to knowing how to teach by confronting the day-to-day challenges" (Feiman-Nemser, 2001, p. 1027). It is during this time that teachers draw upon an emerging PCK by constantly revisiting this knowledge base as they reflect upon their interactions with students. The rapidly changing PCK of a new teacher makes it a useful construct to study in order to document the development of PCK.

The first years of teaching represent the formative time in which the teacher learns to teach. Ultimately, it is during the beginning years that teachers are enacting a beginning repertoire by building a coherent subject matter structure for teaching by combining knowledge of subject matter and knowledge of pedagogy into PCK (Feiman-Nemser, 2001; Lee, et al., 2007). This transformation is often captured through teachers' representations of the content (e.g., models and analogies). There is a plethora of research on chemistry teachers' use of models (e.g., Henze, van Driel, & Verloop, 2007; Van Driel & Verloop, 1999) and analogies (e.g., Coll, 2006; Oliva, Azcarate, & Navarrete, 2007; Orgill & Bodner, 2005). However, there has been little research on chemistry teachers' representations of the triplet relationship (e.g., De Jong & van Driel, 1999; Van Driel, et al., 2002). Therefore, the goal of this study was to explore the choices in representations of the triplet relationship by beginning chemistry teachers.

Research Questions

To understand the change in PCK among beginning chemistry teachers, the research questions that guided this study were:

1. How do beginning chemistry teachers conceptualize and enact the triplet relationship during their first three years? Do these representations change over time?
2. In an examination of the representations of one fundamental aspect of chemistry content (i.e., atomic structure) over time, how does a beginning teachers' knowledge of student learning impact their enactment of the representations?

To address these research questions, I focused on the beginning chemistry teachers in this study who were part of two different National Science Foundation (NSF) grant research projects (PI, Luft): First, *Exploring the Development of Beginning Secondary Science Teachers in Various Induction Programs* and second, *Persistent, Enthusiastic, Relentless: Study of Induction Science Teachers* (PERSIST) (NSF grants 0550847 and 0918697). In the overall design of these studies, beginning science teachers participated in various induction programs provided either by schools, districts, or university faculty and research associates. From our analysis of the PCK data for all teachers in the two studies, we know that how the teachers represent their instruction is statistically significant over time (Luft, 2009). This dissertation study aimed to analyze the data at a finer grain size in order to understand how chemistry content specialists represent the curriculum, along with the decisions that impacted the implementation of those representations.

Significance of Study

This study of the development of PCK of new chemistry teachers provides insights that will be of value to the field of science education. The first contribution of this longitudinal study addresses the need for research on the change over time in PCK of beginning chemistry teachers. Much of the past and current research in chemistry education on the development of PCK has focused on the preservice and experienced secondary chemistry teachers.

The second contribution of this investigation addresses the need for research on single-subject endorsements or content specialists. Each discipline has a unique framework in which to make decisions about what and how to teach the subject (Donald, 1983; Stodolsky & Grossman, 1995). Grouping teachers from diverse fields of study (e.g., biology, chemistry, physics, and geology) fails to distinguish the unique features of each field's content and pedagogical strategies. In order to capture the framework of a specific field (e.g., chemistry), it is important to study teachers in individual content areas. This research project focuses specifically on the PCK of secondary chemistry teachers in the United States who were participants in longitudinal research studies. By focusing solely on secondary chemistry teachers, the study takes into account the unique framework that is the backdrop for making curricular decisions.

The third contribution of this research study is to examine how experiences and knowledge about students cause changes in PCK. Much of the research on teacher growth only follows teachers from a few weeks to one year (e.g., Lee, et al., 2007; Loughran, et al., 2008; Van Driel & de Jong, 1999; Van Driel, et al., 2002). Research has shown that the first three years are the formative years for beginning teachers (e.g., Brock & Grady, 2007; Feiman-Nemser, 2001; Veenman, 1984). In order to increase our understanding of teacher development, there is a need for longitudinal studies that follow new teachers through their third year in the classroom. Hence, this study contributes to this area by using chemistry teachers' instructional practices to capture the change in PCK over a three-year time period.

Finally, this dissertation investigation provides insight into the decisions regarding student learning on the enactment of the triplet relationship by beginning chemistry teachers. Research on the chemistry triplet relationship has predominantly focused upon students' difficulties learning chemistry (e.g., Gilbert & Treagust, 2009c; Johnstone, 1982, 1991, 2000) or the theoretical underpinnings (e.g., Erduran, Bravo, & Naaman, 2007; Talanquer, 2011; Treagust, Chittleborough, & Mamiala, 2003). This research study contributes to understanding how beginning chemistry teachers' represent the triplet relationship and the decisions based upon student learning that may change these representations over the first three years.

Overview of Study

The second chapter includes a review of the research literature in areas related to this study on the development of PCK of beginning chemistry teachers. The first section of Chapter 2 provides an overview of the triplet as the conceptual framework for the study. The second section reviews the research on what is currently known about novice teachers' knowledge of student learning in science and especially in chemistry.

Chapter 3 details the explanatory mixed-methods research design employed to carry out this study (see Creswell, 2005). Using Crotty's *The Foundations of Social Research,* this chapter is discussed using the four elements of any research process. This research design chapter includes a description of the participants and the data sources utilized for each of the research questions. The chapter attends to the description of the piloting phase of the Atomic Structure Interview (ATSI). Finally, Chapter 3 includes a thorough description of the data analysis procedures and analytical strategies employed in this study.

Chapter 4 presents the analyzed data for the eight beginning chemistry teachers in the study. In this embedded explanatory mixed-methods study, the first phase involved the quantitative data as the primary data source in capturing changes in teachers' use of representations of the triplet relationship, while the qualitative data. A second phase involved both the ATSI and the PCK interviews based on the atomic structure to explain the teachers' decisions on the enactment of the representations during the first three years in the classroom. Finally, a discussion of the change in practices and knowledge is included.

Finally, Chapter 5 includes the discussion of the findings, conclusions, implications of the study, and the directions for future research.

Chapter 2

LITERATURE

PCK Conceptual Framework

The PCK construct captures teacher knowledge of teaching and learning. At its core, PCK represents an amalgam of the major knowledge domains: subject matter, context, and pedagogical knowledge. These knowledge domains impact the choice of instructional practices used for a specific group of students (De Jong, van Driel, & Verloop, 2005; Friedrichsen, et al., 2009; Veal & MaKinster, 1999). Teachers' instructional choices are based upon their understanding of the content, pedagogy, and their students. Therefore, PCK is a teacher's understanding of how best to help students learn specific subject matter (Magnusson, Krajcik, & Borko, 1999). PCK includes

> the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others … the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. (Shulman, 1986, p. 9)

Because PCK is such a complex, dynamic, and encompassing construct, it demands much of the teacher with regard to determining how to present subject matter.

Knowledge domains influence the components that make up PCK. Regarding the implementation of curriculum, Shulman (1986, 1987) asserted that

PCK was comprised of two components: representations and learning difficulties. Representations are instructional strategies teachers employ to make subject matter comprehensible to their students. They include analogies, metaphors, examples, demonstrations, and explanations. Learning difficulties of the students were described as misconceptions, conceptions, or preconceptions that students held about the subject matter. For the practicing teacher, the components are depicted as the strategies implemented in class to help deal with students' understanding of a topic.

Since Shulman (1986, 1987) first introduced PCK components, education researchers have suggested further components. The conceptualization of one such researcher, Tamir (1988), included two new PCK components: curricular knowledge and knowledge of assessment. Curricular knowledge was defined as "the nature, structure, and rationale of Bloom's Taxonomy" (p. 100), and knowledge of assessment was the understanding of various modes for assessing students. A second researcher, Grossman (1990), added knowledge of curriculum and conceptions of purpose for teaching the subject matter to the two original PCK components (see Figure 2). Building upon Tamir's definition, Grossman described curricular knowledge as the knowledge of curriculum materials available for teaching a subject along with knowledge of the horizontal and vertical curricula for a subject. Grossman defined purposes as the "overarching conceptions of teaching a subject [that] are reflected in teachers' goals for teaching particular subject matter (p. 8)." Building upon the work of Shulman, Tamir and Grossman provide a broader conception of the components that make up PCK.

<table>
<tr><td colspan="3">Pedagogical Content Knowledge</td></tr>
<tr><td colspan="3">Conceptions of Purposes for Teaching Subject Matter</td></tr>
<tr><td>Knowledge of Students' Understanding</td><td>Curricular Knowledge</td><td>Knowledge of Instructional Strategies</td></tr>
</table>

Figure 2. Grossman's model of teacher knowledge. Adapted from "The making of a teacher: Teacher knowledge & teacher education," by P. L. Grossman, 1990, New York: Teachers College Press, p. 5.

Magnusson et al. (1999) conceptualized PCK for teaching science as having five components based on the work of Tamir and Grossman. Using the components knowledge of curriculum and knowledge of assessment, as well as modifying Grossman's purposes and renaming them as orientations (see Figure 3), Magnusson et al. conceptualized the components as:

1. Science teaching orientations: knowledge and beliefs about purposes and goals for teaching science for a particular grade level (p. 97);
2. Knowledge of student understanding of science: the knowledge teachers must have about students in order to help them develop specific science knowledge (p. 104);
3. Knowledge of science instructional strategies: the knowledge of subject-specific and topic-specific strategies that are useful in helping students learn the concepts (pp. 109-110);
4. Knowledge of science curriculum: refers to mandated goals and objects, and specific curricular programs and materials (p. 103); and

5. Knowledge of assessment in science: teachers’ knowledge of assessment strategies and the dimensions of science most important to assess (p. 108).

Each researcher from Shulman through Magnusson et al. conceptualized the PCK components differently; however, each relied upon their own visualizations and understandings to describe PCK.

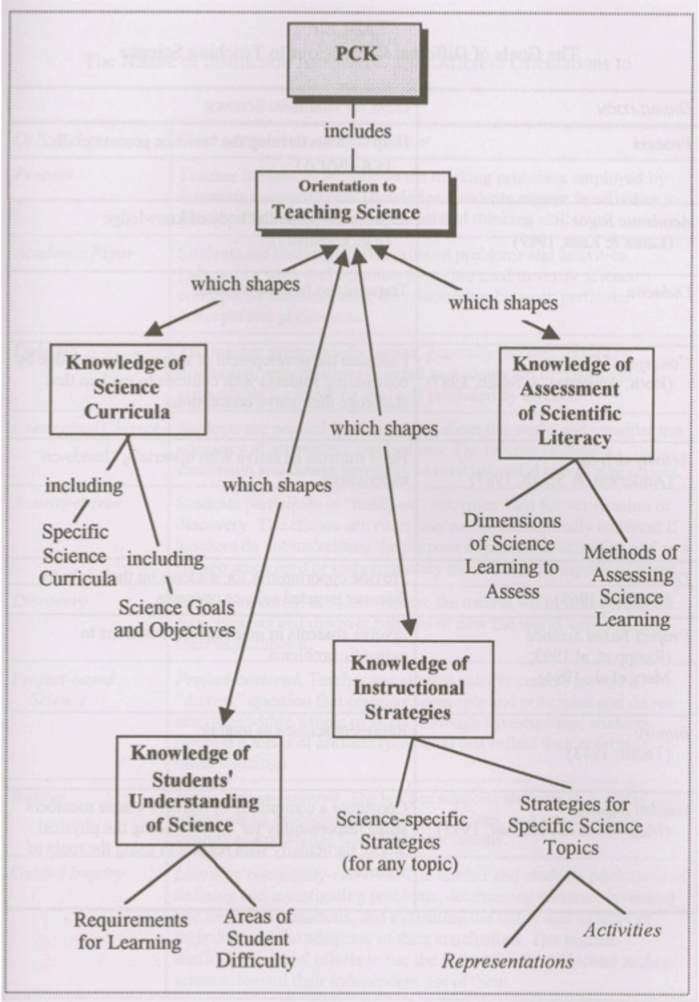

Figure 3. Components of pedagogical content knowledge for science teaching. Adapted from “Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching,” by S. Magnusson, J. Krajcik, and H. Borko, 1999, Examining Pedagogical Content Knowledge, J. Gess-Newsome and N. G. Lederman (Eds.), p. 99.

To address the researchers use of their own visualizations of PCK, Luft, and Roehrig (2007) developed a PCK rubric based upon current research and emergent PCK categories from the teacher's perspective. While experienced teachers relied upon all of the components of PCK mentioned by the previous researchers, Lee et al. found the teachers' responses were most salient regarding the components knowledge of instructional strategies and knowledge of student learning in science.

Knowledge of instructional strategies consisted of teacher representations and utilization of the NRC (2000) scientific inquiry.[2] Knowledge of student learning captured teacher knowledge of students' prior knowledge, variations in students' approaches to learning, and students' difficulties with specific science concepts. The use of the teachers' view provides support for the conceptualization of the PCK components.

The PCK of beginning chemistry teachers can be understood through the lens of Lee et al.'s components in conjunction with Johnstone's (1982, 1991) triplet relationship. In an effort to address students' difficulty in learning chemistry, Johnstone introduced three categories of representations that have since been termed the macro, the submicro, and the symbolic. The triplet relationship can be used to discuss various subjects in science (e.g., chemistry, physics, and biology) as well as specific topics (e.g., atomic structure). The way a

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[2] The essential features of scientific inquiry involve the learner through engaging in scientifically oriented questions, give priority to evidence in responding to questions, formulate explanations from evidence, connect explanations to scientific knowledge, and communicate and justify explanations.

teacher presents chemistry through the triplet relationship corresponds to the knowledge of representations. This connection is based upon the various levels of chemistry represented in classroom instruction. Teachers choose methods based on their knowledge of students' learning in science and must consider students' prior knowledge, variations in students' approaches to learning, and students' difficulties in learning chemistry (atomic structure, in this instance). The conceptual framework used for this dissertation's study can be found in Figure 4.

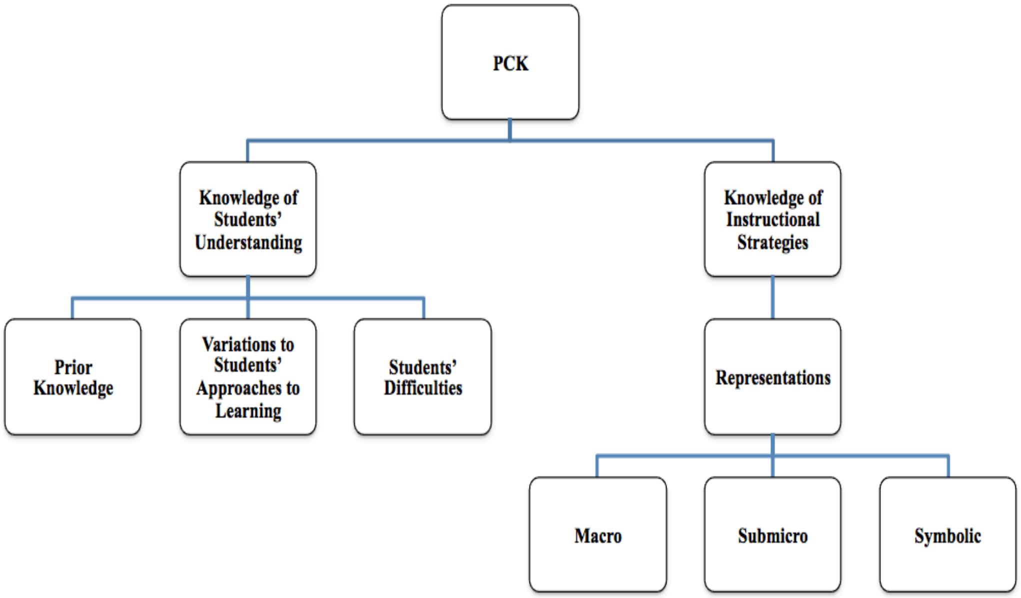

Figure 4. The combination of PCK using Lee et al.'s (2007) view and Johnstone's (1982, 1991) triplet components.

Specifically, the triplet relationship aligns with Lee et al.'s (2007) description of PCK through knowledge of instructional strategies (see Figure 2). Knowledge of instructional strategies refers to the knowledge of topic-specific (e.g., atomic structure, acid bases, and thermodynamics) strategies "that are useful for helping students comprehend specific science concepts" (Lee, et al., 2007, p. 111). Relating this PCK component to the triplet relationship, a teacher may implement an instructional strategy such as a laboratory activity that can be disaggregated using the categories of the triplet relationship. Effective science teachers know how and when to engage particular representations to support student learning.

A second component of PCK, according to Lee et al. (2007), is the knowledge of students' understanding. Magnusson et al. (1999) identified subcategories of this component as teachers' awareness of students' prior knowledge, variations in students' approaches to learning, and students' difficulties with learning science content. As teachers make decisions about their practices, they determine which activity to implement based on what they know about their students.

Using Lee et al.'s (2007) PCK components, this study seeks to understand how beginning chemistry teachers conceptualize and enact the triplet relationship and the decisions behind their choice of instructional practices. In order to support this research, chapter 2 will focus upon both the conceptual framework of the triplet as defined by current chemistry educators (e.g., Chandrasegaran & Treagust, 2009; Talanquer, 2011) and teachers' knowledge of students' understandings, as described by Magnusson et al. (1999).

The Triplet

Johnstone (1982) initially proposed the triplet idea to address the Joint Committee on Chemical Education's search for a "Chemistry for All" component. "Academic chemists can view our subject on at least three levels… Trained chemists jump freely from level to level in a series of mental gymnastics. It is eventually very hard to separate these levels" (p. 377). This is in contrast to how the non-chemist would spend much of their understanding within the observable world.

Since its introduction, there has been little consensus on the triplet beyond its applicability in the chemistry classroom. Areas of little consensus include the terminology for the components (Gilbert & Treagust, 2009a) and differing descriptions (e.g., Chandrasegaran, Treagust, & Mocerino, 2007; Hinton & Nakhleh, 1999; Kern, Wood, Roehrig, & Nyachwaya, 2010). Thus, this literature review will compare the definitions for the macro component along with the combination of the submicro and symbolic components then provide the definition to be used by this particular study to analyze the triplet representations.

Macro component. In chemistry education research, the term macro is universally understood to be based on sensory input of observable properties (e.g., density, flammability, and color). Yet, within the descriptions, there are variations. For instance, some researchers focus solely upon the macroscopic properties (Gabel, 1999; Hinton & Nakhleh, 1999; Treagust, et al., 2003) and other researchers include students' experiences with the phenomenon (Chandrasegaran, et al., 2007; Treagust, et al., 2003). The key difference between the two macro descriptions is the type of experience. In the first, the experience is scientific in nature with students' measuring, observing, and categorizing based on the unique macroscopic properties (Gabel, 1999; Hinton & Nakhleh, 1999; Treagust, et al., 2003). An example could be gold, which has a specific color, density, melting point, and malleability. In the second definition, using gold as an example, the experience is based on prior experiences with gold may involve the students' personal experiences with the price of gold and the societal and cultural meanings placed upon it. When teaching chemistry, the intention of the activity may dictate the preference for either the students' scientific or personal experiences.

A third experience not mentioned in the definitions of the macro component is the historical. Science education reform has placed a greater emphasis on the historical perspective of science through the contributions of various cultures, philosophers, and scientists (AAAS, 1993; NRC, 1996). When looking at the concept of atomic structure, teachers may emphasize the history of the atom through the experiences of Democritus, John Dalton, Ernest Rutherford, and J. J. Thomson. This is an appropriate orientation, as Ben-Zvi, Eylon, and Silberstein's (1986) research on students' understanding of atomic structure found that focusing on a historical view helped address student misconceptions about the abstract concept.

Of the three types of experiences discussed: scientific, personal, and historical, each provides different understandings, views, and insights into the macro environment. Ultimately, the experience should focus on the scientific. Historical and personal experiences provide context but do not always provide the conduit to understanding what is occurring at the subatomic level between interactions of subatomic particles, atoms, or molecules. Thus, the definition for macro to be used for the purposes of this dissertation is based upon Gabel (1999) and Hinton and Nakhleh (1999) and defined as concrete observations of macroscopic properties that are observable, measurable, quantifiable, and reproducible.

Submicro and symbolic components. Two components of the triplet involve two abstract entities. The submicro level is comprised of entities not observable by the naked eye, which includes the atom and its two subcategories: the molecule and the ion (Chandrasegaran, et al., 2007; Kern, et al., 2010; Levy Nahum, Hofstein, Mamlok-Naaman, & Bar-Dov, 2004; Treagust, et al., 2003). The symbolic level consists of a variety of symbols for chemical elements and mathematical equations (Chandrasegaran, et al., 2007; Taber, 2009). However, descriptions of the two components often include the discussion of models (e.g., ball and stick, atomic drawings). The following will provide a rationale for the use of models in the symbolic component.

Chemistry is based upon representations of the atom. Chemists often use representations to illustrate “unseen entities and processes” (R. Kozma, Chin, Russell, & Marx, 2000, p. 106). External representations, which are visual and/or oral transmissions of information, include models, ideas, equations, analogies, graphs, diagrams, pictures, illustrations, multimedia, and simulations. These types of representations can help students learn specific concepts (Bucat & Mocerino, 2009; Pozzer & Roth, 2003). External representations lie along a continuum from less abstract with more detail (i.e., everyday experiences) to more abstract with less detail (i.e., graphs; (Pozzer & Roth, 2003). This causes problems when studying teachers’ representations, thus the researcher must know the intent of the model in order to determine whether it should be categorized as either submicro or symbolic.

Talanquer (2011) described the visual language of chemistry as being made up of symbols and icons. Though symbols represent real, tangible substances (i.e., P for phosphorous), they are just symbols (Hoffman & Laszlo, 1991; Hoffmann, 2007; Talanquer, 2011). Icons are objects designed to represent an entity (i.e., ball-and-stick representations of molecules, particulate drawings, drawings of electron shells). Hoffman[3] and Laszlo (1991) argued that both symbols and icons are incomplete representations, unable to represent all of chemistry but useful for bridging the symbolism to meanings. To compensate for this incompleteness of symbols and icons, chemistry has combined symbolic and iconic values to produce a hybrid status between symbols and models. For example, Figure 5 represents the geometry of water (H_2O) using the Lewis structure along with lines to communicate the perspective of the molecule. The elemental symbols (H and O) and lines represent symbols, while the two-dimensional structure has an iconic value.

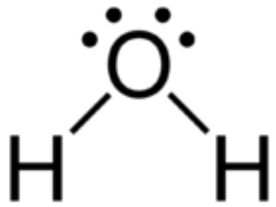

Figure 5. Symbolic and iconic representation of water (H_2O).

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[3] Roald Hoffman won the Nobel Prize in chemistry in 1981 for his work on the structure of inorganic and organometallic molecules.

To distinguish between symbolic and iconic values, one must look at the nature of the two components. For a representation based upon signs (i.e., positive or negative), the symbolic representation would be the best component. However, if the models were thought of as descriptive and explanatory, with predictive power, the iconic representation, called the submicro component, would be the better descriptor.

Researchers have distinguished between the use of submicro and symbolic based on reality and representation (Davidowitz & Chittleborough, 2009; Treagust, et al., 2003). Treagust et al. (2003) described the submicro component as "real," though the particles are too small to observe, and the symbolic component as representational, due to the reliance on symbols and equations. Using Figure 6, the macro is real and visible; the submicro is real and invisible while the symbolic representations include the chemical diagrams that connect the submicro content, as depicted by the dashed line (Davidowitz & Chittlborough, 2009). As a result, using real and representational as a determining factor, models would be found only in the symbolic. A teacher's use of molecular representations (i.e., ball-and-stick, drawings, models) would be designated as symbolic. The researcher would then only need to determine what connections teachers make between the symbolic representation and the macro and submicro categories. As Talanquer (2011) summarized, the key to the symbolic component is that the models do not have any predictive power.

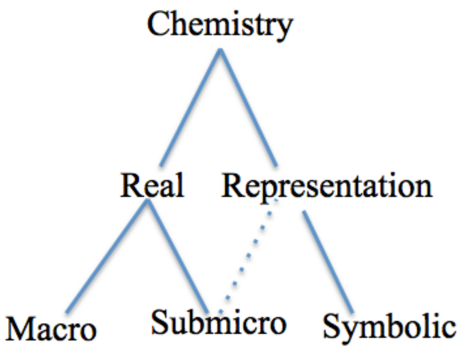

Figure 6. The relationship between the three levels of chemical representations and real and represented chemical data (B. Davidowitz and G. Chittleborough, 2009, “Linking the macroscopic and the sub-microscopic levels,” p. 172.

To determine whether models should be considered submicro or symbolic, I drew upon Davidowitz and Chittleborough’s (2009) argument of real and representational components, thus determining that models were symbolic components. Submicro was defined as providing explanations at the particulate level (i.e., explanations of observed behavior at the atomic level). Symbolic was defined as symbols, elemental names, positive and negative signs, models (ball & stick, drawings), mathematical formulas, and electron configurations.

Summary of the triplet. The triplet provides a way to explain different components found in chemistry; it categorizes chemistry elements as the macro level (observable properties of matter), the submicro level (atoms, molecules, ions: the explanation for the observable), and the symbolic level (symbols, mathematical equations, and models).

Chemistry Teachers and The Triplet Components

To date, few studies have focused on chemistry teachers’ knowledge of the triplet relationship. The studies have focused upon (1) implementation of the components (Lewthwaite & Wiebe, 2010; Sande, 2010) and (2) chemistry teachers' development of PCK (Van Driel, et al., 2002). These studies represent teachers' knowledge of the triplet relationship.

One study by Lewthwaite and Wiebe (2010) reported teacher development for 74 Canadian chemistry teachers over four years for the use of a new curriculum based upon a modified triplet relationship[4]. In the implementation of the new curriculum, teachers were offered three professional development days that focused upon a specific topic for teaching 11th or 12th grade chemistry students. As a result of participating in the professional development and working with the new curriculum, teachers moved from implementing primarily the submicro and symbolic representations to an increase in the use of macro representations. However, the classroom representations engaged students in performing more calculations than manipulations or viewing visual images, demonstrations, and simulations. Overall, the teachers gradually implemented an integrated view of the components over time.

Another study by Sande (2010) followed four chemistry teachers and their understanding of the triplet components with respect to the gas laws. In this dissertation study, Sande found that teachers focused upon macroscopic and symbolic representations without using submicro representations. If the teachers did discuss kinetic molecular theory for classroom instruction, they did not return to the submicro component to explain the students' observations in further lesson activities. Sande concluded that teachers have a limited ability to connect one

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[4] The Canadian curriculum is based upon the tetrahedron (tetra) orientation of chemistry. The tetra includes a new component called the "human element" which focuses upon a historical, social, and socioscientific issue orientation.

representation to another. As a result, teachers are not intentionally planning their lessons for development of knowledge between the three components of the triplet.

Lastly, a study by Van Driel, de Jong, and Verloop (2002), followed 12 preservice teachers' development of PCK with respect to the macro-submicro components. At the start of the program, the preservice teachers demonstrated limited PCK with regard to macro-submicro components. To varying degrees, by the end of the program, teachers had become aware of (1) the manner in which they presented the macro-submicro components, (2) the impact of mixing macro and submicro terms on students' difficulties, and (3) the need to use explicit language in describing macro and submicro levels and the relation between them. The preservice teachers developed an understanding of the impact of the triplet representations on student learning as a result of the program.

These studies show that chemistry teachers have a limited knowledge of the triplet components on student learning. For chemistry as a whole, chemistry teachers utilize the submicro and symbolic representations for classroom instruction (Lewthwaite & Wiebe, 2010). The teachers are not aware that they are not connecting the macro representations to the submicro and symbolic representations especially with respect to the gas laws (Sande, 2010). Teachers need to be made aware of the triplet components as it impacts their knowledge of the concepts and knowledge for teaching those concepts (Van Driel, et al., 2002). Even when curriculum focuses upon the components, awareness of those components occurs gradually from continued exposure and support from professional development (Lewthwaite & Wiebe, 2010). While there are few studies on teachers' knowledge and use of the triplet components, there is further need for a study on beginning chemistry teachers' use of the triplet and the decisions that impact those representations.

The Chemistry Classroom

Chemists often think about the atom in terms of the macro, the submicro, and the symbolic levels seamlessly, as one representation instead of individual components (Johnstone, 1982; Talanquer, 2011; Treagust, et al., 2003). The chemistry teacher, however, must be aware of the triplet when presenting content to students, as they will have difficulty recognizing the differences between the three levels (De Jong & van Driel, 1999; Johnstone, 1991; Robinson, 2003; Van Driel, et al., 2002). It has been hypothesized that students primarily live and operate in the macroscopic world without making connections between their surroundings and chemistry (Gabel, 1999; Mayer, 2011), and thus have problems moving between the different components.

Science teachers design classroom instruction to address students' prior knowledge, the wide variation in their approaches to learning, and their difficulties with the presented concept (Lee, et al., 2007; Magnusson, et al., 1999). As a result of these three variables, the teacher must have numerous representations available for use in the classroom. These representations may be based on research or derived from the "wisdom of practice" (Shulman, 1986, p. 9). In the process of selecting a representation, the teacher must be aware of how students interpret and understand the representation. In chemistry, there is no one representation that is considered the most powerful approach for teaching a topic (Banks, Leach, & Moon, 2005). This section reviews the importance of students' prior knowledge, differences in students' approaches to learning, as well as students' difficulties in chemistry.

Students' prior knowledge. Students' prior knowledge refers to the teachers' recognition of what students know about a concept (Friedrichsen, et al., 2009; Meyer, 2004). Accessing students' prior knowledge is important when helping students construct their understanding (Hailikari, Katjavuori, & Lindblom-Ylanne, 2008; Hailikari & Nevgi, 2010; Hailikari, Nevgi, & Lindblom-Ylanne, 2007). By comprehending this prior knowledge, instruction may be designed to address potential difficulties inherent in learning chemistry.

Teachers recognize the importance of prior knowledge to classroom instruction (Davis & Smithey, 2009; Friedrichsen, et al., 2009; Meyer, 2004; Meyer, Tabachnick, Hewson, Lemberger, & Park, 1999) but they have differing views about why this knowledge is important. For instance, prior knowledge may be viewed as the foundation upon which teachers build deeper understanding of a concept (Friedrichsen, et al., 2009; Meyer, 2004; Otero & Nathan, 2008) or as motivation for student participation (Friedrichsen, et al., 2009; Meyer, et al., 1999). Alternately, prior knowledge may be seen as providing insight into why students participate in classroom activities (Abell, Bryan, & Anderson, 1998; Friedrichsen, et al., 2009; Meyer, et al., 1999). Teachers view prior knowledge as a building block to understanding concepts obtained from students' previous experiences. These experiences may be through formal instruction, informal instruction – TV shows or museums – and general life experiences (Otero & Nathan, 2008).

Students' varied approaches to learning. Teachers make instructional decisions based upon their knowledge of how students approach learning. This involves recognizing how students of differing ability levels or differing learning styles vary in developing specific understandings (Magnusson et al., 1999). For instance, in high school, teachers, guidance counselors, and students often work together to determine the appropriate chemistry courses students take based upon his or her abilities and future career aspirations.

A learning style is a student's preference for a specific mode in which to receive information as well as the mode through which they demonstrate their knowledge of a particular topic (Felder & Brent, 2005; Fleming, 2010; Kolb, 1984; Lawrence, 1993; Magnusson, et al., 1999; Towns, 2001). Bretz (2005) identified four learning schema prevalent in chemistry education: Visual-Aural-Read/Write-Kinesthetic (VARK), Myers-Brigg Personality Type Indicator, Kolb's Experiential Learning model, and Felder-Silverman Index of Learning Styles. For all of the four schemas, learning would include various representations such as

- Visual learning strategies: graphs, pictures, textbooks, and symbols.
- Aural learning strategies: information and ideas heard during lecture and classroom discussions.

- Reading and writing learning strategies: lists, handouts, textbooks, and essays.
- Kinesthetic learning strategies: field trips, laboratories, and role-playing.

Research has found that students rely upon multiple learning styles (i.e., visual and aural) and not just a single mode for learning (Fleming, 2010). Effective teachers are aware of students' needs and are able to make adjustments to classroom practices in order to engage all students.

Magnusson et al. (1999) suggested that to address variation in students' learning styles, the teacher would need to implement different representations in classroom instruction, such as the models, illustrations, analogies, problems, and experiments that science teachers use to present specific topics (Grossman, 1990; Lee, et al., 2007; Magnusson, et al., 1999). In the science classroom, the teacher must implement multiple modes to present and link lessons to the target knowledge. A teacher's ability to enact and conceptualize specific representations to facilitate student learning often hinges upon the individual's knowledge of various strategies in which to teach specific concepts.

Students' difficulties with chemistry. Teachers make instructional decisions based on their students' difficulties with chemistry. This category refers to teachers' knowledge of areas within chemistry and specifically atomic structure which students' find difficult to learn. Two areas that research has identified in which students find chemistry difficult are the triplet relationship and atomic structure.

Difficulties with the triplet relationship. Students may have difficulty developing an integrated view of a topic, even when a program emphasizes the triplet. Chandrasegaran, Treagust, and Mocerino (2007) studied 9th and 10th grade chemistry students (N = 787) for development of the triplet after nine months of instruction using the triplet specifically. Despite the emphasis on the triplet, students still had confusion between macro and submicro concepts, and limited understanding of the symbolic representations. There are several explanations for students' difficulty in learning the subject: movement between the components of the triplet (Chandrasegaran & Treagust, 2009; Chandrasegaran, Treagust, & Mocerino, 2008; Johnstone, 1991; Van Driel, et al., 2002), difficulty connecting the macro and symbolic (Bennett, 2004; Laws, 1996; Lin, Cheng, & Lawrenz, 2000; Nakhleh, 1993; Nakhleh & Mitchell, 1993; Reid & Yang, 2002), as well as with the submicro level (Gabel, 1999; Mayer, 2011).

Macro-symbolic difficulties. Much of the field of chemistry relies upon algorithms and mathematical calculations (symbolic component) to understand observed phenomenon (macro component), but teaching often fails to produce conceptual understanding in students (Nakhleh, 1993; Nakhleh & Mitchell, 1993; Sanger, 2005). Students often rely upon memorizing formulas with the assumption that deeper understanding is not necessary (Bennett, 2004; Gabel & Bunce, 1994; Reid & Yang, 2002). However, this does not always prove successful in problem-solving activities. Sanger (2005) interviewed 156 university freshman chemistry students about the processes they used to balance a chemical equation and solve a stoichiometric calculation. Besides having difficulty with balancing the chemical equations, the students were unable to utilize information from the balanced equation to solve the stoichiometric algorithms, though they understood the process to solve the problem.

Macro-submicro difficulties. Students may make incorrect assumptions about the nature of a phenomenon without a clear conceptualization of the macro-submicro view (Erduran, et al., 2007). These invalid assumptions may include the conception that chemicals that appear similar at the macro level will behave similarly at the submicro level (Bhushan, 2007; Erduran, et al., 2007; Scerri & McIntyre, 1997), assuming that temperature and average kinetic molecular theory are the same (van Brakel, 1997, 2000), and confusing molecules with compounds (Hoffmann, 2007; Onwu & Randall, 2006). For the chemistry teacher, making students aware of the nature of the macro-submicro views involves the use of laboratory activities, models, and analogies to understand chemical concepts.

Research tells us that students have difficulty building bridges between what they observe and the way chemistry describes and explains the phenomenon (Gabel, 1999; Mayer, 2011). For example, Mayer (2011) administered pre- and post-tests on the nature of gases to 63 chemistry students in the 10th grade. Though the study found students' understanding of the nature of gases increased after a demonstration and laboratory experiment,[5] many students expressed disbelief in the observed results and repeated the experiment, determined that

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[5] The laboratory involved recording the mass of carbon dioxide (dry ice) before and after it sublimated within a closed system. The demonstration involved filling a balloon with hydrogen and oxygen gas. On a hot plate, another balloon was attached to a flask with 30-50 mL of water. Students diagramed what was occurring in both balloons.

something had gone wrong. The students' deep-seated beliefs that gases would have less mass than solids persisted even when discussed several weeks later. Teachers need to be aware of the potential for confusion in working with macro and submicro views of chemistry.

Difficulties with atomic structure. From Democritus's atomic nature of the physical world (460-370 BC) to John Dalton's pioneering of modern atomic theory to current work in quantum theory, atomic structure has been an important concept in science, and specifically in chemistry. The importance of atomic structure has been referenced in the National Science Education Standards (NSES; (*National Research Council* [NRC], 1996). NSES identified a set of science content standards for student outcomes, one of which is an understanding of atomic structure in grades 9-12. Chemistry education researchers have identified atomic structure as a threshold concept to aid in understanding areas such as quantum mechanics, spectroscopy, and bonding theory (Park & Light, 2009).

The NSES standards (NRC, 1996) define matter as comprised of particles called atoms and describe the fundamental aspect of atomic structure as particles that have mass and electrical charge. The electrical force holds the atom together, while the nuclear force holds the nucleus together. There have been various models of the atom over time: the plum-pudding model of J. J. Thomson in 1897; Hantaro Nagaoka's planetary model in 1904, which was improved by Ernest Rutherford in 1911; and the most common model used in chemistry, the Bohr model by Niels Bohr in 1913. The Bohr model represents the atom as a planetary structure with electrical forces holding the atom together. The use of the planetary structure helps visualize the location of the electrons in the atom. However, the model does not accurately depict the atom as chemists describe. Within the overview of the concept, the NSES suggests that students at the 9th-12th grade level are developmentally prepared to relate macro phenomenon to submicro and symbolic phenomenon.

Research has identified specific misconceptions that are associated with atomic structure (Ben-Zvi, Eylon, & Silberstein, 1986; Griffiths & Preston, 1992; Park & Light, 2009; Schmidt, 1997). With respect to atomic structure, students try to apply their understanding of everyday occurrences to atoms. Harrison and Treagust (1996) interviewed 48 high school students in western Australia on their mental models of atoms and molecules after having at least one unit of chemistry. Students tended to use properties of their everyday world to explain the properties of an atom. For example, students depicted an orbital model (similar to planetary systems), with filled space (not empty space), and electron shells as similar to seashells and eggshells. Taber's (2001a, 2005) studies of 16-18 year olds in the UK found that students there held similar conceptions of the atom and its structure. In these examples, the students applied their experiences to the structure of the atom in order to explain the submicro component of the phenomenon.

Students saw the models as the reality of the atom rather than as a tool for understanding (Coll & Treagust, 2002; Taber, 2005). In Griffiths and Preston's (1992) study, the students' representations of water were drawn as tiny drops of water instead of the elements oxygen and hydrogen. The students did not realize that the models were visual representations that did not always provide an accurate depiction of the atom (Treagust, et al., 2003).

To identify student misconceptions on the fundamental characteristics of atoms and molecules, Griffiths and Preston (1992) interviewed 30 high school seniors (12th grade) in Canada. From the interviews, they were able to identify 52 misconceptions, 14 of which were related to students' models of atoms. Taber (2001a, 2002, 2003, 2005) corroborated Griffiths and Preston's work on student misconceptions by identifying students' learning difficulties and mental models. Table 1 is a combination of the authors' work on students' misconceptions about atoms.

Table 1.

Students' Misconceptions Regarding Atoms.

Misconceptions	
Structure/shape of atoms	An atom resembles a sphere with components inside.
	An atom resembles a solid sphere.
	An atom looks like several dots/circles.
	An atom is flat.
	Matter exists between atoms.
	Electrons move in orbits and the electrons have a spin because they are rotating (axis or around the nucleus).
	Shells and orbitals are synonymous.
Size of atoms	Atoms are large enough to be seen under a microscope.
	Atoms are larger than molecules.
	All atoms are the same size.
	Heat may result in a change of atomic size.
	Collisions may result in a change of atomic size.
Animism of atoms	All atoms are alive.
	Only some atoms are alive.
	Atoms are alive because they move.
Weight of atoms	All atoms have the same weight.

Note. Adapted from "Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecule," by A. K. Griffiths and K. R. Preston (1992), *Journal of Research in Science Teaching, 29,* p. 616, and from "Learning quanta: Barriers to stimulating transitions in student understanding of orbital ideas," by K.S. Taber (2005), *Science Education, 89,* p. 109.

Research on students' understanding of atomic structure has found that knowledge of the historical view improves their learning. To address student misconceptions of atomic structure, Ben-Zvi et al. (1986) implemented a program that included a historical view of atomic theory to explain the atomic model as a developing model. Though the high school chemistry students (N = 1078) from Israel still had difficulty in distinguishing between the properties of a substance and a single atom, those students (n = 538) who were taught throught historical views of the atom understood the nature and structure of matter better than students in the control group (n = 540).

Novice Teachers and the Chemistry Classroom

Teachers need to consider several aspects of student learning when designing lessons. One such aspect is students' prior knowledge and difficulties regarding a concept (Friedrichsen, et al., 2009; Hailikari, et al., 2008). Novice teachers enter the classroom believing that students will have little knowledge or difficulties with the concepts being taught. In areas of difficulty, the teacher believes he or she needs only to replace information that is faulty (Meyer, 2004; Otero & Nathan, 2008). Another consideration is the types of representations needed to teach and learn the concept (Kolb & Kolb, 2005). Here, the teacher may incorporate students' learning styles, though the novice teacher may oversimplify, and view students as having a single learning style which does not change over time (Southerland & Gess-Newsome, 1999).

Finally, the teacher must consider how to present atomic structure. As atomic structure can be presented in the macro level (experiments), submicro level (atomic models), and symbolic level (electron configuration), the teacher needs to be aware of the impact of the representations on student learning. Asking questions such as, is the student having difficulty and reverting to memorization because the topic is abstract (Coll & Treagust, 2003; Mayer, 2011; Nakhleh & Mitchell, 1993)? Or is there confusion because the teacher's explanations move quickly between the symbolic and submicro levels (De Jong & van Driel, 1999; Van Driel, et al., 2002)? To build understanding, the teacher can engage students with various representations that provide multiple opportunities to bridge the macro level to the submicro and symbolic levels. However, this requires teacher understanding of students' prior knowledge, different learning styles, and difficulties with learning chemistry.

Novice teachers and students' prior knowledge. When planning instruction, novice teachers need to be aware of the students' prior knowledge. This includes understanding what the students' hold, how to obtain the information, and what to do with the information in order to help students learn. However, novice teachers have difficulty with capturing the information and thus incorporate various strategies to compensate for their lack of knowledge.

Novice teachers tend to focus on students' factual knowledge when eliciting prior knowledge (Friedrichsen, et al., 2009; Meyer, 2004; Otero & Nathan, 2008). In a study of four novice secondary science teachers, Friedrichsen et al. (2009) found that participants did not believe students could explain their understanding of concepts. In a study by Otero and Nathan (2008), one-third of the 61 preservice elementary science teachers viewed students' factual knowledge as correct only if they used appropriate scientific terminology. For example, preservice teachers might determine students knew nothing about matter if they did not specifically mention either that it had mass or that it took up space. As a result, they would implement the planned lesson without making any modifications because they believed students did not understand the content.

Novice teachers may have limited methods for capturing student understanding and, as a result, often fail to use prior student knowledge to plan instruction and to discuss concepts further (Abell, et al., 1998; Geddis, Onslow, Beynon, & Oesch, 1993; Meyer, 2004; Tabachnick & Zeichner, 1999). For example, Otero and Nathan (2008) found that when teachers used a KWL chart – K *what you know*, W *what you want to know*, L *what you learned* – the teacher often focused on how students had changed over the course of the lesson or unit, but did not use the chart to inform themselves of students' prior understanding. This is different from the experienced teacher, who has a variety of activities and questions to implement through classroom instruction to capture students' prior knowledge. Instead, novice teachers often capture students' prior knowledge unintentionally through classroom interactions. For instance, Meyer (2004) observed a beginning chemistry teacher answering questions about chemical bonds from students in small groups. It wasn't until the teacher had been asked the same questions several times that she stopped instruction to ask if they had learned about the concept before. Again, the teacher's focus was to identify an area in which students had no knowledge.

Most of the teachers in Otero and Nathan's (2008) study felt that students learned by being introduced to the topic in previous years. Novice teachers often describe students as having little to no knowledge prior to entering the classroom. For the new teacher, this means the teacher is responsible for providing the foundation for student understanding of the topic (Friedrichsen, et al., 2009; Halim & Meerah, 2002; Meyer, 2004).

To compensate for the lack of deep understanding of students' background knowledge, novice teachers' relied upon their own experiences in learning (Friedrichsen, et al., 2009; Meyer, 2004; Simmons et al., 1999; Veal, 2004). Friedrichsen et al. (2009) found that novice teachers based their lesson planning on the assumption that students would have similar motivation, knowledge, and attitudes towards learning and processing information to their own past experiences from when they were students. In Meyer (2004), novice teachers used examples from their own lives to elicit students' prior knowledge and assumed the students would find their examples relevant or interesting. However, these examples focused on exceptional activities (e.g., family trips, scuba diving, and museums) and not common everyday experiences that could indeed provide a bridge to student comprehension. By using their own motivations, attitudes, and unique experiences, teachers may inadvertently hinder access to students' prior knowledge – particularly when students and teachers are from different school settings and economic backgrounds.

Novice teachers and students' varied approaches to learning. Implementing various representations into classroom instruction creates an inclusive learning environment for students. However, novice teachers tend to consider student learning variations to only a limited degree (Friedrichsen, et al., 2009; Koballa, Glynn, Upson, & Coleman, 2005; Lee, et al., 2007; Loughran, et al., 2008; Luft, 2009; Southerland & Gess-Newsome, 1999). Lee et al. (2007) found that the 24 beginning science teachers in their pilot study initially did not consider variations in student learning styles. In a study of 22 preservice elementary teachers in a science methods course, Southerland and Gess-Newsome (1999) reported that teachers recognized students' learning styles but believed that learners had fixed abilities. One novice teacher participating in a study conducted by Bianchini and Cavazos (2007) blamed his preservice program for not providing the necessary tools to reach all students.

When planning instruction, teachers need to be aware that students are individuals as well as a part of a group. Loughran et al. (2008) found that when preservice science teachers were unfamiliar with the content, they resorted to delivering instruction and did not diversify instruction to reach all students. The preservice teachers were cognizant of this discrepancy and reported being dissatisfied with their instruction as a result. In Bianchini and Cavazos's (2007) study, beginning science teachers focused on struggling students rather than meeting the needs of all students in the classroom. And in the Southerland and Gess-Newsome (1999) research project, preservice teachers labeled students according to their learning styles (i.e., visual, auditory, high and low ability), and believed that to reach a particular student, multiple activities must be implemented related to that student's learning style. For example, one study participant discussed a low achieving student who was artistic and might benefit from more visual representations. These studies indicate that novice science teachers do not consider the possibility of helping students to become capable in other modes of learning, thus do not connect the various representations for deeper understanding of a topic.

An effective teacher must decide which representations are most useful to support students' learning. In doing so, the teacher must be aware of both the weaknesses and strengths of various representations to support learning, as well as the sequencing of these representations to "scaffold students' developing understanding of science concepts" (Zembal-Saul, Krajcik, & Blumenfeld, 2002, p. 444). DeMeo (2007) studied novice chemistry teachers' criteria for choosing a particular laboratory experiment on determining the empirical formula of a compound. Only allowing the teachers to research three similar experiments, DeMeo placed preservice chemistry teachers in situations that most teachers engage in as they use their own personal criteria in choosing a particular activity or laboratory experiment. The novice teachers' criteria fell into five overarching ideas: procedural concerns, conceptual values, materials, safety issues, and student motivation. Unfortunately, the least mentioned criterion was student motivation, which is considered an important component in conducting inquiry-based activities (NRC, 2000). In designing a classroom that involves the student, the teacher needs to consider students' prior knowledge and variations in learning styles, as well as students' difficulties with the concept.

Novice teachers and students' difficulties with learning chemistry. When designing lessons, many novice teachers believe students will not have any difficulty answering questions (Halim & Meerah, 2002) and learning concepts (De Jong & van Driel, 2002; Friedrichsen, et al., 2009). Those teachers who are aware of the possibility of student misconceptions report learning about it from a methods course (Meyer, 2004). However, as with prior knowledge, teachers are not likely to adapt lessons to address student misconceptions (Meyer, 2004). A teacher's lack of understanding of scientific concepts may further hinder his or her awareness of students' misconceptions. A teacher outside her or his field of study also may be unable to identify students' misconceptions. For example, in a study of three physics teachers and three biology teachers, Hashweh (1987) found that the physics teachers were unable to identify the central concept in a biology textbook, whereas biology teachers could not correct a misconception in a physics chapter. Kruse and Roehrig (2005) used the Chemistry Concepts Inventory (CCI; (Mulford & Robinson, 2002) to capture practicing chemistry teachers' (N = 33) conceptions of chemistry. There was a significant difference between the in-field and out-of-field chemistry teachers' scores on the CCI. Of special interest, the out-of-field teachers confused the terms element (involving macro and submicro components) and atom (macro component). This type of error may affect the information being presented to students.

Even when teachers are within their area of expertise, misconceptions and an incomplete integration of the concepts under study may occur because of their lack of full understanding of the specific concepts. Haidar’s (1997) study of 173 prospective chemistry teachers from Yemen found their understanding of chemistry concepts ranged from sound knowledge understanding to partial understanding with misconceptions to no understanding. In a study by Rollnick, Bennett, Rhemtula, Dharswey, and Ndlovu (2008), two South African chemistry teachers with 5-10 years experience did not have a developed understanding of the mole. The teachers focused solely upon the algorithmic component of the concept versus integrating the symbolic with the conceptual aspects of the mole (the submicro component). In another study of two preservice science teachers by Halim and Meerah (2002), the teachers were unable to identify student misconceptions due to their own misconceptions about the concepts.

According to Johnstone (2000, p. 9), “chemistry is regarded as a difficult subject for students. The difficulties may lie in human learning as well as in the intrinsic nature of the subject.” When designing the chemistry classroom, the teacher must be aware of the impact of classroom practices on learners (Friedrichsen, et al., 2009; Loughran, et al., 2008; Van Driel & de Jong, 1999). This involves chemistry teachers’ ability to translate chemical knowledge through various representations of chemical phenomena using macro, submicro, and symbolic representations (Ardac & Akaygun, 2004; De Jong & van Driel, 1999; Hinton & Nakhleh, 1999; Treagust, et al., 2003).

Part of the problem students have with learning chemistry is that teachers describe concepts using various representational scales and students have difficulty adapting to teachers' movement between the triplet components, often resulting in their confusion. In Van Driel et al.'s (2002) study of 12 preservice chemistry teachers, terminology used by the teachers to explain chemistry phenomena hindered student understanding of particle theory. The knowledge needed for this topic includes both macro and submicro views. While the novice teachers had strong understanding of the content, they had difficulty translating that knowledge into classroom instruction because they were unaware of the macro-submicro structure of chemistry. Teachers caused unnecessary confusion for students when their classroom explanations jumped back and forth between macro and submicro views (Johnstone, 1993; Van Driel, et al., 2002). This may result in students attributing macro properties to atoms and molecules (e.g., electron shells and eggs; (Harrison & Treagust, 1996; Taber, 2001b, 2005). Though this example describes movement between the macro and submicro, the same confusion could apply if a symbolic component was part of the lesson discussion.

Research has shown that teachers do not make the necessary adjustment to classroom instruction to integrate the three representations (Gabel, 1999; Rollnick, et al., 2008). For some chemistry teachers, it is because the teachers themselves have difficulties with a concept. In the study by Rollnick et al. (2008), participating teachers were unable to discuss the concept of a mole in terms of macro-submicro levels and instead relied upon chemical calculations. In another study by Gabel (1999), teachers failed to make the necessary connections between the laboratory activities and the submicro and symbolic because the specific activities did not clearly make the necessary connections for the student. It is the teacher's responsibility to clarify the connections between macro, submicro, and symbolic elements.

Summary of novice teachers' PCK. Current research suggests that novice teachers have undeveloped PCK when first entering the classroom (e.g., Friedrichsen, et al., 2009; Lee, et al., 2007; Van Driel & de Jong, 1999). Novice science teachers must identify and address students' prior knowledge and misconceptions (e.g., Friedrichsen, et al., 2009; Griffiths & Preston, 1992; Hailikari, et al., 2008; Halim & Meerah, 2002) and recognize the nature of the concept (e.g., Coll & Treagust, 2002, 2003; Reid & Yang, 2002; Sanger, 2005). Novice chemistry teachers, specifically, should be aware of the triplet relationship (e.g., Bennett, 2004; De Jong & van Driel, 2002; Treagust, et al., 2003) and students' understanding of the atomic structure (e.g., Coll & Treagust, 2002, 2003; Griffiths & Preston, 1992; Harrison & Treagust, 1996; Park & Light, 2009). To manage these constraints, this dissertation investigation will concentrate on chemistry content specialists teaching primarily secondary chemistry courses within their first three years in the classroom.

Chapter 3

METHODS

The purpose of this study was to examine beginning chemistry teachers reported and actual classroom uses of the triplet relationship and the extent to which teachers' knowledge of student learning impacted their representations. Specifically, it was reasoned that beginning chemistry teachers' would focus primarily on the abstract components (i.e. submicro and symbolic representations) of the triplet relationship across the three years. Furthermore, it was believed that the teachers would consider the student learning component of PCK as they gained experience with the students through classroom instruction. Therefore, this study examined beginning chemistry teachers' use of representations in terms of the teachers' depiction of the chemistry content through the triplet relationship and modifications as a result of considering students' understanding.

The Four Elements for Research

In laying the foundation for research into beginning chemistry teachers' practices, Crotty (1998) identified four basic elements of research: epistemology, theoretical perspective, methodology, and methods (see Figure 7). The purpose of the four elements is that they "help ensure the soundness of our research and make its outcomes convincing" (p. 6). According to Crotty, epistemology is the theory of knowledge in which governs the research. The epistemology provides the foundation for the research in which the theoretical perspective is built. The methodology is then selected which shapes the use of a particular method and links them to the desired outcomes. Each element of research provides the basis for the next and is arranged hierarchically so as to be contained within the epistemology. This section will describe each element of research in terms of this research study.

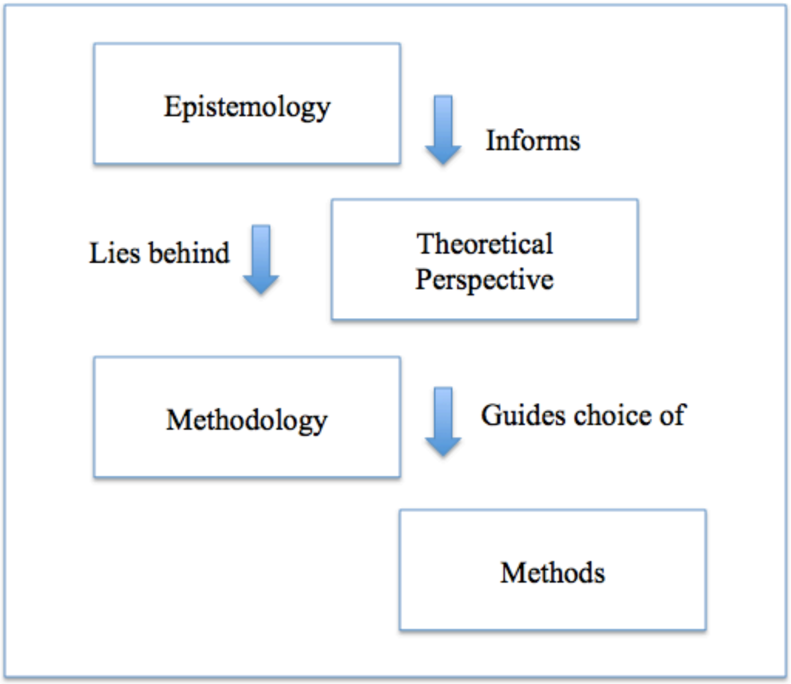


Figure 7. Crotty's (1998) conceptualization of the research design process. *Note.* Modified from *The Foundations of Social Research: Meaning and Perspective in The Research Process* by M. Crotty, 1998, p. 4.

Epistemology, Theoretical Perspective, and Methodology

This study is framed under the epistemology of constructionism and the theoretical perspective of interpretivisim. With the constructionist perspective, meaning is socially constructed with both individuals and groups participating in the creation of a perceived reality. Constructionism is the view that "all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context" (Crotty, 1998, p. 42). In addition, this reality is ever changing as a result of social interaction as humans engage with the world being interpreted. However, the social patterns are agreed upon through consensus though social views may be broad and diverse (Crotty, 1998). Constructionism underlies the way of understanding and explaining the reality of the observed world that is captured.

Constructionism is embodied within the theoretical perspective interpretivisim. An interpretivist approach provides insight into the social world in which meanings are constructed by the individual as they interact with the world they are interpreting (Crotty, 1998). In addition, there are multiple truths in which to understand the social world since each individual or group holds a particular truth based on their viewpoint. An interpretivist perspective thus does not try to determine which truth is the best answer instead one must focus upon providing an accurate and thorough representation of each revealed truth (Crotty, 1998). Using the interpretivist perspective within a study provides insight into the social world, which is constructed, based on each participant's reality.

The use of the interpretivist tradition in this research study made sense specifically because PCK is a complex construct that is based upon a unique set of knowledge bases and experiences (Lee, et al., 2007; Magnusson, et al., 1999; Van Driel, et al., 2002). Meaning making is focused upon teacher knowledge change as explained through the enactment of classroom instruction (Clarke & Hollingsworth, 2002). In terms of the interpretivist perspective, the PCK conceptual framework captures the change in the individual's knowledge through their interactions with the social world via experiences in various school settings (e.g. K-12 and preservice programs). These experiences are critical in the transformation of subject matter knowledge into the knowledge for teaching that engages in practices that build student understanding of the content.

The theoretical perspective needs to be appropriate for the methodology and consistent with the epistemology. This research study used a mixed-methods design as both qualitative and quantitative data were required to answer the research questions (Creswell & Plano Clark, 2007; Teddlie & Tashakkori, 2009). Using the criteria set by Teddlie and Tashakkori (2009), it was determined that the two-phase Embedded Experimental design by Creswell and Plano Clark (2007) was the best mixed-methods design for this research study (see Figure 8). This research design involved Phase I in which the primary data approach, whether quantitative or qualitative, is supported by a secondary data approach (Creswell & Plano Clark, 2007). Phase II, the experimental phase, involved the collection of qualitative data during and after the embedded phase to explain the process of change in participants. This methodology was appropriate as it involved the collection, analysis, and mixing of qualitative and quantitative approaches at various phases of the research process in light of the philosophical assumptions to the drawing of conclusions in a single study (Creswell, 2009; Creswell & Plano Clark, 2007; Greene, 2007; Teddlie & Tashakkori, 2009).

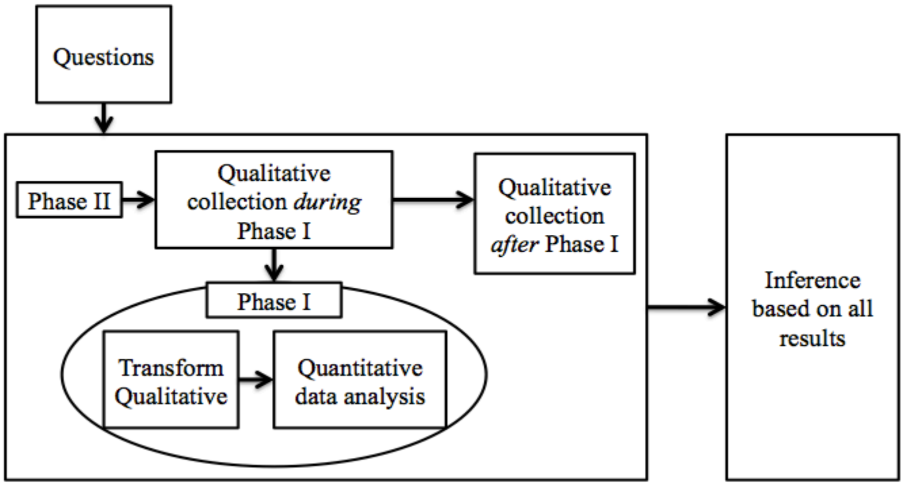


Figure 8. Embedded experimental mixed-methods design. *Note.* Phase I indicates the embedded component. Modified from *Designing and Conducting Mixed Methods Research* by J.W. Creswell & V.L. Plano Clark (2007), p. 68.

This study incorporated the methodology Embedded Experimental design by collecting qualitative data transformed into quantitative results and using qualitative to examine participant perspectives during the first three years in the classroom. The quantitative method, Phase I, was used to study the trends in teachers' implementation of the triplet relationship over time. It also allowed for the exploration of the integration of the triplet components for captured artifacts. During Phase II, the qualitative methods were utilized in order to explore the impact on representations as a result of teachers' knowledge of students' learning. Multiple approaches were implemented because one single approach was insufficient for the study's multiple questions (Creswell & Plano Clark, 2007). This model was beneficial to the development of the study, as the research questions guiding this study required different forms of data. Data from both sources were merged in order to understand the change in beginning chemistry teachers' implementation of the classroom representations.

Methods

Researchers collected data in a mixed-methods study to address the research questions. The data collection procedure needed to fit the type of mixed-methods design as in the case for this embedded experimental study (Creswell & Plano Clark, 2007). The sequential design required using procedures for quantitative data that was collected and analyzed prior to the collection and analysis of the qualitative data. In this type of design, the qualitative data collection built upon the quantitative data collection. The background, participants, Institutional Review Board (IRB), and timeline are first outlined then the procedure that follows the embedded experimental methodology is described.

Background. This dissertation study resided within the NSF grant 0550847, *Exploring the Development of Beginning Secondary Science Teachers in Various Induction Programs* (Luft, PI), which investigated the impact of different induction programs upon practices, beliefs, and knowledge of beginning secondary science teachers. The induction groups involved were categorized as: general, intern, science-specific, and electronic mentoring. General group teachers received support from their school or district and focused on general topics like general teaching strategies and administrative responsibilities. Intern teachers received general support from their schools but did not have a formal teaching certificate and were in pursuit of certification while teaching. Teachers in the science-specific induction program received monthly face-to-face mentoring by science teacher educators or science teachers at a university in the Midwest or Southwest. Teachers in the electronic mentoring program also received science-specific support, but did so by participating in an online community and meeting face-to-face once a year. The induction programs lasted for the first two years for all teachers. A complete discussion of the research project can be found in Luft (2009).

The research project followed 138 participants from five states around the Midwest and Southwest regions of the United States. After three years, 82 teachers were still involved in the study. Over the course of the study, teachers left for reasons that included: taking a teaching position outside of the science field or out of the secondary level (grades 6-12).

Participants. Implementing a purposeful sample selection process involved selecting participants from the larger population who align with the purpose of the study: the implementation of the chemistry triplet by beginning chemistry teachers. Selection for the dissertations study used the following criteria to determine that the participants: (1) held certification to teach chemistry and (2) taught primarily chemistry. Within Phase I, there were eight teachers who met the criteria. All of the teachers in this study taught primarily chemistry to 9th-12th grade students during their first three years.

The eight teachers were all beginning chemistry teachers certified to teach chemistry within the Southwest and Midwest regions of the United States. All teachers were certified to teach prior to entering the classroom and were employed full-time at a public or private school during the remainder of the three years of data collection (see Table 2). Of the participants, four were male and four female; seven held undergraduate degrees in either chemistry or chemical engineering; all eight taught at the high school level (grades 9-12) working in either a suburban or urban community. Of the beginning chemistry teachers, six were from the Midwest and two from the Southwest. In this study, the percentage of students eligible for free or reduced lunch (FRL) was used to represent the school socioeconomic status. Using this criteria, seven teachers worked in schools where 0-29% of all students were eligible for FRL, and one teacher worked within a school where 30-59% of the student population were eligible for FRL.

Table 2

Background Demographics of The Study Participants

Teacher *	Gender/ Region	Academic Degree(s)	School Location/Level/ Type/SES
Chris[Δ]	M/Midwest	BS Chemistry;	Public/Secondary/ Suburban/High
Dale	F/Southwest	BS Chemistry; MBA & MEd	Public/Secondary/ Urban/High
Edith[Ω]	F/Southwest	BA Nutritional Science Minor Chemistry; MEd	Public/Secondary/ Urban/High
Pam[Δ]	F/Midwest	BS Chemistry & Chemical Engineering; MEd	Public/Secondary/ Suburban/High
Keith[Δ]	M/Midwest	BS Chemical Engineering, Minor Chemistry, MEd	Public/Secondary/ Urban/Middle
Stephanie	F/Midwest	BS Chemistry;	Public/Secondary/ Suburban/High
Jonah	M/ Midwest	BS Chemical Engineering, Minor Chemistry; MEd	Public/Secondary/ Suburban/High
Patrick[Δ]	M/Caucasian	BS Chemistry, Minor History; MEd	Private[a]/Other[b]/ Suburban/High

Note. BS: Bachelor in Science, MBA: Master in Business Administration, MEd: Master in Education, and SES: socio-economic status.

*All names are pseudonyms per IRB requirements.

[Δ] Participants in Phase II ATSI.

[Ω] Participated in Pilot study.

[a] This private school is a Catholic, all-boys, college-preparatory, military day school.

[b] The school level Other refers to a school with grades 7-12.

As this was an embedded experimental mixed-methods study, Phase II involved the use of Phase I participants. Using criterion 2 from above, only participants who were currently teaching chemistry were contacted to participate in the ATSI. Teachers were contacted via email, Facebook, and phone to request participation in the study. Each teacher was offered a stipend to participate in the study. This resulted in five of the eight chemistry teachers meeting this criterion but only four responded to a request to participate in the follow-up interview. Those that participated in the ATSI are marked in Table 3.

All four teachers that participated in Phase II of this study were employed full time as a chemistry teacher throughout the first five years in the classroom. Of the ATSI participants, one was female and three were male. The four teachers pursued similar degrees and taught in the same state in the Midwest section of the United States (see Table 3). Each of the beginning chemistry teachers entered the teaching field after beginning their college career pursuing a chemistry or chemical engineering degree. Prior to going to college, Patrick had decided he would pursue a career as a chemistry teacher. However, he did not follow that plan until after he finished his degree in chemistry (Patrick ATSI, May, 2011). For Chris (ATSI, July, 2011), he changed directions during his third year in the chemical engineering program and pursued a chemistry degree. Both Pam (ATSI, May, 2011) and Keith (ATSI, June, 2011) graduated with chemical engineering degrees and made a career move after each had worked a year in the field of chemical engineering. All four teachers entered the same program to earn a postbaccalaureate certification at a university in the Midwest in order to teach chemistry courses.

The school settings in which these teachers taught varied from private school (Patrick) to public schools in urban (Keith) and suburban (Pam and Chris) areas. Pam, Patrick, and Keith have remained at the same schools in which they began their first year teaching. However, Chris changed schools at the beginning of his third year due to his spouse finding employment in another section of the state with the similar demographics. He has since moved again to another school for the same reason. At the schools, the teachers predominately taught chemistry to 10th – 12th grade students.

IRB. Prior to data collection, the research proposal was IRB approved at Arizona State University and the University of Minnesota to conduct classroom observations and interviews that focused solely upon the teachers' practices (see Appendix B for IRB approval). Data pertaining to students was collected including: demographics (e.g. males and females), level of participation, and the classroom instruction (e.g., cooperative group, lecture, and directed inquiry). Field notes were approved and these depicted what students were doing during the lesson. IRB allows for further data collection with the original participants. As a result, this dissertation study fell within these guidelines and it was possible to conduct follow-up interviews with various participants.

Data Collection

For this study, data collection occurred over a period of five years. The data consisted of participants' responses to a variety of semi-structured interviews including the PCK interview, monthly interviews (MI), and the ATSI. Data also included classroom observations (OBS) collected during the first three years. Finally, a research-generated matrix was created from the PCK interviews, MI, and OBS that specifically captured teachers' conceptualization and enactment of atomic structure.

The timeline for the research study, including the data collection can be found in Table 4. Specifically, the first PCK interview was conducted before the teachers entered the classroom (Y0). Throughout the subsequent months, eight MI and bi-monthly OBS were collected at regular intervals and repeated in each of the following two years for a total of three years. At the end of each school year, the PCK interview was repeated for the first year (Y1), second year (Y2), and third year (Y3). Finally, the ATSI, the unique contribution to this research study, was administered to four participants at the end of the fifth year. This resulted in a total of 4 PCK interviews, 24 MI, 12 OBS, and 1 ATSI with a total of 41 data points possible per teacher. The data collection schedule allowed for a longitudinal study of teachers through the first three years in the classroom. Table 3 provides an overview of the data collection schedule.

Table 3

Data Collection Schedule

Interview Name	Collected	Year	Data Source
Y0	Pre year 1	Summer 2005	PCK
	During year 1	September-May 2005-2006	MI, OBS
Y1	Post year 1	Summer 2006	PCK
	During year 2	September-May 2006-2007	MI, OBS
Y2	Post year 2	Summer 2007	PCK
	During year 3	September-May 2007-2008	MI, OBS
Y3	Post year 3	Summer 2008	PCK
	Post year 5	April-July 2011	ATSI

The PCK protocol interview. The first form of data was the participants' responses to the PCK interview developed by Lee et al. (2007). Appendix C includes the key PCK questions along with follow-up questions to the PCK interview. The interviews occurred either in person or over the telephone and were audio taped for data collection purposes. During the PCK interview, the researcher would read the semi-structured questions and simultaneously collected field notes based upon participant responses. When needed, the researcher would ask follow-up questions to gain understanding of provided responses. For the Y0 annual interview, teachers were asked to describe any lesson or unit. In subsequent annual interviews, select teachers were asked to provide information about a particular topic in chemistry: Y1 balanced equations (*n* = 7); and Y2 and Y3 atomic structure (Y2 [*n* = 5] and Y3 [*n* = 2]).

The PCK interview was not used in the manner that it was intended. Instead, the PCK interview transcripts were read line by line to identify teachers' conceptualization of the triplet relationship using the Triplet Rubric. In addition, the interview was used to identify components of the knowledge of student learning that impacted atomic structure representations. Further discussion of the analysis is provided in the section Data Transformation of this chapter.

Classroom practices: Monthly Interviews. The format for collecting the teachers' instructional practices was based upon Lawrenz, Huffman, Appeldoorn, and Sun (2002). The MI occurred once a month during a specified two-week time frame. The interviews with teachers focused upon teachers' classroom practices, classroom organization, materials/technology used, and forms of assessment for one week of lessons. The interviews were conducted eight times a year for a total of twenty-four interviews for each teacher over three years. In cases where unforeseen circumstances interfered with the collection of a monthly interview, a makeup interview was conducted during the month of May. Each semi-structured interview was approximately 20 minutes in length. While the teacher answered open-ended questions, researchers captured teacher responses through both audio recordings and field notes (see Appendix D for the Monthly Interview protocol). Like the PCK interview, the MI was not used as intended but instead provided information about the teachers' conceptualized representations.

Classroom practices: Observations. The third form of data collected involved the observation of the teachers that occurred four times per school year. The OBS was collected during a two-week period that coincided with the MI collection in the months of October, December, February, and April. Prior to visiting the classroom, teachers were contacted to determine if a class was being conducted and the nature of the lesson. Observations were rescheduled during the same time frame to avoid observing class during shortened days or days when the primary activity was either a test or watching a videotape.

During each OBS, research assistants visited the participants' classroom for one class hour. The observers wrote down salient activities performed by both the teacher and the students during a five-minute interval. Written accounts of the observation are considered field notes and analogous to interview transcripts (Merriam, 1998). Field notes were also taken to describe the classroom environment in which the students worked (e.g., desk arrangement, posters, number of computers) and the classroom interactions. The OBS protocol was based upon components of *The Collaboratives for Excellence in Teacher Preparation core evaluation classroom observation protocol* (CETP-COP) for use during classroom observations in order to document the practices of teachers (Lawrenz, Hufman, & Appeldoorn, 2002). A sample portion of the observation protocol can be found in Appendix E.

The five-minute intervals were used to determine how much time each teacher spent on a particular representation by triplet component. How the triplet components were determined is discussed later in the chapter. Time spent on each component was represented by a time factor that was developed to depict how much time each teacher spent in an hour on a particular triplet component. To take into account the differing lengths of the class hour, using a calculated time factor for each observation using the formula (class hour length/60 minutes). For example: for a 50-minute course (50 minutes/60 minutes), the time factor would be calculated as 0.83. If the participant spent 10 minutes on the macro component, the resulting time usage per hour would be 8.3 minutes.

As with the PCK and MI, the OBS was not used as intended. Instead, it provided information on how the teachers enacted the triplet representations and the amount of time spent on each particular component of the triplet.

Classroom practices: Artifacts. Whenever possible during MI and OBS, supplementary materials associated with the lesson(s) were collected from beginning teachers. Such classroom artifacts as worksheets, reading material, and PowerPoint presentations associated with the lesson were collected during the observation. These artifacts served as support for the depiction of the components of the triplet utilized in classroom instruction by capturing the full intent of a lesson.

Research-generated matrix. The researcher prepared a researcher-generated matrix from the OBS, MI, and PCK interview to be given to each participant of the ATSI interview. The matrix captured the individual teacher's representations of atomic structure across the first three years in the classroom. The matrix placed each triplet component in columns and was separated by data collection date and source. This was done in order to provide ATSI teachers with the representations discussed and enacted during the first three years. Teachers were provided with the matrix two to three days prior to the ATSI via email; and were encouraged to review the matrix and recall the events documented in the matrix. The provision of the research-generated matrix for teachers allowed them to observe and reflect on their own changes in classroom practices over time. Appendices G - J provides the original research-generated matrix of each participant of the ATSI.

ATSI. The final data source, the ATSI was developed to explain how teachers' knowledge of student learning impacted their representations of atomic structure (see Appendix A for the ATSI protocol). There were two reasons why atomic structure was chosen for this research study. First, atomic structure was chosen because it has been found to be a threshold topic for chemistry (Park & Light, 2009). This means to understand many chemistry topics one must have a strong understanding of atomic structure. Second, the PCK interviews in Y2 and Y3 focused upon teachers' conceptualization of teaching atomic structure including considerations of students' prior knowledge, varied approaches to learning, and difficulties with the topic.

The ATSI questions were developed to elicit teachers' reasons for implementing as well as modifying particular atomic structure representations over time. The interview consisted of questions on the background of the participant, why the teacher chose the specific representations for each of the three years using the research-generated matrix, and probed for the impact teachers' knowledge of student learning on their decisions for the particular representations. The ATSI question "Why did you choose these activities during the first year? The second year? The third year?" was utilized to determine if the teachers' considered the student learning component of PCK. If the teacher did not identify students’ prior knowledge, varied approaches to learning, or student difficulties, follow up questions were implemented to garner information about the impact of this knowledge component on their chosen representations (Merriam, 1998).

The interview protocol was administered after the teachers’ fifth year teaching chemistry in the secondary classroom. Each one-hour interview was conducted by telephone and audiotaped as well as field notes were collected. The use of a semi-structured interview allowed for the researcher to respond to the information presented, any emerging ideas, and any new information on the topic (Merriam, 1998). Interviews continued until the teachers no longer provided original insights into their practices. The participants were given the opportunity to provide any additional information regarding their practices that was not discussed throughout the ATSI interview. Finally, the teachers were asked if they would like to receive information gathered from their practices as a result of the ATSI. This information was emailed to the individual participant and each was encouraged to respond to the information. The ATSI interviews were each transcribed from the audiotape for the use of the qualitative analysis.

Reliability establishment for the ATSI. Reliability refers to the extent to which research findings can be replicated (Merriam, 1998). A pilot study is a preliminary trial of research that is essential to test an instrument, program, or experiment. The use of a pilot study can reveal deficiencies in the design and procedures. To test the pilot study, the ATSI was administered to two beginning chemistry teachers who were similar to the teachers in the dissertation studies population (Corbin & Strauss, 2008; Merriam, 1998; Miles & Huberman, 1994). Specifically, the pilot study was utilized to check for appropriateness of the instrument and improve data collection methods.

The pilot of the ATSI was analyzed in order to determine that appropriate inferences could be made using the instrument. Analysis of the two teachers' responses to the ATSI, it was found that the teachers' responses did focused on why each individual teacher implemented the particular representations. In addition, with the use of follow up questions the impact of the teachers' knowledge of student learning on representations could be determined.

To improve data collection methods, the participants of the pilot study were given an opportunity to provide feedback regarding necessary revisions needed for the final instrument. However, neither participant offered suggestions for modification, instead each felt the questions were fair and understandable. As there were no further questions to be added, the ATSI was administered to the four participants of this dissertation study.

Phases I and II

Data analysis is a process of making sense of data. As this was a sequential embedded experimental mixed-methods design, qualitative and quantitative data analysis were used to explain teachers' representations with regards to the triplet relationship and implementation as a result of their knowledge of student learning. The design analysis was conducted in two main phases (Creswell & Plano Clark, 2007): Phase I included the transformation of qualitative data into quantitative data as well as the analysis of the quantitative data; and Phase II involved the analysis of the qualitative data (see Figure 9).

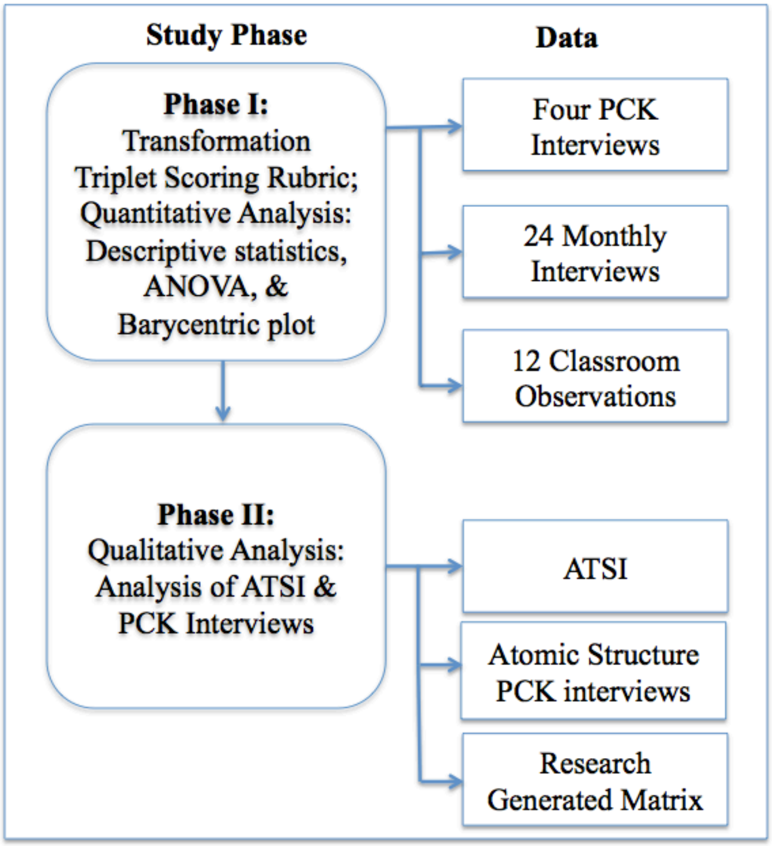


Figure 9. Phase diagram of embedded experimental mixed-methods design. *Note.* Modified from *Designing and Conducting Mixed Methods Research* by J.W. Creswell & V.L. Plano Clark (2007), p. 126.

Phase I – Quantitative Data Analysis

Within this phase, specific qualitative data were collected using the PCK interview protocol, MI, OBS, and classroom artifacts which were then transformed to quantitative data.

Data transformation. For the quantitative portion of this study, responses for the PCK and MI protocol, the OBS, and artifacts were transformed using the Triplet Scoring Rubric (see Appendix F). Quantification of the data involved marking occurrences per activity by underlining the specific representations that aligned with the Triplet Scoring Rubric. For example, Edith was asked to discuss balancing equations in the Y0 PCK interview. There were several occurrences in which she talks about both symbolic and submicro, but Edith is referring to a single activity so the activity was scored as consisting of one symbolic representation and one submicro representation. The following is an example from Edith’s interview, with the scoring explanation embedded within the transcript.

IN: Just describe how you would teach the topic of balancing equations. Are there places in the concept map that you can point to where you think that fits in?

R: We could start teaching how these things go together and learning how to write the equation [submicro and symbolic: mentions an explanation for what goes into a balancing a chemical equation]. Then after you write it, you have to balance it [Symbolic only as this does not specify why balancing chemical equations is important for chemistry]. Balancing equations—we struggled with that too. But once they got it, they were very good at it. The most confusing thing for them was, first of all, learning how to make the molecules [Submicro as this references an explanation for how molecules are produced], like here’s the oxidation numbers [Symbolic as it represents a number]. You have to make the balanced equation neutral [Submicro as an explanation for why balancing equations is

> important]. They didn't quite get that crisscross. <u>You can put your 2 here and a 3 here, it's going to be a 2 here and a 3 here</u> [Symbolic for the numbers, does not reference what is meant]. <u>And what do these numbers mean versus what is a superscript versus a subscript</u> [Submicro as it explains what the coefficients and oxidation numbers represent in balancing a chemical equation].

Not quantified were lessons that: (1) introduced the scientific method, metric system, dimensional analysis, or significant figures as these do not represent topics limited to the field of chemistry; (2) any lesson that did not involve a chemistry concept; and (3) those involved in the review of or implementation of classroom assessments.

Transformed OBS data were coded not only for individual occurrences but also as to the actual time dedicated to each activity. With the use of the OBS, time can be determined from the five-minute coding that is included in each document. Some components were captured, but may represent various increments of the five minutes. For example, Jonah's students worked on a project that involved both the symbolic and submicro components. Jonah's Y2 OBS included this description from the researcher's field notes: "They are organizing element cards based on various characteristics (more than one) that they will describe (thinking in terms of rows and columns)". The time for this activity was 20 minutes with 10 minutes coded submicro and 10 minutes coded symbolic. Actual time using either component was estimated because the original data collection was not intended for this use. The time for each component was then calculated using the time factor that was discussed in the previous section.

Validation of the Triplet Scoring Rubric. To address validity and reliability of the Triplet Scoring Rubric, two methods were utilized. First to establish validity, Creswell (2009) suggests including sample items in the discussion of the instrument. Sample coding was included in the discussion of the instrument as mentioned in the above section with researcher notes embedded within the transcript of Edith's PCK interview. Second, the reliability was established by calculating the inter-rater reliability of the instrument between the author of this dissertation and two research assistants. Each research assistant was trained to use the instrument by scoring various MI, OBS, and PCK during a planning meeting (Maxwell & Delaney, 1990). Once scorers consistently provided a consensus of 90% amongst the group, researchers were assigned data from different participants within the dissertation study. The inter–rater reliability between the author and the research assistants was calculated to be 88% agreement.

Quantitative data analysis. The transformed data were analyzed quantitatively using SPSS Version 19 and a barycentric coordinate plot. Descriptive statistics, means and standard deviations, were used to report the usage of the triplet representations by data source (i.e., OBS, MI, and PCK), specific topics (e.g., atomic structure), participant, and time spent on specific topics by triplet component over the three years.

The scores from the Triplet Scoring Rubric were also analyzed using a one-way repeated-measures analysis of variance (ANOVA). The use of the ANOVAs were an appropriate analysis for longitudinal studies (Green & Salkind, 2008;

Maxwell & Delaney, 2004). The frequency counts for each triplet component were analyzed using repeated-measures ANOVA based upon two of three variables (i.e., year, data source, or participant). For example, the first analysis was based upon teachers' use of the triplet components by year and data source (triplet components * year * data source). The one-way ANOVA method was employed to examine the differences between the independent variables and the triplet components.

In hypothesis testing, the significance level is the criterion used for rejecting the null hypothesis (Maxwell & Delaney, 2004). The null hypothesis for this study was that teachers would use the triplet relationship equally regardless of the year, data source, or participant. The calculated probability was compared to the results of the frequency counts of the Triplet Scoring Rubric using the significance level of 0.05 ($p = 0.05$). At this level, there is 95% confidence that the results of the analyses are a reflection of the reality. If the probability is found to be equal or less than the significant level, then the null hypothesis can be rejected and the results are said to be statistically significant; otherwise the null hypothesis is true and the results are not statistically significant.

The frequency count of the triplet components for each classroom artifact was used to plot a barycentric coordinate plot with Excel. Within the barycentric coordinate plot, the three variables sum to a constant and the ratios of each component of the triplet were then plotted within the equilateral triangle depicting how the teacher integrated the triplet components into classroom instruction. To read a barycentric coordinate plot, Figure 10 depicts a basic x-, y-, and z-axes with representative coordinates.

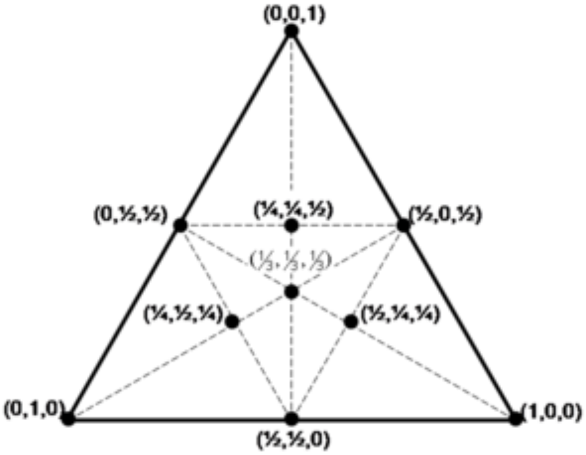


Figure 10. An example of a barycentric coordinate plot. *Note.* (0, 0, 1) would read 100% in the z-axis. (1/3, 1/3, 1/3) would read the center of the plot or 1/3 in the x-, y-, and z-axes. (1/2, 0, 1/2) would represent ½ in the x-axis and z-axis with 0 plotted in the y-axis.

Phase II – Qualitative Data Analysis

The qualitative portion of this study consisted of two parts. First, the corpus of the data for both the ATSI and PCK interviews on atomic structure were read collectively. Only the PCK interviews from Y2 and Y3 were read as they captured the teachers' knowledge of student learning with regards to the teaching of atomic structure. After reading all of the responses, the data was coded based upon the researchers conceptual framework and research questions (Miles & Huberman, 1994). In the case of this study, both the conceptual framework and question were based upon the component of PCK – knowledge of students' understandings – to understand changes in beginning chemistry teachers' practices. As a result the codes were students' prior knowledge, variations in approaches to learning, and difficulty with the content. One additional theme emerged from the reading transcribed ATSI and PCK interviews, structure of the chemistry content. From the categories, data was analyzed using the NVivo 9 qualitative research tool allowed for the organization of multiple codes across various documents.

The second part involved in the qualitative analysis involved the development of the case study. Case studies refer to the collection and presentation of detailed information about an individual or small group. This qualitative analysis tool draws conclusions about the specific group in specific contexts (Merriam, 1998). The four teachers that participated in the ATSI were selected due to having taught chemistry for the previous five years and having a PCK interview focused upon a lesson or unit for atomic structure. This study explored four beginning chemistry teachers' knowledge of student learning and how that knowledge impacted the classroom representations. The cases were bound by the particular year (Year 1, Year 2, and Year 3). This was done to capture changes over the first three years collectively. Following the suggestions by Yin (2009), the codes utilized by year are presented as a traditional narrative of multiple-cases within a single chapter (Chapter 4).

After the individual cases were constructed for each of the three years, cross-case analysis was conducted to discover any trends that might materialize from comparing different cases (Miles & Huberman, 1994). A time-ordered display was appropriate for this particular study as they are helpful in the organization of events during a period of time, "especially those events that are indicators of some underlying process or flow" (Miles & Huberman, 1994, p.

200). As this dissertation study was longitudinal, time-ordered displays were beneficial to study beginning chemistry teachers' choices for particular representations depicting the triplet components (see Appendix K for the Time-Ordered Matrix).

Data Integration

The integration of the data is done in order to support or refute the results of the datasets as part of an embedded experimental design. Within this phase, results take into account "convergent, inconsistent, and contradictory evidence" (Mathison, 1988, p. 13). The integration of findings was done through Creswell and Plano-Clark's (2011) strategy that allowed the use of a theoretical framework (i.e., PCK conceptual framework) to "bind together the data sets (p. 66)." For this project, data were analyzed via different methods to capture how beginning chemistry teachers represent chemistry and the decisions they make in implementing the specific representations. This involved collecting and analyzing both quantitative and qualitative data at various stages for beginning chemistry teachers. Reported practice interviews were collected at times of classroom observations. Additionally, PCK interviews collected during Year 2 and Year 3 can be used to support or refute the results of the ATSI interview. Quantitative and qualitative data were analyzed in order to reveal findings for the conclusions of the dissertation study.

Validity and Reliability

In any research design there are potential threats to the validity of the conclusions. There are four criteria for establishing trustworthiness: credibility, transferability, dependability, and confirmability (Corbin & Strauss, 2008; Creswell & Plano Clark, 2007; Merriam, 1998; Miles & Huberman, 1994). Credibility is an evaluation of whether or not the research findings provide a reasonable interpretation of the data (Lincoln & Guba, 1985). Transferability is the degree in which the findings can apply to other contexts beyond the study. Dependability is the degree to which enable other researchers to develop a similar study and results with regards to the use of similar data collection, data analysis, and theory. Finally, confirmability is a measure to how well the studies findings are supported by the data collection. In this dissertation study, trustworthiness was enhanced through the use of the strategies below.

Credibility can be enhanced by prolonged engagement in the natural setting and examination of previous research findings. This particular study used prolonged engagement in the teachers classrooms and discussions as the majority of the teachers' participated in the PERSIST study for four or more years. Also implemented was a comparison of the results of this study to that of previous research findings. Together this helps support credibility of the studies findings.

With respect to transferability, it is provided by rich descriptions of the context, participants, and the actions of the participants. In this study the participants were rather homogenous; located in either the Midwest or Southwest region, taught primarily chemistry at the secondary level, and the entered the classroom after earning either a Bachelor's degree or a minor in chemistry. Further descriptions of the participants' actions are discussed in Chapter 4. However, it is up to the audience to determine whether the results of the study are transferable to other situations (Merriam, 1998; Shenton, 2004).

A third criterion to establish reliability and validity is dependability. Within this study, the processes utilized were reported in detail with respect to who, what, how, and when the data collection and analyses took place (Miles & Huberman, 1994; Shenton, 2004). Additionally, it included accounts of how and why the research process changed as time progressed. This was addressed with respect to the particular data collection methods (i.e., PCK interview, MI, OBS). Dependability was done to ensure the replication of the study to gain the same or similar results.

Finally, confirmability refers to the degree, which others could confirm the results. This is established by describing procedures for checking and rechecking as well as reporting negative instances within the data throughout the study (Miles & Huberman, 1994). In terms of this study, methods of rechecking were discussed using (1) outside research assistants to confirm the reliability of the Triplet Scoring Rubric; and (2) reading the transcripts multiple times in order to confirm results. Negative incidents that contradict prior observations are reported within the presentation and analysis of data in Chapter 4 and Chapter 5. Together these four criteria help establish the validity and reliability of the research study.

Chapter 4

RESULTS

This chapter presents the quantitative and the qualitative results of the data analysis of the beginning chemistry teachers included in this study. As this is an embedded explanatory mixed-methods design, the analysis will be presented in the same order as it was collected and analyzed. Phase I involved the quantitative data analyses of the transformed data and will be presented by overall use: of the triplet components, by participant, by topic, and integration of the triplet components. Phase II involved the qualitative results through the analyses of the corresponding data matrix. The qualitative analysis will be presented by year (Y1, Y2, and Y3). Additionally, the final section of the chapter consists of cross-case comparisons by the teachers, based on the assumptions directly related to the original questions.

Phase I - Quantitative Findings

In this phase, the quantitative analysis will be presented as overall conceptualization and enactment of the triplet components and the use of the triplet components by classroom practices.

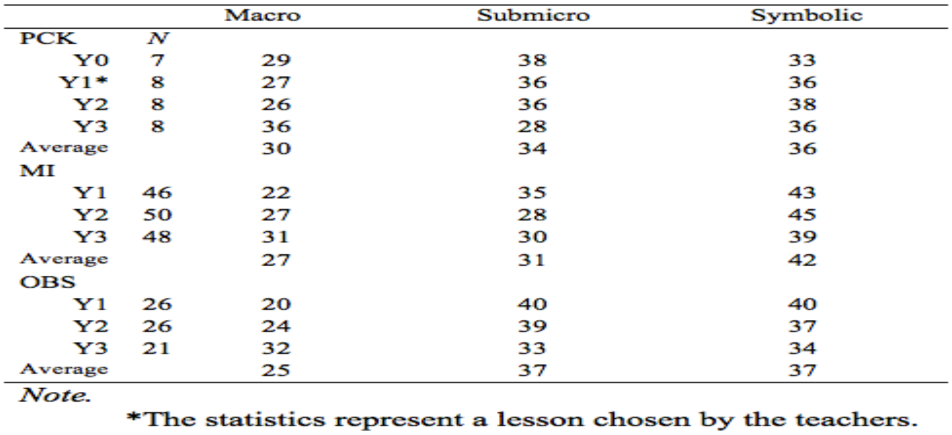
Overall Conceptualization and Enactment of Triplet Components. As a reminder, the transformed data sources provide differing amounts of detail to depict the utilization of the triplet components: (a) PCK may be either a lesson or unit, (b) MI includes a week of lessons, (c) OBS provides one class hour (ranging from 50 to 70 minutes) as well as occurrences, and (d) the artifact may be used for one class hour or classroom activity. In addition, PCK and MI are a report of how the teacher conceptualizes classroom practices while OBS and artifacts represent the enacted classroom practices. As a result of the differences in the perspective (participant or researcher) and detail amongst the data sources, the data will be analyzed and described by data source.

Triplet components by year for each data source. To compare the changes in the beginning chemistry teachers' use of the triplet from the first year teaching to the end of their third, a one-way within-subjects ANOVA was performed on the quantized Triplet Score by data source for each year (Y0, Y1, Y2, and Y3). The mean and standard deviations along with the maximum/minimum of the occurrence per data source can be found in Table 4. The use of the triplet component by average was also calculated (Table 5). Across the three years, teachers presented chemistry topics emphasizing both the submicro and the symbolic (i.e. abstract nature of chemistry) rather than the macro (i.e. observable and measurable) by occurrences.

Table 4

Triplet Means and Standard Deviations Per Source For All Time Points

Percentage of Triplet Component By Occurrences Per Year



		Macro	Submicro	Symbolic
PCK	*N*			
Y0	7	29	38	33
Y1*	8	27	36	36
Y2	8	26	36	38
Y3	8	36	28	36
Average		30	34	36
MI				
Y1	46	22	35	43
Y2	50	27	28	45
Y3	48	31	30	39
Average		27	31	42
OBS				
Y1	26	20	40	40
Y2	26	24	39	37
Y3	21	32	33	34
Average		25	37	37

Note.

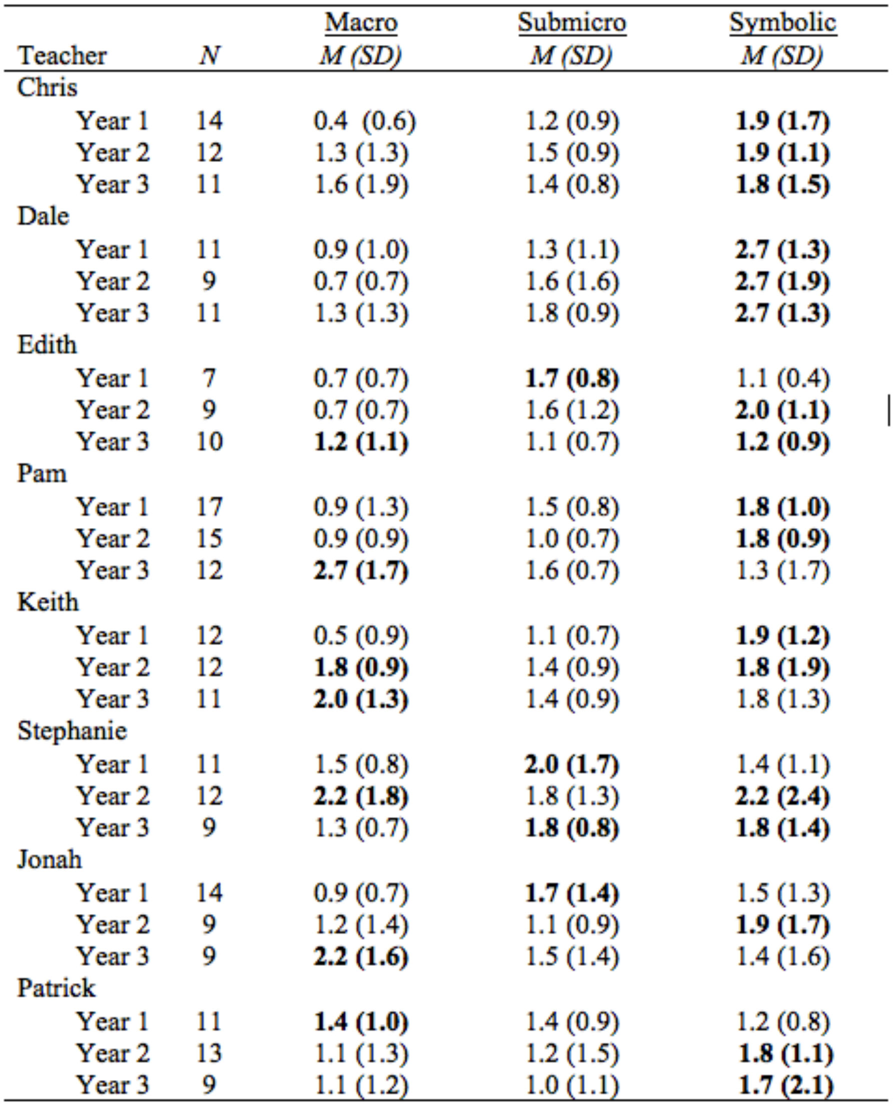
*The statistics represent a lesson chosen by the teachers.

The results for the ANOVA by the factors data source and year indicated that there was no significant change between year and source and the Triplet Score, Wilks'Λ = .97, *F*(14, 510) = .93, $p > .05$, multivariate $\eta^2 = .01$. The results of the ANOVA indicate there was no statistically significant difference throughout the three years in the classroom when compared to the transformed triplet components. As a result, it was not necessary to continue with further statistical tests.

Triplet components by participant by year. Teachers may implement various representations that focus upon different components of the triplet when teaching chemistry. As a result, the second factor run was the participants' usage of the triplet components from their first year to the third year. The means and standard deviations by participant were compared and it was found that there was some fluctuation between the Y1, Y2, and Y3 usage of the triplet components (Table 6). During the first and second year, the majority of the teachers' used the symbolic component that involves the focus upon algebraic equations and chemical symbols (Y1 *M(SD)* =1.7(1.2); Y2 *M(SD)* =2.0(1.5)). The third year, teachers as a whole emphasized both the symbolic component (Y3 *M(SD)* =1.7(1.5)) and the macro component in which students observe and measure concepts under study (Y3 *M(SD)* =1.7(1.5)). Though each year the participants seemingly emphasized different components, the results for the within-subjects ANOVA (Wilks'Λ = .88, *F*(28, 490) = .28, $p > .05$, multivariate $\eta^2 = .06$) and between-subjects ANOVA (*F*(14, 246) = .57, $p > .05$) indicated that there was no significant difference between triplet use and the factors year and the participant.

Table 6

Triplet Use by Participant Across The First Three Years



Teacher	*N*	Macro *M (SD)*	Submicro *M (SD)*	Symbolic *M (SD)*
Chris				
Year 1	14	0.4 (0.6)	1.2 (0.9)	**1.9 (1.7)**
Year 2	12	1.3 (1.3)	1.5 (0.9)	**1.9 (1.1)**
Year 3	11	1.6 (1.9)	1.4 (0.8)	**1.8 (1.5)**
Dale				
Year 1	11	0.9 (1.0)	1.3 (1.1)	**2.7 (1.3)**
Year 2	9	0.7 (0.7)	1.6 (1.6)	**2.7 (1.9)**
Year 3	11	1.3 (1.3)	1.8 (0.9)	**2.7 (1.3)**
Edith				
Year 1	7	0.7 (0.7)	**1.7 (0.8)**	1.1 (0.4)
Year 2	9	0.7 (0.7)	1.6 (1.2)	**2.0 (1.1)**
Year 3	10	**1.2 (1.1)**	1.1 (0.7)	**1.2 (0.9)**
Pam				
Year 1	17	0.9 (1.3)	1.5 (0.8)	**1.8 (1.0)**
Year 2	15	0.9 (0.9)	1.0 (0.7)	**1.8 (0.9)**
Year 3	12	**2.7 (1.7)**	1.6 (0.7)	1.3 (1.7)
Keith				
Year 1	12	0.5 (0.9)	1.1 (0.7)	**1.9 (1.2)**
Year 2	12	**1.8 (0.9)**	1.4 (0.9)	**1.8 (1.9)**
Year 3	11	**2.0 (1.3)**	1.4 (0.9)	1.8 (1.3)
Stephanie				
Year 1	11	1.5 (0.8)	**2.0 (1.7)**	1.4 (1.1)
Year 2	12	**2.2 (1.8)**	1.8 (1.3)	**2.2 (2.4)**
Year 3	9	1.3 (0.7)	**1.8 (0.8)**	**1.8 (1.4)**
Jonah				
Year 1	14	0.9 (0.7)	**1.7 (1.4)**	1.5 (1.3)
Year 2	9	1.2 (1.4)	1.1 (0.9)	**1.9 (1.7)**
Year 3	9	**2.2 (1.6)**	1.5 (1.4)	1.4 (1.6)
Patrick				
Year 1	11	**1.4 (1.0)**	1.4 (0.9)	1.2 (0.8)
Year 2	13	1.1 (1.3)	1.2 (1.5)	**1.8 (1.1)**
Year 3	9	1.1 (1.2)	1.0 (1.1)	**1.7 (2.1)**

Note. Bolded areas represent the component with the greatest mean by participant by year.

Triplet components by topic by year. Comparing the average of all topics captured within the data sources over time may hide the intricacies of the teachers' responses, so I also investigated the means of the topics per year and the PCK, MI, and OBS data sources using a one-way between-subjects ANOVA. See

Table 7 for a list of topics captured across the three years and sample numbers (*N* = 270). The means and standard deviations of the topics were compared and found that there was some fluctuation between the Y1, Y2, and Y3 usage of the triplet components (Figures 11, 12, and 13 respectively). During the first two years, the statistical means were predominantly higher for both the submicro component (Y1 *M(SD)* =1.5(1.1); Y2 *M(SD)* =1.4(1.1)) and the symbolic component (Y1 *M(SD)* =1.7(1.7); Y2 *M(SD)* =2.0(1.5)). The two components represent the abstract nature of chemistry through the discussion of entities not seen and the use of symbols to describe concepts. In the third year, there were more instances of the macro component (*M(SD)* = 1.7(1.5)) being equal or higher to the submicro component (*M(SD)* = 1.5(0.9)) and the symbolic component (*M(SD)* = 1.7(1.5)).

Table 7

List of Chemistry Topics Captured and Number of Data Samples

Topic	Data Samples
Atomic Structure	62
Bonding	57
Reactions	29
Gas Laws	26
Stoichiometry	18
Thermodynamics	17
Other[a]	15
Balancing Equations	12
Organic Chemistry	12
Solutions	12
Acid Bases	10

Note. Chemistry topics across MI, OBS, Artifacts, and PCK.

[a] Topics in this group include solutions, balanced equations, and petroleum.

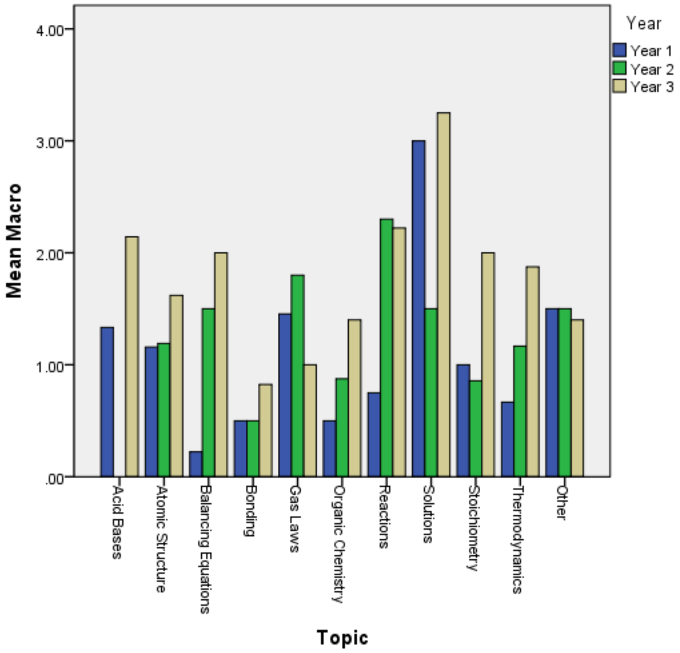


Figure 11. SPSS 19 bar graph of macro component by topic for the first three years.

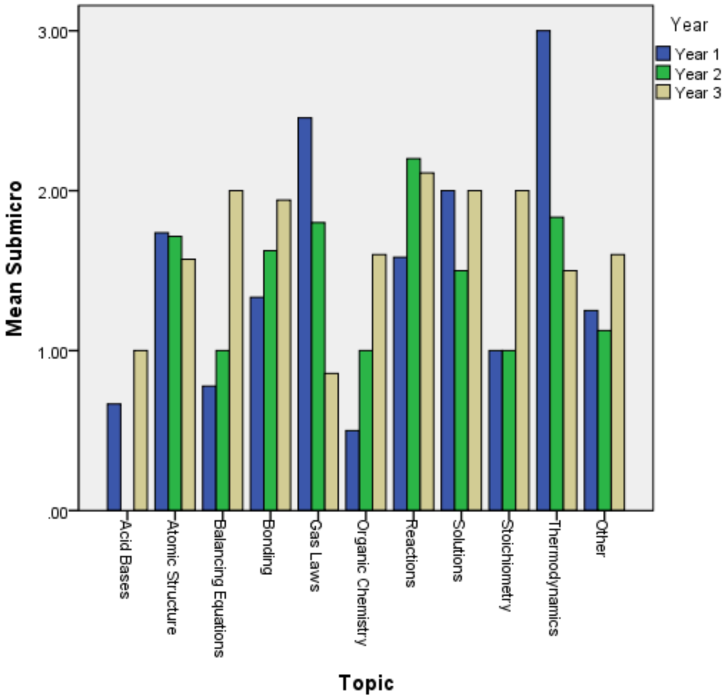


Figure 12. SPSS 19 bar graph of submicro component by topic for the first three years.

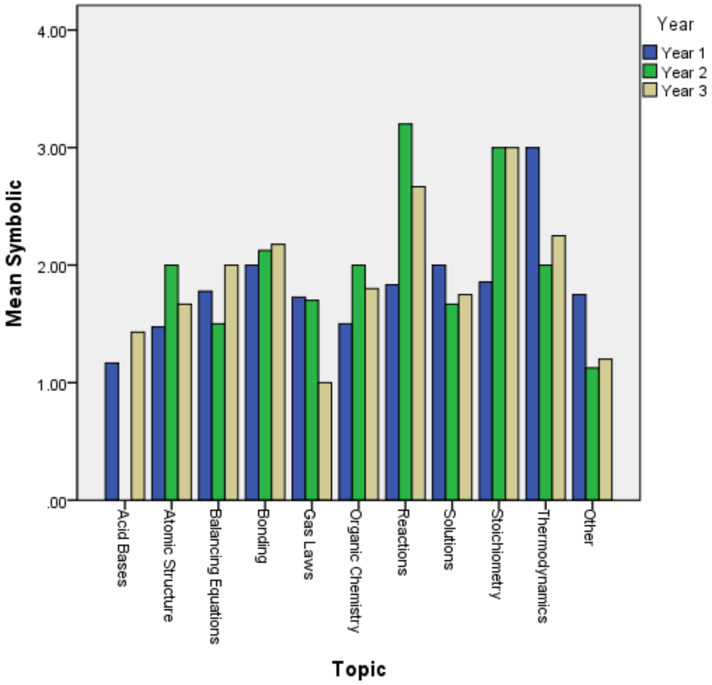


Figure 13. SPSS 19 bar graph of symbolic component by topic for the first three years.

Though the means did change, when the data was disaggregated by topic and year the differences were not statistically significant (See Table 8). For the PCK data source, there were too few incidents over the three years to generate a report of significance. MI on the other hand were approaching significance with a value of p = .08 at the .05 level. Inspecting the one-way within-subjects ANOVA output for post-hoc tests found the topic Reactions was approaching significance in comparison to Atomic Structure and Bonding with a value of p = .09 at the .05 level. However, findings show the teachers' responses with respect to the topic remained consistent through all time points.

Table 8

One-Way Repeated Measures ANOVA Scores for Tests Within-Subjects Effects by Topic for Each Data Source

Source	*F*-value	*p*-value
OBS	*F* (9,18) = 2.0	.10
PCK	**	**
MI	*F* (17,111) = 1.6	.08

Note.
** Too few topics across three years to generate a significance report.

Use of the triplet components by classroom practices. In analyzing the results of the triplet component for the classroom, the time spent on each component for OBS and MI along with the integration of each component for classroom artifacts will be discussed.

Time spent on each triplet component. Though not significant, the differences between the specific components by concept were viewed to see if there was a difference on the amount of time spent on a topic. Data analysis so far has been analyzed by year, however, not all topics were captured each year. As a result, classroom practices will be discussed as overall usage across the three years. Expanding on how the triplet components were presented by topic, an analysis of the OBS time spent on each component was determined. Prior to reporting the descriptive statistics on time spent on each component, time was converted using a calculated time factor for each OBS. The resulting means and standard deviation of time spent on the component by topic are presented as well as the average of all topics in Table 9. With a class hour average of 55 minutes, teachers spent a comparable amount of time on the macro (10.6 minutes) to observe and measure particular concepts and the submicro (11.0 minutes) explaining the students' observations per hour for the OBS. The one-way between subjects ANOVA found that there was no statistical difference between the topic and time *F* (10, 57) = 1.17 at a *p*-value > .05.

Table 9

Classroom OBS Time by Minutes per Hour Spent on The Triplet Components by Topic

		Macro	Submicro	Symbolic
	N	M (SD)	M (SD)	M (SD)
Acid Bases	2	13.5(19.1)	18.1(12.7)	14.6(5.3)
Atomic Structure	14	14.5(12.5)	9.4(8.5)	7.5(8.9)
Balancing Equations	3	0.0(0.0)	19.4(23.7)	8.9(4.7)
Bonding	19	5.2(8.7)	8.4(8.2)	9.9(7.9)
Gas Laws	5	20.8(10.2)	12.0(10.0)	5.5(7.2)
Organic Chemistry	3	3.0(5.3)	17.2(1.9)	15.8(5.8)
Reactions	7	16.8(10.4)	11.4(11.2)	6.7(10.3)
Solutions	2	20.0(7.1)	5.0(7.1)	5.0(7.1)
Stoichiometry	5	7.9(10.0)	6.2(5.1)	11.7(4.2)
Thermodynamics	3	14.7(19.4)	12.1(5.8)	9.7(2.5)
Other	5	10.4(11.4)	21.2(10.9)	5.4(5.8)
Total Average	68	10.6(10.7)	11.0(9.7)	8.7(7.6)

The OBS time was used to calculate the amount of time per week teachers spent on a particular topic from the MI[6]. The average number of class time per week that teachers engaged students in discussing the various chemistry topics was found to be 3.4 classes per week, which is equivalent to 187 class minutes. Using the amount of class time spent on each triplet component per particular topic, the percent average time spent on each triplet component was calculated

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[6] Reminder there is 4 OBS and 8 MI that is equivalent to 40 class hours of instruction.

and can be found in Table 10. Topics such as Acids and Bases, Gas Laws, and Solution Chemistry were found to spend a large percentage of the class week in the laboratory or discussing macroscopic properties. However, bonding, organic chemistry, and stoichiometry were spent focusing upon models, symbols, or algebraic equations. Based on the studies sample size, only 28.2% of the class week was spent explaining macro and symbolic components.

Table 10

Percent Average of Classroom MI Spent on The Triplet Components By Particular Topic by Week

	N	Macro	Submicro	Symbolic
Acid Bases	4	59.9	40.1	0.0
Atomic Structure	28	38.1	32.2	29.7
Bonding	28	6.8	32.6	60.6
Gas Laws	14	46.6	36.6	16.8
Organic Chemistry	5	8.5	24.1	67.3
Reactions	18	41.9	31.0	27.1
Solutions	8	75.0	11.6	13.4
Stoichiometry	8	21.6	12.1	66.3
Thermodynamics	11	31.3	33.9	34.8
Total Average	124	36.3	28.2	35.1

The integration of the triplet components. Thus far, the data analyses have been used to capture the use of each individual triplet component. To graphically represent how a representation utilizes all three components, a barycentric coordinate plot was used to analyze the total artifacts by the average of each laboratory activity (see Figure 14). As viewed with the barycentric coordinate plot, the majority of the laboratory activities connect the macro representation to the submicro and symbolic components. Only titration does not make a connection between the macro and symbolic representations to the submicro component.

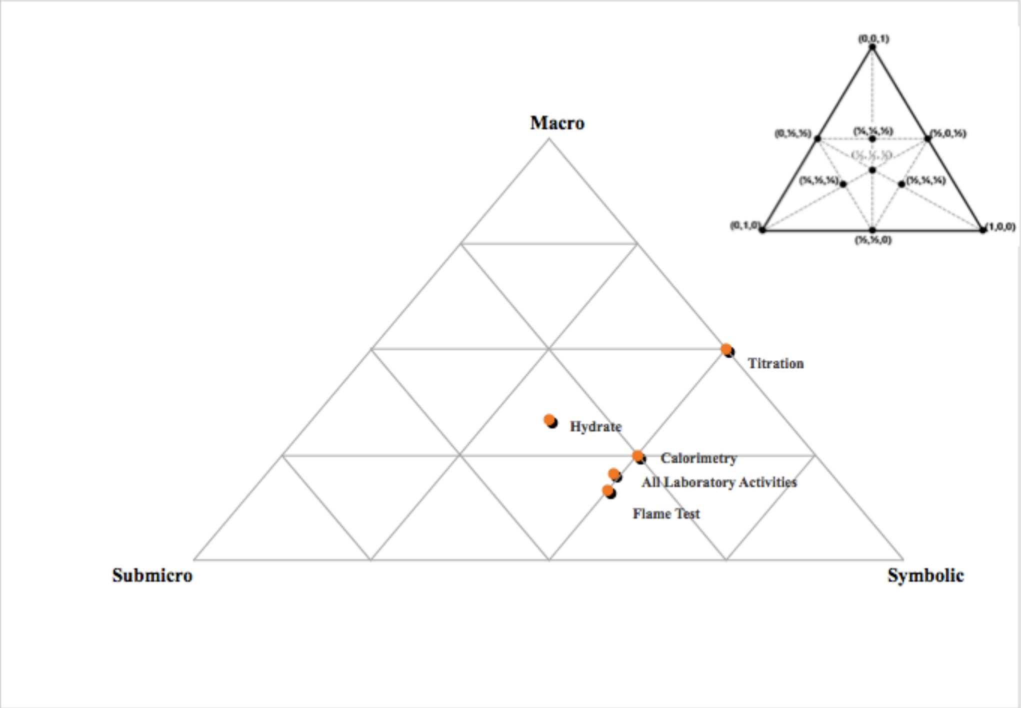

Figure 14. Barycentric coordinate plot of classroom laboratory activity artifacts per the triplet components.

Summary of Quantitative Data

Overall, the quantitative data showed that beginning chemistry teachers focused predominately upon the submicro and symbolic representations as they conceptualized and enacted the triplet relationship. Specifically, this group of teachers showed a change in moving from the emphasis of the submicro and symbolic components to a greater emphasis of macro components over time. However, the ANOVA statistics showed that there was not a statistical difference between the individual components of the triplet and (1) the three years, (2) the specific teacher, and (3) the specific chemistry concept. Even though particular topics showed vast differences between the triplet components, the overall time spent on each triplet component in chemistry showed no difference when averaging all the topics together. Lastly, by analyzing specific laboratory activities, we can see that the teachers were integrating the triplet components and not using them as single components in the classroom. The results of the quantitative data will be compared with the qualitative data later in the chapter.

Phase II - Knowledge of Student Learning Impacting the Enactment of the Triplet

Phase II explored how beginning teachers' knowledge of student learning impacted their enactment of the representations. To answer this question, four teachers - Pam, Chris, Keith, and Patrick - agreed to participate in the ATSI interview at the end of their sixth year teaching chemistry. Phase II involves the presentation of the multiple-cases for the results of the analysis of the ATSI interview for each year – Year 1, Year 2, and Year 3. To situate their knowledge of student learning, the teachers' view of atomic structure will be discussed.

Teachers' view of atomic structure. Atomic structure to these teachers represented different facets of the atom - from the electrons to all subatomic particles of the atom. Keith, Chris, and Patrick discussed their view of atomic structure based upon the representations in the research-generated matrix (see Appendices G - J). Atomic structure for Keith involved an emphasis on the historical development. "I sequence the energy levels and sublevels using a historical sequence - how these ideas were a result of historical development" (Keith ATSI, June, 2011).

For Chris, atomic structure focused upon the current view of the atom by emphasizing electron configurations. “I look at the model we use today. The electron configuration is important for the structure of the periodic table and answers problems [laboratory activities and inquiries] seen in my class and in chemistry” (Chris ATSI, July, 2011). Both Keith’s and Chris’ view of the atomic structure stressed the importance of the arrangement of the electrons in understanding the atom.

Though Patrick focused on describing atomic structure through electron configurations in his Y2 PCK (2007) interview, in the ATSI he described a progression of how atomic structure was taught in each of the three years.

> My first year, I was more focused on the rounded picture of chemistry than on the electrons…. My second year, I focused upon electron configurations because this was an area students struggled with. It made me fixated on that for the [Y2 PCK] interview. The third year, I focused upon the broader picture [of atomic structure] (Patrick ATSI, May, 2011).

The broader picture of atomic structure for Patrick in that third year involved the discoveries of not only the electron but also the protons and neutrons. Patrick’s view of atomic structure fluctuated between focusing solely upon the arrangement of the electrons within an atom and involving both the electron configuration and the discoveries of the subatomic particles.

Pam also focused upon the historical development but her view became more sophisticated over time. Within Pam’s interview she discussed “isotope theory and isotope rotation” (Pam ATSI, May, 2011), not a common topic found in high school chemistry classrooms. As a result, a follow-up question was asked regarding how she viewed atomic structure when she started teaching. Her response was “I did not have a good grasp [of the concepts] in year one. By the end of the second year, I had a better understanding of the concepts” (Pam ATSI, May, 2011). Pam’s view of atomic structure moved beyond the discoveries of the subatomic particles to include the study of the differences between isotopes. While the four teachers’ view of atomic structure primarily focused upon the historical view, there was some variation in the whether this view focused upon the early discoveries (protons, neutrons, and electrons) or the most recent theories (quantum mechanics).

Results of ATSI Interview

The second dissertation question focused upon how beginning chemistry teachers’ knowledge of student learning impacts their enactment of the representations. This PCK component captures the teachers’ knowledge on students’ (a) prior knowledge, (b) variations in their approaches to learning, and (c) difficulties with learning the content. To understand the impact of the knowledge of student learning on the choices of representations, the ATSI interview was qualitatively analyzed. The ATSI involved the discussion of the individual teacher’s representations for atomic structure as captured from MI, OBS, and PCK interviews. As a reminder, MI and OBS were captured during a two-week window that captures up to one week of representations of how the teachers’ conceptualized and enacted atomic structure. PCK interviews may capture a lesson or unit on atomic structure.

Year 1 – Not based on student learning. Beginning chemistry teachers' knowledge of student learning made no impact on their enactment of the representations. It is important to note that the Atomic Structure representations (see Appendices G - J) were captured between September and November for all four teachers. Teachers in this year made modifications to the representations given to them by their colleagues or found from the Internet and textbooks. However, the modifications were not a result of their knowledge of student learning.

The teachers were unanimous in why they chose the particular representations. They chose them because of their colleagues. As Patrick (ATSI, May, 2011) stated, "I was completely going off what the other teachers were doing." In his September MI (2005), Patrick discussed how he used the same laboratory activities as his colleague.

> I did exactly what the other chemistry teacher did. She set-up the lab and I would just do it with my students. All I had to do is just go and get the materials during my planning if they were doing a lab.

In Keith's (ATSI, June, 2011) circumstance, he discussed feeling pressured to do what the other teachers were doing.

> There were mainly two other chemistry teachers at my school. The students changed teachers between trimesters. I had to make a significant effort to be on the same schedule more or less… We tried to be on the same page even down to the day. I felt pressure to be at the same place with the other chemistry teachers.

During Keith’s (September MI, 2005) atomic structure lessons, he wanted to reorder the scope and sequence of the course, but “for now I am following the order of the other teachers in my department… I was concerned I would not be able to keep up.” As a result, Keith implemented the same representations to keep to the same experiences for all students.

Even when asked if they consider their students in this first year, teachers repeatedly insisted that the representations were a result of their colleagues’ influence. In the following quote, Pam reiterated that she did not have a good grasp on the material in her first year to consider students.

> Researcher: Did you consider your students in this first year of teaching?
>
> Pam: You float through the first year, crossing your fingers to get through it. I didn’t have a chance to consider the students. The lessons come from the textbook, especially the activities. Lots of things come from our curriculum, textbook, colleagues, occasionally from online. (Pam, ATSI, May 2011)

In the first year, teachers were concerned with obtaining materials to teach atomic structure rather than considering students’ prior knowledge, difficulties with the material, or variations in learning.

The teachers did consider students with regards to engaging students in the classroom through discussions. From the MI in the first year, the four teachers’ were found to have created their own lessons primarily when it involved lecture-based instruction. The reason for the change to the representations was in order to address the teachers’ preferred style for presenting the content. For example, Pam made modifications as necessary to the representations used in the classroom instruction. “I edited the activities from my co-workers and online materials to fit my classroom” (Pam ATSI, May, 2011). Another example of modifications to the lectures was found with Patrick (ATSI, May, 2011), “I was modifying how I presented them though I used their PowerPoint presentations but I made it more interactive than lecture.” The changes made to the representations were a result of considerations of student engagement within the classroom discussions.

Experiences with the representations led one of the teachers to alter the level of inquiry to engage students in the subsequent years. Patrick changed the representations to reflect more inquiry. “Instead of ABC [step-by-step] labs, I try to make it more of an open-ended inquiry-type lab” (Patrick ATSI, May, 2011). When asked why he made this change to add more inquiry in the classroom, Patrick responded, “I felt pushed to try it when I was participating in Glenda’s class[7]. I had to do inquiry during student teaching. The openness is intimidating, but when you give it a try you see they are more actively engaged.” Again the reason for altering the representations was a way in which to engage students in the classroom instruction. Patrick utilized his knowledge of science strategies that focuses upon the knowledge of inquiry.

Year 1 - Summary. It is clear during the first year that the changes made to the representations were based on their knowledge of instructional strategies and not student learning. The teachers found different ways to deliver the content as modified from their colleagues’ representations to engage students in learning

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[7] Pseudonym for a science education professor.

atomic structure. This was evident in the modifications to the representations prior to its enactment in the classroom. The changes were an effort in presenting the material to engage students in the classroom instruction. While recognizing that students need to be involved in the classroom activities through discussions and inquiry activities, the teachers did consider altering representations of content. However, they were not considering the student learning component of PCK.

Year 2 - Enactment informed by knowledge of student learning. It is during the second year that beginning chemistry teachers discuss their knowledge of student learning as impacting the enacted representations. The teachers described choosing particular representations based on their knowledge of students' difficulties with atomic structure, varied approaches to learning, and prior knowledge. In addition, teachers' subject matter knowledge informed when a particular concept was introduced. As a result of both the knowledge of student learning and subject matter knowledge, many of the representations were added, modified, or eliminated from their teaching repertoire.

Knowledge of students' difficulties with atomic structure. In discussing the enacted representations, the teachers based many decisions on their knowledge of students' difficulties with atomic structure. The choices were made regarding the students' difficulties with a particular concept (e.g. filling of atomic orbitals) within atomic structure as well as the difficulties caused by the representation itself to understanding the content. To illustrate this PCK knowledge, Chris, Keith, and Patrick recognized the role that representations played in helping or hindering students' understandings of the content.

Chris used the representation to bridge the gap between a difficult concept and the representation. Chris (PCK, July, 2007) described the filling of the electron subshells in electron figurations using a "rock concert" analogy. When discussing this representation in his PCK interview, he understood that the students had difficulty with electron configurations beyond eight electrons. "I do this because they did not have much prior knowledge… they all understand they [atoms] have eight electrons or up to eight… they thought there was nothing beyond that" (Chris PCK, July, 2007). In the ATSI interview, Chris builds on this to focus upon students' difficulty understanding why the elements with d-orbital and f-orbital are not found on the same row of the corresponding energy level for the s-orbital and p-orbital. "I do this because they don't understand why d and f [orbitals] lag behind. The 5d is closer than some others in the rock concert" (Chris ATSI, July, 2011). For example, Krypton: $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $\mathbf{4s^2}$, $\mathbf{3d^{10}}$, $\mathbf{4p^6}$; the $4s^2$ is presented prior to $3d^{10}$ which is counter to the expected pattern for the elements prior to potassium. Chris used the rock concert's seating arrangement to address students' difficulty with the filling of the atomic orbitals.

> The rock concert shows an orbital or square. First we decide which concert we go to? With the first ticket, where do you want to sit? Kids want to sit closest to the front…. For example Jill can sit in 1s … The students begin to put the pattern together… They start to make the connection to the periodic table. (Chris ATSI, July, 2011)

Conversely, Keith recognized how a specific representation hindered students' understanding of a concept and modified his future representations as a result. Keith introduced a card sort because he was “prompted to find a more visual way to present the understanding of the law of definite proportions” (Keith PCK, May, 2007). The representation was introduced to provide a visible representation in which to explain a concept for atomic structure. However, the representation was deemed not as useful as the class size increased because Keith struggled to help all the students make connections between the representation and the content. “The classes were too large. I quit using it because so many of them were walking away confused by the activity. It is too difficult for most kids to get the meaning behind the activity” (Keith ATSI, June, 2011). As a result, he no longer presented the activity in the following years.

Like Keith, Patrick found that his representation hindered students’ understanding of electron configurations. He focused upon how to revise a magnetism laboratory activity to address students’ difficulties. The activity was designed to connect an element’s electron configuration to its ferromagnetic properties. Patrick (ATSI, May, 2011) found that students were having difficulties with the original format of the laboratory activity.

> The lab was initially designed to take a nail, wire, and test the object to see if it picks up anything. The students were relating the electron configuration to see if the example was magnetic. However, students were not getting that two electrons cancel the effect. They were supposed to piece together that metals that produced a magnetic field had unfilled d-orbitals… They were having trouble seeing things.

During the week that he implemented the representations, Patrick (MI, January, 2007) found that the students “appeared to understand it and like it.” By modifying the representation, he addressed student difficulties with connecting the representation to the content.

In order to address students’ difficulties, Patrick engaged students in classroom discussions. “I used end of the class discussion to get them there” (Patrick, ATSI, May, 2011). Through his previous experience working with the students on the laboratory activity and discussions about the lesson, Patrick realized that he needed to make revisions to the methods and types of questions. As a result, Patrick’s new representation prompted the students to “think through the activity… What does the nail represent in this activity? The old one doesn’t tell them about that at all. I rewrote the activity because they did not understand how things went together.” Patrick realized that his activity hindered students’ learning. As Patrick discussed in his PCK interview (June, 2007), after the students test their samples with the magnet “*then* [emphasis added] maybe they see that the ones with only the partially filled orbitals are attracted.” As a result, not only did Patrick modify the lesson prior to its implementation but also he engaged students in discussions during the lessons to help them make sense of the activity.

These examples from Chris, Keith, and Patrick illustrate beginning chemistry teachers’ knowledge of students’ difficulties. The teachers identified the impact of a representation on how students learn atomic structure by either making the content understandable or causing further difficulties to understanding the atomic structure. The result of this student learning component included the continued use, removal, or modification to the representations.

Knowledge of students' varied approaches to learning. Another component of student learning that impacted the enactment of the representations was the knowledge of students' varied approaches to learning. In this student learning component, a teacher may consider the students' various learning styles which included visual and aural learners. Only Pam discussed this concept in the ATSI.

Pam chose specific representations to address students' learning styles through the use of technology. The chemistry department had written a grant for an InterWrite Board, which allowed teachers and students to use technology to interact with the content. Pam used the InterWrite Board to engage students in testing their understanding of the placement of the electrons in the various shells around the Bohr model (Pam MI, March, 2007; OBS, March, 2007). For her, the visual representation reached "more learners, especially visual learners. It also increased class participation" (Pam ATSI, May, 2011). However, the March OBS data (2007) showed that 50%-80% of her students were off-task and not participating in the computer simulation. With this student learning component, Pam purposefully included specific representations to engage all students in the classroom learning. The result of this student learning component on the enacted representations was the teachers continued use and addition of particular representations to the classroom instruction.

Knowledge of students' prior knowledge. The third component of the knowledge of students' learning involves students' prior knowledge. In this second year, data collected from ATSI found teachers enacting particular representations in order to engage students with the content. While Chris did not believe students had any prior knowledge, Pam and Keith referenced the reason behind specific enacted representations was based on their students' prior knowledge.

In Chris's second year PCK interview, he believed students did not have much prior knowledge on valence electrons.

> R: What did you consider about your students when designing these lessons?
>
> T: That they had very little chemistry knowledge at this point so we had to go slow. It was more than how many electrons in the outer shell. They can all do that.
>
> R: Did you consider prior knowledge?
>
> T: Yeah. I considered that they did not have much prior knowledge on this. They all have eight electrons or up to eight and that is it. (Chris PCK, June, 2007).

As a result of believing the students did not have prior knowledge, Chris did not engage students in a representation to support his assertion. Similarly, Keith did not attempt to assess students' prior knowledge because he knew what course his students had prior to applied chemistry. "I assumed that they had learned some of this in their earlier classes, like physical science. I assumed they had heard about atoms and such before" (Keith PCK, May, 2007). As a result, Keith focused on providing "more demos and then lecture about each model and concept." In short, the representations enacted were used to build upon students' previous knowledge of the atom to gain a deeper insight into the structure. In both cases, the teachers did not mention trying to assess the validity of their assumptions about students' prior knowledge.

Conversely, Pam began her lessons with an activity to determine the students' prior knowledge. She asked students to draw a picture of the atom and label the structures to determine what students recalled from middle school about atomic structure.

> R: What did you consider when planning your lesson or unit?
>
> T: Students' prior knowledge. I review on the first day to see what they remember from middle school. I have them draw a picture of an atom and label their structures and see how much they remember. So I get a pretty good idea of what they know. (Pam PCK, May, 2007)

Pam (ATSI, May, 2011) continued using this opening activity for atomic structure because she wanted to know "what is their starting point? What is the range? This varies from year to year." In order to address the students' focusing upon the Bohr model, Pam arranged atomic structure to focus upon the historical aspect of atomic structure leading up to the current views of the atom.

In these cases, the teachers did not always include a representation to engage students' prior knowledge. For Keith and Chris, they believed students had little knowledge with regards to atomic structure. As a result, they did not include a representation to determine the validity of their statements. Pam, on the other hand, designed the opening representation to access what students knew about atomic structure.

Knowledge of the structure of chemistry. While the teachers enacted specific representations as a result of their knowledge of student learning, together the entire representations served as the basis for students' understanding of future concepts in the course. In the second year, two of the teachers identified their knowledge of the structure of chemistry as impacting the enacted representations. Chris and Patrick modified the timing either by reorganizing or spending less time on the representations.

After the first year, Patrick reorganized the content to help students understand atomic structure. "I switched the order [of the content] to find the best way to present the information to them. I was trying to find a way to help them learn the content" (Patrick ATSI, May, 2011). Patrick is referring to the research-generated matrix that captured lessons on atomic structure for year two in January (2007) compared to atomic structure presented in October (2005) of year one. In the second year of teaching, Patrick modified the content and the representations to better help students learn atomic structure.

Chris, conversely, spent less time and removed various representations in order to help students understand the content. The representation from his October (2006) MI involved students analyzing how the periodic table was structured by connecting it to electron configurations and orbital diagrams. His view of atomic structure, as discussed earlier, was to focus upon the modern view of the atom.

Chris (ATSI, July, 2011) held this stance because the modern view of chemistry was most “relevant for my students.” As Chris described how he viewed the history of the atom, he explained why he felt the modern view was most important.

> I breeze through the history because I want to get into what is more important. You look at the model we use today…. It is the electron configurations which helped put our periodic table together…. It helps them in the long run.

Chris was making changes to the amount of time spent upon the enacted representations in order to build students’ learning of atomic structure.

The teachers’ knowledge of the structure of chemistry informed when to teach atomic structure in order to build their students’ knowledge of atomic structure. The subsequent rearrangement of the content by Patrick and the amount of time spent on the representations by Chris impacted the students’ learning of atomic structure. The teachers in this situation made decisions upon the enacted representations based upon their knowledge of chemistry. They were not based upon the teachers’ knowledge of student learning.

Year 2 - Summary. During the second year, the beginning chemistry teachers’ knowledge of student learning informed the enactment of the representations. To varying degrees all the teachers relied upon their knowledge of student difficulty with atomic structure, varied approaches to learning, and prior knowledge. As a result, classroom representations were added, modified, removed, or continued as part of the enacted strategies. In addition, subject matter knowledge also informed when the representations were used and the amount of time allotted to the particular representations within the instruction.

Year 3 - Enactment informed by knowledge of student learning. As with the second year, teachers in the third year made reference to their knowledge of students' difficulties with atomic structure, varied approaches to learning, and prior knowledge as impacting the enacted representations. As a result, teachers continued to use the same representations or modified the sequence based on these student learning components.

Knowledge of students' difficulties with atomic structure. In discussing the representations for year three, several teachers based their decisions on the students' difficulties with atomic structure. The choice was made regarding students' difficulties with particular concepts. As a result, Chris, Pam, and Patrick implemented a new representation to help overcome students' difficulties with this concept.

During the third year, Chris had moved to a new school district to teach chemistry. His colleagues at the school introduced Chris to a legume lab to help students with average atomic mass as referenced by his October MI (2007). Prior to Chris' third year, he engaged students with various problems in which they were to calculate the average atomic mass (Chris, September, MI, 2005). The addition of the new representation was to help students understand that atomic mass is an average of the isotopes for a particular element. As Chris (ATSI, July, 2011) stated, "Atomic mass is a tough concept and the bean activity can get students to get it and understand it… I should have been doing this the past two years.” The addition of the legume representation was to address students’ difficulties with the concept of atomic mass.

Both Pam and Patrick found students had difficulty with the patterns found with the periodic table. Pam discussed students’ difficulties with electron configurations.

> I think they have a hard time with understanding electron configurations. Why they are used; and why they are being taught? It is hard to understand a probability cloud and what is the point of all the shapes and letters. This is really hard to understand. (Pam PCK, May, 2008)

In order to address students’ difficulties with the patterns and symbols, Pam engaged students in a game to help them “learn the rules and relate it more as a life lesson to learning stuff that you might not totally understand in life.” Though she mentioned trying to help students’ make connections with the symbolic representations to the submicro explanations, Pam used the game to help students memorize the patterns.

Conversely, Patrick addressed students’ difficulties with the patterns of electron configurations through class discussion and laboratory activities. He engaged students with a lecture on the energy levels and valence electrons.

> Relating the periodic table and seeing the patterns and knowing the charges for each row and knowing why. Students just memorize the pattern but do not know why. I try to break through the memorizing to get at the why. I talked about the number of electrons in the energy levels. I tried to focus in on the valence electrons and get into that aspect and

> compare it to the stable configuration of the noble gases and how you get there. (Patrick PCK, May, 2008)

When asked about his third year representations in the ATSI, Patrick responded that he was trying to include more activities similar to the ferromagnetic activity during the second year. “I tried to include more of those as I went along I try to tie… more explanations that students could reference on their own to understand the content” (Patrick ATSI, May, 2011). In the ATSI, he focused on the importance of understanding the submicro explanations instead of memorizing patterns.

The teachers during this third year addressed students’ difficulties by including not only new representations and lectures. Though Pam recognized students had difficulty with patterns, she failed to move beyond memorizing the sequences of electron configurations. Only Chris and Patrick engaged students in understanding the submicro level in order to address difficulties with atomic structure by continuing to use particular representations.

Knowledge of students’ varied approaches to learning. Several teachers considered students’ varied approaches to learning in regards to atomic structure. As with the second year, focus was upon students’ learning styles as impacting atomic structure representations. However, Pam and Patrick were also concerned to about providing multiple representations to help students with learning atomic structure.

Patrick provided various activities to engage students’ learning styles. Patrick (PCK, May, 2008) used a card sort representation that included “atomic size, colors of the atoms, and number of spokes off each atom" to engage visual learners. "The cards were for the visual learners and talking about them in groups so kids could pool their knowledge since they all know different things." He continued to discuss the importance of activities to connect the submicro explanations to various visual representations. "I tried to provide students with more tangible activities and more visual aids to connect learning" (Patrick ATSI, May, 2011). Though he recognized visual learners in the PCK interview, in the ATSI Patrick saw the visual representations as a way to connect the representation to the content regardless of learning styles.

Pam utilized both students' learning styles and differentiated instruction in the enacted representations. Addressing students' learning styles, Pam chose to include demonstrations of the conservation of mass to engage the visual learners.

> They are visual for kids… By using everyday things, it is easy to see, it is very visual so students can grasp the concept. It is one more way to catch a learner that might not be an auditory or another type of learner, anticipation of not knowing if they don't know the part before (Pam ATSI, May, 2011).

While Pam focused predominately on visual learners, she recognized that not all were visual learners. "I try to hit multiple styles by the end of the hour." To involve the different learning styles, Pam provided multiple representations to address differences between students for approaching learning in her PCK interview. "We did a variety of activities to learn the same concepts. Especially in this chapter they learn about orbital configurations with beads in the configurations, science games with marbles for the Bohr model" (Pam PCK, May, 2008).

Though both Pam and Patrick discussed students' varied approaches to learning for their visual learners, the teachers tried to engage all students' with the various representations in the classroom instruction. Patrick described the continued use of various representations as visual aids to connect the content. Pam viewed the third year atomic structure representations as a way to reach all students by the end of the class hour. As a result, she included a variety of representations to engage students in learning.

Knowledge of students' prior knowledge. In discussing the enacted representations, the teachers based decisions on their knowledge of students' prior knowledge. The choices were a result of the teachers' knowledge of students' background experiences to engage them with the content. Teachers gained this information from knowing what information they were gathering from other classes. Patrick, Pam, and Keith were the only teachers that mentioned the influence of their students' prior knowledge on their enacted representations.

Patrick and Pam identified determining prior knowledge by knowing students' previous experiences prior to entering their classroom. When asked about prior knowledge, Patrick (PCK, May, 2008) stated "I get it from classroom discussion of previous knowledge for their feeder school. I also have information from the other students in the different classes of students over the last two years." He used this information to determine "what I thought they could handle in one day and how often they needed information repeated." As a result, Patrick used this knowledge to determine the amount of time spent on the representation.

As seen from the previous year, Pam (PCK, May, 2008) continued to ask students to "draw picture of what they think of atomic structure. I see a lot of Bohr models or like a logo for a company." As a result, she focused upon the historical stance for students to understand "what a model is and what they represent." Pam historically sequenced the representations to help the students answer these questions.

> We begin with the historical contributions to the atom by particular scientists: Lavoisier, Proust, Dalton, and Avogadro. I'm trying to get the students to move from Bohr's contributions. There is a lot on Bohr, but there is not much on Dalton. (Pam ATSI, May, 2011)

She continued to use representations from previous years as well as added representations in order to connect students' prior knowledge to the most recent views of the atom.

Keith, on the other hand, preferred to historically sequence the discoveries to build students' prior knowledge about electron configurations. While Keith had focused upon the historical view of atomic structure in each of the previous years, during the third year he led up to the introduction of electron configurations through the discoveries of the atom.

> With the energy levels and sublevels, I sequence it on a historical sequence. How these ideas were a result of historical development? Always thought the history of science was interesting and relevant

> background… I do this to provide students with the relevant background to understand electron configurations. (Keith, ATSI, July, 2011)

Keith (ATSI, June, 2011) used the timing of the representations to provide the background needed to understand electron configurations. Keith used students' prior knowledge to sequence the representations enacted in the classroom.

The teachers enacted atomic structure representations based upon their knowledge of students' prior knowledge from their previous classes and through the sequencing of the representations. Patrick and Pam enacted their representations based on their knowledge of students' prior experiences with the content. For Patrick, this determined how much time he should spend on a representation. Keith focused upon the particular activities to build the necessary background knowledge to understand electron configurations. Only Keith mentioned that the change in the sequencing of the representations was to address students' understanding of the concept. The result of this student learning component on the representations was to provide the setting in which to present the content in order to build student learning of atomic structure.

Year 3 - Summary. During the third year, all three student learning components informed changes made to the representations. Teachers in this year focused upon students' prior knowledge, varied approaches to learning, and difficulties with specific concepts. The changes to the representations were an effort to engage students and overcome areas of difficulties based on the teachers' previous students rather than determining what the students' knew about atomic structure. The teachers did not mention that they had tried to determine their current students' prior knowledge to identify their interests, difficulties, or current understandings. The teachers used their knowledge of student learning to engage and motivate students as well as deal with students' difficulties through the representations enacted.

Summary of Qualitative Data

Teachers' enactment of the triplet representations and the knowledge of student learning behind the changes were analyzed using the PCK framework. The variations within the teachers' data helped identify the trends in the cross-case analysis. These trends clarified how teachers present the chemistry content and the results of their considerations based on their students' learning needs.

Overview of the knowledge of students' learning. An effective teacher needs to consider the students' knowledge and difficulties with learning (Magnusson, et al., 1999; NSES, 1996). This includes the knowledge of students' (1) prior knowledge, (2) difficulties in chemistry, and (3) various approaches to learning. This dissertation study sought to determine how beginning teachers' knowledge of student learning impacted the enactment of the atomic structure representations. A cross-case analysis was conducted to compare the individual knowledge components across the three years.

The four teachers that participated in the ATSI utilized their knowledge of student learning as well as other forms of knowledge in various ways on the representations enacted (see Table 11). Across the three years, all teachers referenced all three of the student learning components. The overall impact on the enactment of atomic structure in the classroom was that teachers added, modified, continued using, and removed representations. All of which encouraged the utilization of some laboratory activity, demonstration, or macro representation (e.g. fireworks video, rock concert) to help students learn atomic structure.

Table 11

Impact of Teachers' Knowledge on The Enactment of The Atomic Structure Representations

	Prior Knowledge	Students' Difficulties	Variations to Learning	Other
Year 1				Pam*, Patrick*
Year 2	Chris[α], Keith[α] Pam[Φ]	Chris[Φ], Keith[β], Patrick*	Keith[α], Patrick[Φ], Pam	Chris*, Patrick*
Year 3	Pam*, Keith* Patrick*	Chris[α], Patrick[Φ], Pam[α]	Pam[α], Patrick[Φ]	

*Modified representation

[Φ] Continued use "as is" of the representation

[β] Removal of the representation

[α] Addition of a new representation

Impact on representations based on students' prior knowledge. The teachers used the students' prior knowledge to primarily engage and motivate students through the enacted representations during the final two years of the study. The teachers fell into two groups when it came to determining if the students had prior knowledge: teachers did or did not assess their students' prior knowledge.

Chris and Keith did not assess their students' prior knowledge when enacting the representations. Chris assumed that students had little to no prior knowledge during the second year. Instead, he implemented representations to provide students with the necessary information to understand electron configurations. Conversely, Keith assumed that the students had prior knowledge about the atom based on their previous experiences in his and other courses for both the second and third years. As a result, Keith continued with his planned representations in order to build upon students' prior experiences with either another course or with the material itself. Though both Chris and Keith enacted the planned representations without making modifications, the teachers failed to assess the validity of their assumptions about students' prior knowledge.

In contrast, Pam and Patrick discussed implementing instruction to gauge students' prior knowledge. Pam, in the second and third year, and Patrick, the third year, tried to ascertain students' prior knowledge about the subatomic level through classroom discussions. Pam used the information to determine where she should start instruction and how deep into the material could she go with her students. For Patrick, he used this knowledge to judge the pace in which to present the content. It seems that while Pam and Patrick did determine students' prior knowledge, all four teachers did not make any modifications to the representations utilized in the class instruction.

Impact on representations based on students' difficulties with atomic structure. In comparing the three years with respect to this knowledge component, the teachers discussed their main concerns were with (1) connecting symbolic representations to submicro explanations and (2) connecting macro representations to submicro explanations.

In order to connect the symbolic level to the submicro explanation, all four teachers engaged students with representations that were meant to provide a symbolic representation of what was occurring at the submicro level. During his second and third years, Chris focused upon his knowledge of students' difficulties with atomic structure for enacting the representation. With the Rock Concert activity, Chris (ATSI, July, 2011) incorporated this analogous scenario to illustrate why the "d- and f-orbitals lag behind." Chris addressed students' difficulty with average atomic mass in his third year. He used the Legume activity because "it seems like it works. It's [average atomic mass] a tough concept and it seems like the students' get it and understand it. It's a tough concept."

With the same focus, Keith used a card sort activity that illustrated the law of definite proportions. However, the representation proved to be too difficult for students to make the necessary connections to the content without a concerted amount of help from the teacher. As class sizes increased, Keith was unable to provide the necessary instruction time for continued use of this representation. Similarly, Patrick used classroom lectures to help students' understand the patterns found with electron configurations. Though Pam discussed the need to connect the submicro to the symbolic levels, she focused primarily upon the skills to write electron configurations through a game to learn the rules. While all four teachers engaged students with various representations, Keith was the only that discussed the need to remove the representation.

Only one teacher engaged students with a representation to address students' difficulties with connecting the macro representation to the submicro explanations. Patrick, in his second year, recognized the limitations of a representation as written to connect a macroscopic property (i.e. magnetism) to the subatomic explanation (i.e. electron configurations). Without modifying the representation, Patrick's students relied upon class discussions to make the necessary connections to the content. Patrick altered his instructions to students based upon previous difficulties with the representation experienced by students the prior year.

All four teachers were primarily concerned with students' difficulties with connecting the symbolic representations to the submicro explanations. Accordingly, the teachers implemented various representations to address students' difficulties. However, Keith recognized that his representation was too difficult and no longer utilized this activity. Only Chris, in his second year, discussed the need to make modifications to the representation to help students connect the macro representation to the submicro explanations.

Impact on representations based on students' varied approaches to learning. After comparing the teachers' knowledge of students' varied approaches to learning, teachers considered students' learning styles by implementing a single or multiple representations. Pam and Patrick were the only teachers to discuss this knowledge component.

Pam, in her second and third year, identified specific representations enacted were to engage the students through their multiple styles for learning. Technology was used to engage students because she believed that the representation would "reach more learners, especially visual learners. It also increased class participation. I think it does. That is why we wrote another grant to get a promethium board" (Pam ATSI, May, 2011). The same was said the following year with regards to demonstrations for the conservation of mass. “It is very visual to help students grasp the concept. The demonstrations provide one more way to catch a learner that might not be an auditory or another type of learner.” By the end of the class hour, Pam would try to engage multiple learning styles through various representations. Likewise, Patrick used a card sort representation to initially engage the visual learners during his third year. As he continued to discuss, the card sort also was to provide a tangible activity in which to connect the submicro explanations. Regardless of what the enacted representation involved, Pam and Patrick used them to engage students’ varied learning styles.

With this student learning component, Pam and Patrick utilized specific representations to address learning styles. From the second to the third year, both teachers shifted from one learning style to multiple learning styles in which to involve students in the classroom learning. In considering multiple learning styles, the teachers enacted various representations to engage this student learning component.

Impact on representations was not a result of knowledge of students’ learning. While the teachers did consider the student learning components to various degrees throughout the second and third years, they identified three factors that impacted the enacted representations in the first two years that did not relate to this PCK component. The largest factor was the teachers’ colleagues in determining how to teach atomic structure. The final two factors the teachers’ identified were the knowledge of scientific inquiry and knowledge of the structure of chemistry.

Initial representational repertoire. Initially, teachers relied upon their colleagues to determine how to represent atomic structure to students. For instance, Patrick followed his colleagues in his enacted instruction. For Pam (ATSI, May, 2011), this was a result of feelings of being overwhelmed as she crossed her "fingers to get through it [the first year]." Conversely, Keith expressed feeling pressured to do so because of the school's trimester schedule. He worked to not fall behind by staying on the same page as his colleagues. As a result, the teachers' relied upon their colleagues to help build their initial representational repertoire.

Any modifications to the representations in the first year were based upon their personal teaching styles to engage students' learning. Chris, in spite of relying upon his colleague for representations, made modifications based on his personal teaching style as he stated "I rewrote the lessons for me" Chris (ATSI, July, 2011). Similarly, Pam edited her activities in order to fit her classroom. Patrick represented a teacher that made modifications to engage students by making PowerPoint presentations to be more interactive rather than lecture based. The teachers relied upon their colleagues but worked to make the representations fit their classroom and engage students in this first year.

Knowledge of scientific inquiry. A teachers' knowledge of scientific inquiry is based upon their understanding of science specific strategies (i.e. inquiry). Patrick was the only teacher to make reference to adding or modifying the instructional representations due to the need to implement inquiry in the classroom. He recognized that his colleague's representations in the first year were step-by-step laboratory activities. Patrick worked to modify some representations to align with the science strategies supported in his science education courses.

Knowledge of the structure of chemistry. Teachers also identified the reason for change in their representations was a result of how they viewed the structure of chemistry. Patrick and Chris identified the need to change the representations as a result of their knowledge of chemistry in the second year. This was a change from following their colleagues in what and when the teachers would present representations in the first year.

After the first year, Patrick reorganized when the content was presented in order to help students understand atomic structure. For Chris, he still used representations from the first year but rushed through those. He did this in order to spend more time on electron configurations. Chris felt students would benefit more by focusing upon electron configurations rather than the history of atomic structure. Conversely, Pam and Keith only mentioned following their colleagues and continued to present similar representations over the next two years. This suggests that their colleagues initially influenced how the teachers viewed the structure of atomic structure because the teachers did and did not need to make changes to the representations.

Summary. From this study, it is evident that the enacted representations of atomic structure were impacted by the teachers' knowledge of student learning as well as other forms of teacher knowledge. As a result, teachers' made modifications, which included (1) the addition of new representations to build student learning; (2) the deletions of representations that hindered student learning or no longer proved relevant; (3) continued use or modification of previous representations; and (4) the when and how long the teacher spent on a particular representation(s). These changes to the enacted representations of atomic structure were regardless of the component of the knowledge of student learning utilized (see Table 10).

Chapter 5

CONCLUSION AND IMPLICATIONS

Using the conceptual framework of PCK, this dissertation study focused upon two components of teacher knowledge: knowledge of student learning (Lee, et al., 2007) and knowledge of representations (Magnusson, et al., 1999). These foci were selected in order to answer the following questions regarding beginning secondary chemistry teachers' use of representations through the triplet relationship (Gilbert & Treagust, 2009b):

- How do beginning chemistry teachers conceptualize and enact the triplet relationship during their first three years? Do these representations change over time?
- In an examination of the representations of one fundamental aspect of chemistry content (i.e., atomic structure) over time, how does a beginning teachers' knowledge of student learning impact their enactment of the representations?

Using the mixed-methods research design described in Chapter 3, I quantitatively analyzed the use of triplet representations by teachers during their first three years in the classroom. I then qualitatively examined the influence of teacher knowledge of student learning on the representations enacted by the teacher. Using a mixed-methods process during the interpretation phase (Creswell & Plano-Clark, 2011), integrated conclusions were drawn. These conclusions are discussed in light of the literature presented in Chapter 2. The integration of findings was done through Creswell and Plano-Clark's (2011) strategy that allowed the use of a theoretical framework (i.e., PCK conceptual framework) to "bind together the data sets (p. 66)." Finally, the implications for the field of science and chemistry education are presented in this dissertation.

Conclusions

The central goal of this study was to capture change in beginning chemistry teachers' knowledge and practices over their first three years in the classroom. Two conclusions were drawn from the integration of the data. When emphasizing the knowledge of representations, this study found that beginning chemistry teachers developed a more sophisticated repertoire over time. When focusing on the knowledge of students' learning needs, teachers developed understanding of their students' needs in light of their enacted repertoire.

Developed a More Sophisticated Repertoire

This study found that the beginning chemistry teachers developed a more sophisticated repertoire for the triplet relationship for atomic structure as a result of increased experience working with students. This change manifested itself through the: 1) shift from abstract representations to macro representations, 2) identification of student barriers within representations, and 3) incorporation of a broader set of representations.

Over time, teacher repertoire development for atomic structure led to an increase in the quantity of macro representations used in the classroom. This study found that the teachers began their career enacting instructional strategies centered on the abstract components of the triplet relationship. Across the three years, a macro repertoire evolved that provided both an observable feature to atomic structure and connection to the submicro and the symbolic components. Despite this change, teachers indicated that they did not intentionally plan to address all three components of the model.

Previous research suggests that this change may be due to chemistry textbooks that often include multiple representations that address all components of the triplet (Bodner & Domin, 2000; Gabel, 1999; R. B. Kozma & Russell, 1997; Levy & Wilensky, 2009; Lewthwaite & Wiebe, 2010; Van Driel, et al., 2002). Another source of influence may be the laboratory activities used by the teachers. These activities did address different components of the triplet. Regardless of the reason (textbooks or laboratory activities), the teachers expanded their triplet representation repertoire.

Another distinguishing characteristic of the more developed repertoire was an increase in the teachers’ ability to identify learning barriers within various atomic structure representations. Barriers were those elements that teachers found to cause confusion and foster misconceptions amongst students. With this information, the teachers identified the strengths and weaknesses of various representations in addressing the students’ learning.

This aligns with the research by Clermont et al. (1994) that found experienced chemistry teachers were more aware of the complexities of a given representation than their novice counterparts. In this study, the third year teachers were experienced in comparison to their practices in the first year teaching. The experienced teachers, in this study, identified suitable variations to a representation in order to reduce the complex nature of the instructional strategies.

With increased classroom experience, the teachers also increased the overall quantity of atomic representations they used in their classrooms. This increase is captured in Table 6. Note the increase of macro representations alongside the continuation of incorporating various abstract representations. This supports the research findings by Clermont et al. (1994) in which experienced teachers held a broader set of representations for presenting the content than novice teachers. These differences included a greater number of alternative representations to address the needs of the students. However in this study, the teachers did not discuss the reason for the inclusion of more representations in a class hour. Instead, they focused on a single representation presented in a lesson and how it addressed student learning.

The teachers in this study developed their beginning repertoire. They did this by shifting practices that included more macro representations, recognized barriers to representations, and incorporated more representations. These findings support the notion that the teachers were broadening and diversifying their repertoire through experiences with both the students and the representations.

Began to Recognize and Modify Instruction Based on Students' Learning Needs

This study found that when changes to the classroom representations occurred often it was a result of the teachers' considerations of students' learning needs. Specifically, teachers referenced students' difficulties, varied approaches to learning, and prior knowledge. This was similar to what Lee et al. (2007) reported in their study of beginning and experienced secondary science teachers.

Over the three-year period, the teachers recognized students' difficulty with aspects of the triplet that led to modifications to the implemented representations. This study found that teachers focused on students' challenges with connecting the symbolic representation to the submicro explanation. They addressed these challenges by modifying instructional representations for this specific connection over time.

This finding supports the research by van Driel et al. (2002) that found preservice teachers recognized the difficulties students had with connecting the various components of the triplet by making changes to their instruction. Clermont et al. (1994), on the other hand, found that experienced teachers addressed student difficulties by implementing simple and straightforward representations. The majority of the teachers in this study were not ready to abandon the more complex representations. Instead, they made modifications to the complex representations as well as they added more to representations to address the students' difficulty with atomic structure.

With increased classroom experience, teachers responded to students' diverse approaches to learning by purposefully enacting specific and varied representations. As the teachers became more astute in recognizing the different needs of their students, they shifted from the use of one representation to the use of multiple representations. This aligns with the research by Clermont et al. (1994) that found experienced teachers provided students with multiple representations in order to represent a specific topic in chemistry. In addition, the experienced teachers added more representations to present the topic from varied angles. This was not the case for the teachers in this study. Instead the experienced teachers in this study discussed the use of varied approaches to engage students in learning atomic structure.

To varying degrees, the teachers recognized and responded to students' preconceptions of atomic structure over time. While all teachers mentioned prior knowledge, not all believed that students held any previous understandings of atomic structure. They accounted for the students' lack of knowledge because the teachers knew the students' previous course experiences, which is consistent with the findings by Otero and Nathan (2008).

Geddis et al. (1993) found that when beginning teachers captured students' prior knowledge, they did so in limited ways. This finding is consistent with the beginning teachers in this study. For instance, teachers in this study implemented a short answer question prior to beginning the atomic structure unit. Regardless of whether or not the teacher intentionally established students' prior knowledge, they used their perceived knowledge of students' preconceptions to structure the order for the representations of atomic structure to build upon students' understanding.

The teachers in this study developed a deeper understanding of the needs of their students across the first three years in the classroom. This finding was drawn from the teachers' discussions in which they identified some aspects of students' prior knowledge, varied approaches to learning, and difficulty with atomic structure. As a result, the teachers made changes to their triplet representation instruction over time. These findings support that the beginning chemistry teachers gained new perspectives of students' learning needs by working with the students and the triplet representations. This finding is consistent with the findings by Shulman (1986, 1987) and other scholars' research on specific chemistry topics and teachers' instructional decisions (e.g., Clermont, et al., 1994; Sande, 2010; Van Driel, et al., 2002).

While the teachers showed growth in their PCK, the findings cannot be generalized beyond these participants. A small sample size has a greater probability that the observations occurred may be unique to the study (Maxwell & Delaney, 2004). The teachers were recruited from the American Southwest and the Midwest with the qualitative data focusing upon teachers from the Midwest. Therefore, there may be an impact due to regional differences, which would make generalizing the findings to all beginning secondary chemistry teachers difficult. As such, these findings cannot be generalized to the broader community based solely on this study.

Implications

This study was designed to investigate the development of beginning chemistry teachers' PCK through the knowledge of representations and knowledge of students' understandings. The findings from this dissertation study revealed implications for research on the triplet relationship, chemistry teacher preparation programs, professional development for chemistry teachers, and the chemistry education community.

First, this research has expanded upon prior studies by providing a lens into beginning chemistry teachers' classrooms in the United States. Prior research on chemistry teachers use of the triplet relationship was conducted with beginning and experienced teachers in Canada (Lewthwaite & Wiebe, 2010) and preservice teachers in the Netherlands (Van Driel, et al., 2002). In addition, this study adds to prior discussions about the triplet relationship with specific topics in chemistry as with chemical reactions (Van Driel, et al., 2002) and gas laws (Sande, 2010). The current study provides new information into how beginning chemistry teachers represent the triplet relationship along with how they responded to students learning needs with atomic structure. More research needs to be done on American chemistry teachers' triplet relationship use with other core chemistry topics in order to provide a better understanding of how teachers represent the content.

The second implication is related to the importance of constructing a beginning repertoire during a preservice program. Studies have found that teachers have benefited from experiences in developing their initial repertoire (e.g., De Jong, et al., 2005; Meyer, 2004; Van Driel, et al., 2002). From this study, the beginning chemistry teachers relied primarily upon colleagues in determining what, when, and how to teach the content during the first year in the classroom. Teachers made changes to the representations during this first year, but they did not consider their students' learning needs. Therefore, if we plan to prepare teachers to respond immediately to student needs, preservice teacher education programs need to address developing this beginning repertoire. Much like the teachers in van Driel et al.'s (2002) study, preservice teachers could benefit from topic specific instruction to build representational repertoire.

Another implication pertains to the importance of explicit development of teacher awareness of the triplet relationship and its role in designing and teaching chemistry. Previous research by van Driel et al. (2002) and Lewthwaite and Wiebe (2010) did not anticipate that teachers would recognize students' difficulty with the triplet relationship as well as modify instruction with the triplet components without participating in professional development on the triplet relationship. While the beginning teachers were found to use the triplet statistically equally, only two teachers discussed the impact of the representation on student learning in order to deepen students understanding of atomic structure. As studies have found, the teacher must make explicit the tacit knowledge of the triplet relationship while also supporting content learning (De Jong & van Driel, 1999; Johnstone, 1991; Robinson, 2003; Sande, 2010; Van Driel, et al., 2002). Chemistry teachers at every experience level (i.e., preservice, induction, and inservice) could benefit from instruction focused upon the development of content knowledge alongside pedagogical strategies through instruction highlighting the triplet relationship.

From this research study as well as others, both novice and experienced chemistry teachers are initially unaware of the result of the triplet relationship upon student learning (Sande, 2010; Van Driel, et al., 2002). In this study, the teachers did consider the triplet, but not all discussed the three components as impacting student learning. As with the teachers in van Driel et al.'s study, only through professional development focused on the triplet relationship engages teachers in explicit discussions about the triplet instructional practices and student learning. To address this need, Feiman-Nemser (2001) suggests support for the development of subject matter knowledge for teaching, design of a responsive instructional program, and extension and refinement of the instructional repertoire. This should be a consideration for the preservice, induction, and inservice professional development programs which are instrumental in supporting the development of pedagogy practices in light of subject specific structures.

A final implication is associated with a revision of the triplet relationship to move beyond a content framework. As defined by the chemistry education community, the triplet focuses solely upon the structure of chemistry (Erduran, et al., 2007; Gilbert & Treagust, 2009a; Talanquer, 2011). I suggest revising the current model to illustrate the need for teachers to make connections between the content structures to some overarching context. Currently, the triplet model does not account about science education concerns about socioscientific issues which would provide a conduit for making science approachable for students (Klosterman & Sadler, 2010). By adding a fourth component, context would be included to help students make meaning of the world by introducing ideas on the nature of science, the history and philosophy of science, and socio-cultural issues through the macro, submicro, and symbolic components (Lewthwaite & Wiebe, 2010; Mahaffy, 2006). As this study utilized the triplet conceptual model, it fails to postion the chemistry content in contexts linked to real world applications. In the growing interest of science education reform, a revised model would situate chemistry education to connect classroom science to the science of the everyday.

Final Thoughts

This study contributed to the much-needed area of research on teachers' use of the triplet relationship and the impact student learning has upon teachers' use of classroom representations. This is one of a few longitudinal studies of teachers' use of the triplet and the only one that focused solely on beginning chemistry teachers. The findings support previous work in which teachers developed a more sophisticated repertoire as well as deepened their understanding students' learning needs. If teachers are cognizant of their students' learning conceptions and difficulties, the end result is a clear and concise representation to present the triplet components. Conversely, teachers that do not consider students' needs may not make the necessary adjustments to the representation.

A better understanding of the development of teacher knowledge, including that of beginning chemistry teachers' representations and knowledge of student learning, is part of the foundation for improving current professional development programs (Feiman-Nemser, 2001; Gess-Newsome, 1999; Long & Kirchhoff, 2008). Preservice, induction, and inservice programs that do not build and support the foundational knowledge for both PCK components leave the teachers struggling with finding instructional practices that address student understanding. As the ACS and fellow science educators push for changes in the preparation of chemistry teachers, only time will tell how the efforts of improving teacher knowledge will be impact student learning in the classroom. However, research into this area of study does provide specific insights into improving the teaching practice of chemistry teachers.

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APPENDIX A

ATSI PROTOCOL

Semi-structured interview:

As you know, we have followed beginning science teachers through the first years in the classroom in terms of beliefs, view of science, and teaching practices. Of particular interest to me are chemistry teachers' knowledge and how they represent the content. Today, I would like to get a better view of how you view chemistry and the atomic structure.

The information you provide in this interview will be used as part of my dissertation research on chemistry teachers. My interest is in learning from your knowledge and experiences with the content.

This interview will take up to one hour with all responses being confidential.

Background information:

1. Have you had any work experience in chemistry or any related fields outside of the classroom? If so, how long did you work in this field? What motivated you to make a career change and go into teaching? [Probe: any summer internships and research assistantships.]

2. Where do you currently teach? What chemistry (science) course(s) do you teach at this time? Has this changed over the 6 years?

3. Why did you choose these activities to use during the first year? Then 2nd, 3rd? (refer across all data and years)

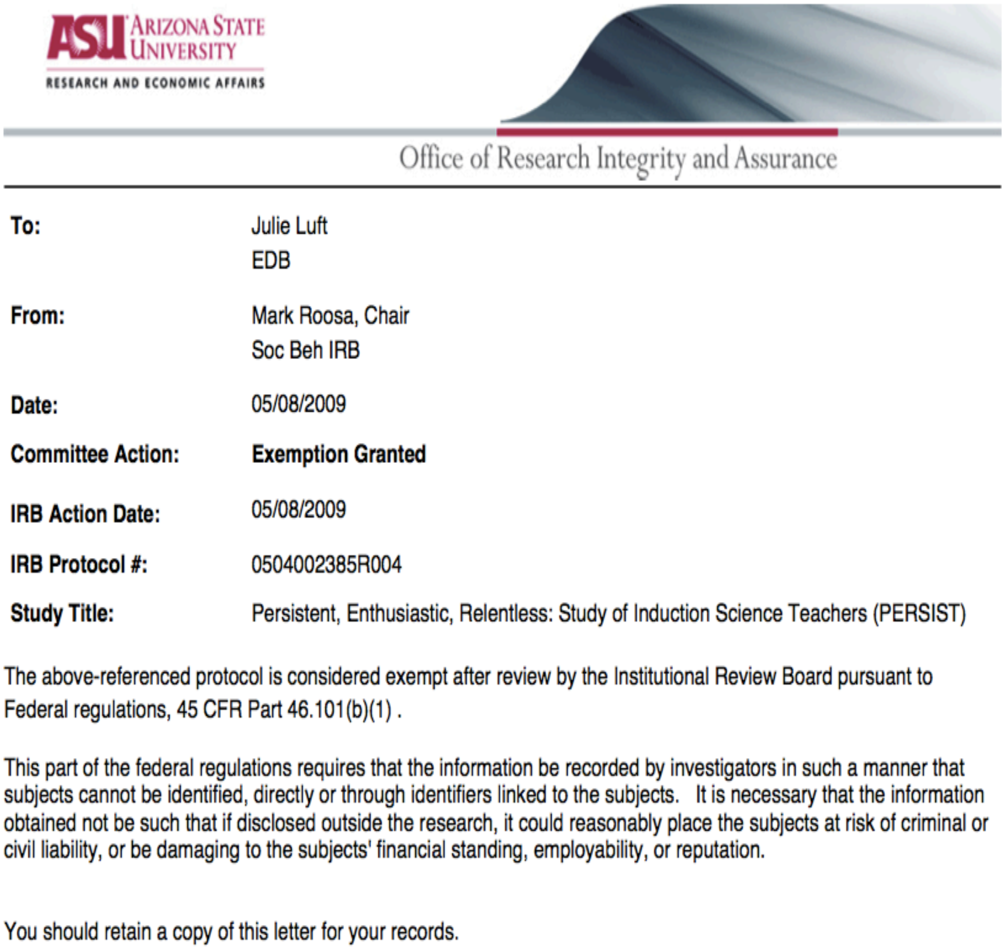
   [Probe for origination of choice, the changing of specific activities from one year to the next, the continued utilization of a particular activity, how these help students learn, and follow-up questions to the respondent's answers]

4. Is there anything else that I have not considered that you think is important in understanding your implementation of these activities for atomic structure?

Thank you for your time in discussing your views of chemistry. Your input is invaluable in the understanding of beginning chemistry teachers.

APPENDIX B

IRB APPROVAL LETTER



ARIZONA STATE UNIVERSITY
RESEARCH AND ECONOMIC AFFAIRS

Office of Research Integrity and Assurance

To:	Julie Luft EDB
From:	Mark Roosa, Chair Soc Beh IRB
Date:	05/08/2009
Committee Action:	**Exemption Granted**
IRB Action Date:	05/08/2009
IRB Protocol #:	0504002385R004
Study Title:	Persistent, Enthusiastic, Relentless: Study of Induction Science Teachers (PERSIST)

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

APPENDIX C

PCK INTERVIEW PROTOCOL

Participant		Interviewer	
Induction Group		T1/T2/T3/T4	
Date		DSS Recording Time	
1.	What do think constitutes a good lesson in science?		
2.	Can you briefly describe a lesson or unit you taught that you thought was successful?		
a.	What did you consider when planning your lesson/unit?		
If not explicitly mentioned – use the following probes			
i.	Did you consider prior knowledge? If so, how?		
ii.	Did you consider variations in students' approaches to learning? If so, how?		
iii.	Did you consider students' difficulty with specific science concepts (misconceptions)? If so, how?		
iv.	Is this a good example of inquiry in science? Why or Why not? If not, how would you change this lesson to reflect inquiry.		

APPENDIX D

MONTHLY INTERVIEW PROTOCOL

Teacher Name: **Interviewer:**
Grade/Subject: **Date:**
Schedule Type Traditional (< 60 mins) Block (> 60 mins)
Class meets: Daily 2-4 days a week
Update# **1** **2** **3** **4** **5** **6** **7** **8** **9mu**

Protocol:

Before

- Read participant file before calling participant --if you are not familiar with the participant.
- Call/e-mail ahead of time to set a time to talk. Follow-up frequently if you don't get a response right within 48 hours.
- Decide which class to collect information on (refer to teacher's schedule). Updates should reflect the composition of classes (e.g., 75% bio/ 25% physics = 6 interviews in biology and 2 interviews in physics).
- Make sure you have the audio recorder and that it is set correctly, and that you have checked the batteries.

During

- Have the teacher describe the lessons and clarify what they taught each day, how they taught it, the origin of the lesson, and what materials they used.
- Block schedule- code a block day for two days
- Type this review, if possible.
- Make sure you ask for the artifacts from the lessons at the end of the interview – establish how you will get these.

After

- Upload file to the computer, mark interview as complete, and file the update sheet. Check board indicating that interview was completed.

Interview questions

Background questions (these questions will be used in our demographic database):

1. What is year of your birth?
2. What is the name of your school?
3. What is your teaching schedule (what are you teaching each period of the day)? Will this be the same all semester?
4. Can you tell me about the science department? The school? Who do you ask for assistance? Who do you collaborate with (e.g., another science teacher)? Who do you talk about science teaching with? Are there others who are important in your work environment at your school?

> The goal of this probe is to capture the interactions that occur between the teacher and others in the school

5. Can you tell me about the administration at your school? Do you interact with your administrators? If so, what about? How would you describe the administration at your school?
6. How has the year started –so far? As you expected, or not? Why or Why not?
7. Is there any additional information you would like to share regarding your teaching that we have not talked about or that would be helpful for us to know?

APPENDIX E

SAMPLE PORTION OF THE OBSERVATION PROTOCOL

I. Background Information

Teacher Name: ___________________ School: _____
Subject Observed: ___________________ Grade Level: _______
Observation is (circle one) in-field/ out-of-field based on major & content
Start Time: ______________ End Time: __________ Date :______
Schedule Type: Traditional (45-60mins) _____ Block (60-over) ______
# of classroom meetings a week 5______ 2-4 __________
Observer: ____________________ Observation # (circle one) : 1 2 3 4
Number of students in class ____
Brief description of students in class:
Socio-Economic Status low
M/F Ratio
# of students
school uniforms
ethnic breakdown

Protocol regarding the observational coding:

- The first priority should be to take notes about the lesson. This will be recorded under III. Description of events over time.
- Record the most salient event during the 5 minute data collection periods. For example, students may work individually and the may work in groups. If they spend more time individually, then code the 5 minute segment as individual.
- Under cognitive activity, code what happens and not the intent of the lesson.
- At the end of the lesson code the 10 items for "quality" of instruction.
- Try to observe a variety of classes that represent the content areas that are taught.

II. Contextual Background and Activities

A. Objective for lesson (ask teacher before observing):

B. How does lesson fit in the current context of instruction (e.g. connection to previous and other lessons)?
*write down agenda

C. Classroom setting: (space, seating arrangements, room for the lesson, if desks are fixed or moveable, posters (science vs. non-science), student work, is it conducive to lab work (or teaching science) etc. Include a diagram).

D. Any relevant details about the time, day, students, or teacher that you think are important? Include diagram. (i.e.: teacher bad day, day before spring break, pep rally previous hour, etc.)

IV. Evaluation of the class in 5-minute increments

Time in minutes	0-5	5-10	10-15	15-20
Instruction				
Organization				
Student				
Cognitive				

Key ---*Note:* Type of Instruction - requires two codes: type of activity and organization (Ind, Group etc.)

Activity codes	
B	bellwork
Lec	teacher led lecture w/o discussion
LWD	teacher-led class discussion
Dir	teacher directions
Dem	teacher-led demonstration
Sim	teacher-led simulation
RT	teacher-led review -test
RH	teacher-led review – homework/ previous day
RI	teacher- led review – in-class assignment
LI	inquiry lab/activity
LG	guided inquiry lab/activity
LD	directed inquiry lab/activity
LV	verification lab/activity
LP	process/skills lab/activity
RP	research project
SR	student reading assigned material
TB	students work from textbook
WK	students complete worksheet
SP	student presentations
V	video/film/DVD
HA	homework assigned
HC	homework collected
FT	out-of-class experience (field trip)
AD	administrative task
Q	quiz
I	interruption
NS	non-science instruction
O	other ______________________ (please specify)

Organization Codes	**Student Attention to Lesson**
WG whole group SG small group CL cooperative learning (ex: roles, individual accountability, etc.) Ind students working individually on assignments	LE low attention, 80% or more of the students off-task. Most students are obviously off-task – heads on desks, staring out of the window, chatting with neighbors, etc. ME medium attention, 50% of students are attending to the lesson. HE high attention, 80% or more of the students are attending to the lesson. Most students are engaged with the activity at hand – taking notes or looking at the teacher during lecture, writing on the worksheet, most students are volunteering ideas during a discussion, all student are engaged in small group discussions even without the presence of the teacher

Cognitive Activity –This should be coded for the students who are participating (not for the intention of the lesson)

1 Receipt of Knowledge--(i.e., lecture, reading textbook, etc.) Students are getting the information from either a teacher or book. This generally includes listening to a lecture, going over homework or watching the teacher verify a concept through a demonstration or working problems at the board. The critical feature is that students are not doing anything with the information.

2 Application of Procedural Knowledge-Students apply their knowledge (from Bloom's taxonomy: Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.). This typically involves students using what they have learned, doing worksheets, practicing problems, or building skills. The critical feature is simple application of information or practicing a skill.

3 Knowledge Representation-organizing, describing, categorizing. Students manipulate information. This is a step beyond application. Students are re-organizing, categorizing, or attempting to represent what they have learned in a different way – for example, generating a chart or graph from their data, drawing diagrams to represent molecular behavior, concept mapping.

4 Knowledge Construction-higher order thinking, generating, inventing, solving problems, revising, etc. Students create new meaning. Students might be generating ideas, or solving novel problems. For example generating patterns across three different data sets, drawing their own conclusions, articulating an opinion in a discussion or debate.

5 Other-e.g. classroom disruption, no science in the lesson, administrative activity

APPENDIX F

TRIPLET SCORING RUBRIC

Triplet Scoring Rubric

OBS/WU:	**Date:**	**Researcher:**
Participant:		**Topic:**

Definitions:

Macro: concrete observations of macroscopic properties that are observable, measurable, quantifiable, and reproducible. (Example: laboratory activities, demonstrations, pressure, density)

Submicro: Provide explanations at the particulate level in which matter is described as being composed of atoms, molecules, and ions. (Example: explanations of observed behavior at the atomic level)

Symbolic: Symbols, elemental names, positive and negative signs, models (ball & stick, drawings), mathematical formulas, electron configurations.

Examples:

WU: Practiced electron configurations. (*Note: cannot determine if teacher focused on explanation of the electron configurations*)

WU: Learn to draw molecular shapes. Teacher holds up a compound and asks students' what they think about this compound and why it has this shape. (*Note: the student should use some kind of reasoning to determine the molecular shape*)

Obs.: Identification of metals flame test lab (Lab = 35 minutes): Teacher lecture: (5 minute mark) "The point is that each element will have a different arrangement of electrons around the atom". (Note: *teacher does not mention writing electron configurations just discusses the arrangement of the electrons*)

Activity	**Macro**		**Submicro**		**Symbolic**	
	Present (Yes/No)	**Time***	**Present (Yes/No)**	**Time***	**Present (Yes/No)**	**Time***
Practice	N		N		Y	
Molecular shapes	N		Y		Y	
Flame test lab	Y	35	Y	5	N	

Not to be coded: (1) lessons on the scientific method, metric system, dimensional analysis, or significant figures as these do not represent chemistry topics; (2) any lesson that does not involve a chemistry concept; (3) involve the review for or implementation of classroom assessments; and (4) videos.

Activity	**Macro**		**Submicro**		**Symbolic**	
	Present (Yes/No)	**Time**	**Present (Yes/No)**	**Time**	**Present (Yes/No)**	**Time**
Total						

APPENDIX G

CHRIS'S RESEARCH-GENERATED MATRIX

Atomic Structure	**Macro**	**Submicro**	**Symbolic**
Year 1			
Monthly Interview Chemistry September		Video on the History of the Atom; Worksheet Lecture on: Periodic table, Bohr's model of the atom, weight of subatomic particles, chemical symbols, mass number. Lecture on isotopes calculate atomic mass. Lecture on isotopes, charges, cations and anions	Bohr's model of the atom Fill in chart (assuming periodic table) Calculated atomic mass Worksheet: examples of cations and anions
Observation Chemistry September		Lecture on the location of s, p, d, and f orbital. Explains short hand electron configuration to students. Notes on atomic size increasing going down family.	Explains short hand electron configuration to students.
Year 2			
Monthly Interview Chemistry October		Fictional periodic table: to get students to think about how the PT is put together.	T-P-S electron configurations and orbital diagrams.
End of the Year Interview		Blank periodic table: look at it the levels are getting closer and closer. Talked about filling shells in order. Rock concert description.	Electron configuration

Year 3			
Monthly Interview Chemistry October	Flame Test Laboratory Activity	Video: Quantum mechanical theory. Lecture brief history Lecture: Principle quantum numbers and sublevels. Legume lab: Average atomic mass calculations The rock concert analogy: Rules for EC and orbital filling; Rules for predicting sublevels. Flame Test Laboratory Activity Simulation: Stair step emission.	Legume lab: Average atomic mass calculations The rock concert analogy Write electron configuration
Observation Chemistry October	Flame Test Laboratory Activity to verify the existence of electron orbital	Flame Test Laboratory Activity to verify the existence of electron orbital	

APPENDIX H

KEITH'S RESEARCH-GENERATED MATRIX

Atomic Structure			
Year 1			
Monthly Interview Chemistry September	Lecture: story of the history of science and the philosophy of science Lecture about the periodic table history Video of combustion of Na metal	Lecture on the parts of the atom, protons, and electrons Lecture on the history of the elements	Historical diagrams Lecture about the symbolism of the elements Drawings of symbols Lecture on calculating atomic mass
Year 2			
Observation Applied Chemistry April	Flame Test	Review: the electrons in the atom when you add energy to a substance the electrons gain some energy and then the electrons bumps up to a different energy level.	We have 2 equations we have been using: $E=hc/\lambda$ and $E=h\nu$
Monthly Interview Applied Chemistry April	Atomic spectra lab Flame test Video: Fireworks, history and science	Lecture Bohr's model Lecture: energizing electrons and relation to the electromagnetic spectrum	

Year end interview	Start with the history: Dalton Cathode ray tubes Do more demonstrations	Talk about subatomic particles. How the cathode ray tube works. History project: have the students look at the evidence of each model and research the model.	Start with various models of the atom. Lecture about each model Card sort activity: Laws of definite proportions Could have students create matter, atoms, and molecules History project: have the students look at the evidence of each model and research the model.
Year 3			
Monthly Interview General Chemistry December	History of atomic structure that went behind newer models of the atom (Computer lab simulations with worksheet) Spectrometers: gas tubes (neon, helium, nitrogen, etc.…) Black light, chalk, fluorescent lights, phosphors in vials	Lecture on light Lecture on light and luminescence and phosphorescence.	Write electron configuration Calculate light energy in atomic spectrum.

APPENDIX I

PAM'S RESEARCH-GENERATED MATRIX

Atomic Structure			
Year 1			
Observation 1 (October) Chemistry 10th and 11th	Demonstration: Steel wool, vinegar and water	What do you think of when you hear the word atom? Lecture on atomic theory	Law of Definite Proportions (Proust Law) Students draw pictures of atoms on the wall
Monthly Interview (November) Chemistry			How to do electron configuration and short configuration
Year 2			
Observation (March) ChemCom	Like a fingerprint each element has a unique color they give off depending on the element	Lecture: Electrons move like going up steps; element has a valence shell with electrons; Like a fingerprint each element has a unique color they give off depending on the element	Computer generated Bohr's model
Monthly Interview (March) ChemCom		Lecture: Bohr Model	Lecture: Lewis Dot Structure Introduction to Bohr Models Computer generated Bohr's model

Y2 Interview	Flame Test: student will relate flame tests and characteristic colors of elements to fireworks Video: fireworks, Gold foil activity simulation	Size of the atom and talk about how it contributes to the macro scale properties Flame Test: student will relate flame tests and characteristic colors of elements to fireworks	Draw a picture of the atom and label their structures Models of the atom
Year 3			
Observation (October) Gen. Chem	Lecture: Facts about Lavoisier and his experiment. Demonstration: Steel wool and vinegar Penny and water ½ tablet of Alka-Seltzer and bottle cap (Measure mass of the entire system)		
Monthly Interview (November) Gen. Chem	Standing wave demonstration Notes on periodic properties Video: fireworks Relate flame test to fireworks Reactivity of Alkaline Earth Metals Lab (Comparing Mg, Ca, and H2O)	Relate colors of electrons to fireworks;	Lecture electron configurations Practice problems: Electron configuration HW: Bohr's Model Worksheet

Y3 Interview	Lecture Lavoisier and the periodic table Flame test Video on fireworks; Historical Scientists model of the atom Old/young lady illusion	Historical scientists model of the atom; Tie that into quantum mechanical model Spectroscope activity	Game to learn the rules for electron configuration Bohr's Model Draw pictures of what they think of the atomic structure Orbital configurations: beads in the configurations, science games with marbles for the Bohr model

APPENDIX J

PATRICK'S RESEARCH-GENERATED MATRIX

Atomic Structure			
Year 1			
Monthly Interview Chemistry October	Lecture on three experiments (no description of the experiments) Lab: Verify conservation of mass	Lecture on atomic structure Lab: Verify conservation of mass	Lecture: Law of definite proportions, Law of Conservation of mass, and Multiple proportions
Observation Chemistry December			Practice electron configuration, orbital diagrams, and noble gas configurations
Year 2			
Monthly Interview Chemistry January	Lab: Relating magnetism to electron configuration	Lab: Relating magnetism to electron configuration	Lab: Relating magnetism to electron configuration
End of the Year Interview	Lab: Relating magnetism to electron configuration	Lab: Relating magnetism to electron configuration Egg carton activity Card game with prongs representing the number of valence electrons Talk about energy levels; I relate that to the first ring can hold 2, then the 2nd ring can hold 8;	Three rules: Hund’s Rule, Aufbau Principle, Pauli’s exclusion principle Lab: Relating magnetism to electron configuration Talk about orbital shapes Talk about energy levels; I relate that to the first ring can hold 2, then the 2nd ring can hold 8;

Year 3			
End of the Year Interview	Video clips of Rutherford’s and Thomson’s experiments Demo: Cathode ray tube	Talked about the number of electrons in energy levels & Valence electrons Container with unknown shapes	Hand out cards with atom sizes, color of the atom, and number of spokes

APPENDIX K

TIME-ORDERED MATRIX

	Y1	Y2	Y3
Chris	Chose most of the lessons because he took them from the other chemistry teacher. The other chemistry teacher and he discussed the structure of the content, which involves moving around the textbook. Spent more time on current model of the atom because it benefits the students more in the long run. Use video because it provides pictures of laboratory activities and real world application.	He chose the "rock concert" activity, which he got from his student teaching experience. Provides a simple way to understand why the d-orbital and f-orbital lag behind the s-orbital and p-orbital. Kids come to class excited about a fantasy rock concert. The lecture ends with the students connecting the pattern of the seating arrangement of the concert to the arrangement of the periodic table.	At the beginning of the school year he had moved to a new school. His new colleagues had a legume-lab activity to explain isotopes in chemistry. This is such an important concept to understand the periodic table and wished he had been doing this for the two years prior.
Pam	In the first year, she felt she did not have a good grasp of the content. Activities were from colleagues though she edited them, textbook, and teacher prep classes.	Implemented more technology because chemistry colleagues had written a grant for a new InterWrite board. Believed it would reach more learners with the technology. Activities are still being gathered from colleagues	There was pressure for her to increase the pace. But felt she compensated by focusing more on depth and lesson breadth. Focused on Lavoisier because a fellow teacher introduced her to his contribution. She uses it to bridge history and conservation of mass.
Keith	Introduced several activities that were in	Many of the activities were from colleagues.	The chemistry department requires

	one unit, but has since moved to other units to deal with flow and the schedule they have. Followed teachers to stay on the same page.	Video on Fireworks is relevant and provides a conduit for discussion. Some activities were too difficult for students to understand.	some of the activities chosen and a few are of things by his choice. Within the unit electron configuration and light, he has organized the unit to emphasize the historical sequence, which is different than his colleagues.
Patrick	Followed the other chemistry teacher the first year.	Tried to make things more inquiry based in the 2nd and 3rd year. Using inquiry encourages the students to more actively engage in the activity.	Incorporated more video clips to help students connect observed behaviors to what is occurring at the atomic level.