A Dissertation

entitled

Exploring Learning Progressions of New Science Teachers

by

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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

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An Abstract of
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First-, second- and third-year teachers can be considered novice teachers with a
solid foundation. The beginning years of teaching are intense times for learning, in
which teachers can build upon their foundational knowledge. However, traditional
mentoring programs often focus on technical advice and emotional support to help
teachers survive the first years. This study set out to understand new science teachers’
pedagogical content knowledge (PCK) in order to identify how their learning progresses.
Understanding teachers’ ideas will allow one to think about the development of educative
mentoring practices that promote the advancement of teachers’ knowledge.

To investigate teachers’ learning progressions, the following research questions
guided this study: What is the nature of pedagogical content knowledge of first-, second-
and third-year science teachers at various points across the school year? To which
aspects of pedagogical content knowledge do first-, second- and third-year teachers pay
attention at various points across the school year? Which aspects of pedagogical content
knowledge are challenging for first-, second- and third-year teachers at various points
across the school year? First-, second- and third-year teachers were interviewed,
observed, and their teaching artifacts were collected across the school year. Data were
examined to uncover learning progressions, when ideas became more sophisticated across first-, second-, and third-year teachers.

The findings of this study contribute to an understanding of how teachers’ learning progresses and allows for a trajectory of learning to be described. The trajectory can be used to inform the design of university-based mentoring programs for new teachers. The descriptions of the nature of teachers’ PCK and the aspects of PCK to which teachers pay attention and find challenging shed light on the support necessary to promote continued teacher learning.
For my husband, Jeff, I will be forever grateful for the support and encouragement you provided. For my son, Cooper, you were my daily inspiration to complete this journey.
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Chapter 1

Introduction

Problem Statement

After many years of school reform, policymakers and educators have realized that what students learn is related to what and how teachers teach, and the quality of our schools is determined by the quality of our teachers (Feiman-Nemser, 2001a). Reforms call for teachers who provide content-rich, learner-centered, relevant experiences for their students, which promote deep understanding and allow for critical thinking and problem solving (Feiman-Nemser, 2001a). However, what and how teachers teach is related to the knowledge they bring to teaching and the opportunities they have to continue learning through practice (Feiman-Nemser, 2001a). This highlights the importance of teacher knowledge and the notion of teacher as learner.

In the area of science education, the goal for all students to be scientifically literate has been prevalent for nearly two decades (National Research Council [NRC], 1996). Teachers play a critical role in improving science education and contributing to the scientific literacy of their students (NRC, 1996), and teachers are considered to be the most important factor in student learning (Committee on Science and Mathematics Teacher Preparation, 2001). They must be able to improve students’ abilities to be active learners who understand complex subject matter and are able to transfer what they have learned to new situations (NRC, 2000). Finding ways to teach subject matter to students in a manner that is understandable is one of teachers’ primary roles in the classroom (NRC, 2000). However, the task of providing students with learning experiences that
promote deep understanding of content requires teachers to have advanced knowledge of how to teach science content effectively.

Despite the critical role of teachers in students’ science education, it appears that most attempts to improve science education have been through revision and creation of content standards and curriculum materials. Despite efforts to improve science education through curriculum and standards-based reform, there is still a need for improvement (NRC, 2007) because these attempts do not address the impact of teachers in the classroom, including how they teach science. It is believed that lack of teacher preparation is one factor that contributes to the reform problem and “constrains how theories of teaching and learning are enacted in school settings” (NRC, 2007, p. 17).

However, a lack of pre-service teacher preparation is not always responsible for inadequate science teaching. Professional development attempts for in-service teachers, most commonly stand-alone workshops or professional conferences, are not effective at extending teachers’ knowledge and promoting continued professional growth. For this reason, there is a need to examine mentoring as a model of professional development for continuing teacher education after the pre-service years.

Regardless of the quality of teacher preparation, aspects of teacher knowledge need to be developed continually during in-service teaching (Feiman-Nemser, 2001b). Induction and mentoring programs, as well as professional development opportunities, have been created as efforts to improve teachers’ knowledge and address how they teach science. However, these efforts are not always successful because most policy mandates lack consideration of beginning teachers’ learning needs, provide short-term emotional support to retain teachers, and fail to provide the necessary experiences to guide the
intense learning that occurs in the first years (Feiman-Nemser, 2012). When teacher
education is cut short and teachers are viewed as finished products, they are not given the
experiences necessary to promote continued learning. The support provided to beginning
science teachers is vital to encourage sound teaching practices that improve science
education for students. However, the issue with current induction programs, which fail to
address the learning needs of beginning teachers, is the lack of attention to the continuing
teacher education curriculum. If the goal is to increase teachers’ knowledge of teaching
to produce effective educators, it is essential to carefully plan a curriculum that extends
upon their pre-service education to advance their knowledge and address their learning
needs.

Formal induction and mentoring programs became familiar features of continuing
education in the mid-1980s and have been used increasingly since then; however, the
quality of the programs varies and few teachers experience high-quality induction
(Feiman-Nemser, 2012). When induction is narrowly defined as a way to help new
teachers survive their first year, its educative role is diminished (Feiman-Nemser,
Schwille, Carver, & Yusko, 1999). *Educative mentoring* is an approach that goes beyond
situational adjustment, technical advice and emotional support and focuses on what
teachers need in the beginning years of practice (Feiman-Nemser, 2001b). Educative
mentoring views teacher support as a component of the broader field of teacher
development and focuses on helping new teachers learn to teach effectively by addressing
ways to engage students in worthwhile content (Feiman-Nemser et al., 1999). Educative
mentoring has provided a framework for thinking about the *learning to teach* continuum,
specifically the curriculum.
Many mentoring programs fail to make the curriculum an extension of pre-service education. In addition, most programs are limited to the first year of teaching, but scholars suggest that mentoring should extend beyond the first year and continue through the third year in order to take on a broad, developmental approach to learning to teach (Feiman-Nemser, 2012; Bartell, 2005). A challenge that can arise when developing curriculum for a mentoring program that includes first-, second- and third-year teachers is considering the various stages of knowledge and learning needs within the diverse group. Given this challenge, it is necessary to determine the nature of new science educators’ knowledge about teaching, where they focus their attention and what they find challenging throughout the year. These aspects of teacher learning are essential to understand in order to create experiences that promote continued learning and professional growth.

Pedagogical content knowledge (PCK) is the knowledge of how to teach specific content to students in ways that promote deep understanding (Shulman, 1986). This knowledge construct guides efforts to improve teacher learning because it defines the unique knowledge needed to teach science (Park & Oliver, 2008) and provides a shared language around the ideas of teacher learning (Loughran, Berry & Mulhall, 2007). PCK was used to frame this study because it is a construct that can help to identify what teachers learn as they practice (Schneider & Plasman, 2011). To help conceptualize science PCK, it was necessary to understand its components. Park and Oliver (2008) have developed a model of PCK for science teaching that includes the following components: 1) orientations to teaching science, 2) knowledge of science curriculum, 3) knowledge of students’ understanding in science, 4) knowledge of assessment of science
learning, and 5) knowledge of instructional strategies for teaching science. PCK involves how these components are understood and enacted in practice (Carter, 1990; Park and Oliver, 2008).

First-, second- and third-year teachers can be considered novice teachers who have a solid foundation. However, this foundation needs to be built upon so they can continue to learn and grow as professionals. Therefore, this study aims to examine the learning progressions of new science teachers in regard to their pedagogical content knowledge. *Learning progressions* are characterized by progress that is continuous and coherent, an incremental sequence from novice to expert performance (Heritage, 2008). Learning progressions can describe a trajectory for learning that spans a longer period of time, which allows teachers to engage in successively more sophisticated ways of thinking about their teaching over a broad span of time (Heritage, 2008). Utilizing learning progressions as a framework to think about teacher learning allows an understanding of how teachers’ ideas become more sophisticated and the development of a learning trajectory for the beginning years of practice.

Many studies conducted with new teachers focus on retention and job satisfaction. However, it is suggested that, in order to examine induction as an educational process, research should seek to answer the question “do teachers learn?” instead of “do they stay?” (Feiman-Nemser, 2012). In addition to studying whether and how new teachers learn, there is a need for experienced science educators to work with new science teachers as well as a need for researchers to study science teachers to realize the learning and teaching potential of science educators (Luft et al., 2011).
Context of Study

This study was situated within a university-based mentoring program, which is a continuation of the Licensure Alternative Master’s Program (LAMP). LAMP is a one-year, graduate, pre-service program for those preparing to become middle or secondary teachers. The mentoring phase of LAMP is different than many support programs for beginning teachers because of its carefully designed curriculum, which extends upon the pre-service LAMP curriculum and takes an educative mentoring approach to continued teacher learning.

The program is intended for current first-, second- and third-year teachers; the selection of this population is supported by scholars who hold the view that mentoring should extend beyond the first year of teaching (Feiman-Nemser, 2012; Bartell, 2005). All three cohorts of teachers participate in the program together. In addition, the mentoring sessions are held on the university’s campus, which allows the teachers to remain connected with the teacher education institution and faculty. Collaboration between schools and universities is an important component of mentoring beginning teachers effectively (Carter & Francis, 2001), and having collaborations with an external network of teachers is also beneficial to teachers during induction (Ingersoll & Smith, 2004).

Faculty members who participated in the pre-service year continue to be involved in the mentoring phase and, thus, are able to extend the learning processes initiated in the pre-service year. There are four mentoring sessions over the academic year. One occurs close to the beginning of the school year, one in the fall, one in the spring, and one shortly after the school year ends. There is also an online component that provides
continuous support between on-campus sessions, and visits to participants’ schools allow for individual mentoring. These aspects of the program enable the program to support progressive learning in a holistic manner. This study follows several first-, second- and third-year teacher participants across the school year.

**Purpose Statement**

The purpose of this study was to determine new teachers’ knowledge and learning needs to determine how their learning progresses and inform the future design of the mentoring program. To do this, it was necessary to understand the pedagogical content knowledge (PCK) of first-, second- and third-year science teachers at various points throughout the school year. In addition, it was important to look the aspects of PCK to which they paid attention and those which they found challenging throughout the school year. Understanding these aspects of teacher learning will allow the development of a curriculum that addresses the complexity of a mentoring program designed for varying levels of teachers by providing insight into learning experiences that attend to their specific needs and function to advance their learning. While having multiple levels of teachers within the same mentoring program can pose curricular challenges, it also has its advantages, as teachers with varying levels of knowledge can collaborate and learn from one another.

This study describes teachers’ ideas about teaching science and how these ideas progress. It did not set out to assess the teachers’ knowledge, the mentoring program, or the teachers’ pre-service program in any way. While the nature of teachers’ PCK will be characterized and explained, it was not the purpose of this study to evaluate teachers’ knowledge or assign labels such as proficient and accomplished, as would be done in
teacher assessments. Additionally, it was not the purpose of this study to make judgments about the effectiveness of the pre-service program or the mentoring program in contributing to teachers’ knowledge.

Learning progressions are a construct to help examine how teachers’ ideas progress as they learn through practice. To address the aims of this study and determine how new secondary science teachers’ learning progresses throughout the first three years of teaching, the following questions guided this research:

1) What is the nature of pedagogical content knowledge of first-, second- and third-year science teachers at various points across the school year?

2) To which aspects of pedagogical content knowledge do first-, second- and third-year teachers pay attention at various points across the school year?

3) Which aspects of pedagogical content knowledge are challenging for first-, second- and third-year teachers at various points across the school year?

This study uses a stratified sample to look at groups of first-, second- and third-year teachers and describe their knowledge and learning needs at various points throughout the year. It is important to point out this study was not longitudinal, and therefore the teachers were not followed for three years. To answer the research questions, this study looked at how the new teachers planned their lessons, enacted their plans, interacted with their students and reflected on their teaching. It was necessary to ask questions that required the teachers to explain their reasoning for why and how they planned and taught. These discussions helped to demonstrate their knowledge and illustrate how they translated their knowledge into practice.

Until recently, studies on PCK have focused largely on evaluating PCK, but not
for the purpose of finding ways to help teachers develop their knowledge (Loughran, Berry & Mulhall, 2013). This study focuses on a much-needed approach to finding ways to help teachers develop their knowledge. There is a need for research that examines PCK from the perspective of enhancing the practice of teaching science at all levels (Loughran et al., 2013). Scholars encourage “explicitly linking experiences of learning science with the practice of, and knowledge about, teaching science” because it “offers access to ways of developing science teachers’ PCK” (Loughran et al., 2013, p. 223). It is clear there is a need to study the PCK of new science teachers to develop high quality mentoring programs that foster the development of PCK by tailoring curriculum to the needs of teachers (Lee, Brown, Luft, & Roehrig, 2007). This study set out to explore teacher learning and will describe the nature of teachers’ PCK as well as the aspects to which they pay attention and those which they find challenging. Learning progressions are explained to demonstrate how teachers’ knowledge becomes more sophisticated as they learn through practice.

**Significance**

The findings of this study are important because they will help teacher educators understand how to support new teachers’ learning across time. The results of this investigation will be used by the LAMP mentoring program to inform its curricular design and the development of educative experiences for the science teachers who participate. Awareness of beginning science teachers’ pedagogical content knowledge, attention, and learning challenges will allow the curriculum to be designed in a way that addresses the needs of teachers at various points in their early careers. This helps attend to the challenge of having a diverse population of teachers with varying needs within the
same program. The findings of this study will also add to the field of science teacher education by contributing to the understanding of how teachers’ knowledge of how to teach progresses in the beginning years of their careers and how their learning can be supported.

Not only will the findings of this study benefit the LAMP mentoring program, they also can inform other mentoring or support programs for new teachers. This study responds to the call for future work that considers the learning progressions of science teachers to enable the field to design effective learning experiences for teachers over time (McNeill & Knight, 2013). The findings will help inform what we know about the knowledge of new science teachers and how it progresses to become more sophisticated over time.
Chapter 2

Review of Literature

Multiple questions guided the inquiry to determine what literature to review for this study. The questions included the following: What theoretical framework allows the examination of teacher learning on a continuum? What knowledge construct is important in guiding the thinking about teaching science content? What research methods have been utilized to study this particular knowledge construct?

The following review of literature outlines the theoretical perspectives for learning to teach and the research addressing the facets of learning to teach through practice. The majority of the review focuses on the teacher knowledge construct, pedagogical content knowledge (PCK), by defining it, describing how it has been conceptualized generally and for science teaching, describing its components and empirical research. Mentoring as a means of promoting continued teacher learning is also discussed. This chapter ends with a review of methods, where research on PCK will be reviewed to provide insight on the procedures and methods for examining this construct.

Science Teacher Learning: A Continuum

According to Feiman-Nemser, (2008) although what teachers should know, care about, and be able to do has been and is the dominant concern in teacher education, scholars have begun to appreciate that teacher learning extends beyond formal teacher education (Feiman-Nemser, 2008). Feiman-Nemser identifies four broad themes for learning to teach: learning to think like a teacher, know like a teacher, feel like a teacher and act like a teacher. The theme of particular interest in regards to this study was to
know like a teacher, which includes the knowledge teachers generate in practice.

Teachers need to know a great deal in order to enhance the academic learning of their students, which requires deep knowledge of content and how to teach it to diverse learners, and knowledge of curriculum, pedagogy, classroom organization and assessment (Feiman-Nemser, 2008).

Feiman-Nemser differentiates between knowledge for teaching, which is learned outside of practice, and knowledge of teaching, which is gained in the context of teachers’ work. When studying teacher learning in the classroom, it is important to focus on knowledge of teaching. Knowledge of teaching is gained as teachers utilize their existing knowledge and beliefs as a lens for interpreting new knowledge and experiences (Feiman-Nemser, 2008). Teacher learning is also influenced by the context in which they are learning, which includes both cultural and social contexts of where knowledge is acquired and used (Feiman-Nemser, 2008). It is important to consider the various settings in which teachers learn to teach because these settings can enable and constrain their ongoing learning (Feiman-Nemser, 2008).

Certain aspects of teaching can only be learned through practice, such as making decisions about what and how to teach over time and responding to students’ thinking (Feiman-Nemser, 2001a). Interpreting students’ ideas and making pedagogical decisions as a lesson develops is something teachers gain knowledge of as they teach within their contexts (Feiman-Nemser, 2001a). The beginning years of a teacher’s career are a time when new teachers have opportunities to learn about these aspects of teaching and improve their practice. However, this task can be challenging, and teachers need opportunities to work with others, including other teachers and mentors, to examine
problems within their classrooms and develop their teaching knowledge with the support of others. The notion of science teacher as learner is important because it “suggests practice carries an ongoing commitment to teaching” (Loughran, 2007, p. 1043). The aspects of this notion will be explored further through this review of literature.

**Situated learning.** Following Feiman-Nemser’s (2001b) assertion that despite the quality of teacher preparation, certain aspects of teaching can only be learned in the classroom, practicing teachers remain students who are learning about teaching and learning within their classroom settings. Brown, Collins and Duguid (1989) elaborate on the contextualized learning to which Feiman-Nemser refers. They challenge the idea that it is possible to separate what is learned from how it is learned and used. Brown et al. believe situations are essential for learning, and different learning experiences can produce different results.

Brown et al. explain that in order for conceptual knowledge to be useful, it needs to be understood within the community or culture in which it is used. They note an interconnection between activity, concept, and culture in which there cannot be an understanding of one without the other; the dynamic between the three is what allows for learning to occur (Brown et al., 1989). Textbook and prototypical examples do not provide the learner with the authentic experiences necessary for true understanding (Brown et al., 1989). Simply providing the learner with hypothetical situations is not sufficient. The learning activity must be immersed within the culture so that concepts can be understood. The authentic experiences to which Brown et al. refer include activities of the domain that are framed by its culture and are coherent, meaningful and
purposeful. Most simply described, authentic activities are the “ordinary practices of the culture” (Brown et al., 1989, p. 34).

The most meaningful context for an in-service teacher is his or her own classroom (Magnusson, Krajcik, & Borko, 1999). While pedagogical content knowledge begins to develop in pre-service programs where a framework is constructed, research indicates that the degree to which this translates to teachers’ understanding of their classrooms depends upon their learning experiences within the context of their classrooms (Adams & Krockover, 1997). Adams and Krockover’s research suggests that the framework teachers develop in pre-service programs is emergent over time. This supports the notion that teacher education is cut short when new teachers are viewed as finished products and argues for the need of a curriculum that continues into the in-service years of teaching to develop knowledge within the context of one’s classroom. Literature addressing the science teacher as learner suggests that during the induction phase, teachers need genuine support to guide them in the task of identifying their learning needs and working to develop their knowledge about teaching and learning science (Loughran, 2007). This suggests that teachers’ learning should progress as they participate as learners within their classrooms.

Reconstruction of experience. It is within the situated learning experience that teachers can reconstruct their previous experiences. The idea of reconstruction of experience comes from Dewey’s (1916) belief that knowledge cannot be transmitted; it is constructed and reconstructed consciously. According to Dewey, the knowledge of teaching gained through practice should be constructed and reconstructed by the learner, thus emphasizing the importance of the notion of teacher as learner.
Dewey (1904) specifically provides his beliefs on teacher education when he states the following:

Ultimately there are two bases upon which the habits of a teacher as a teacher may be built up. They may be formed under the inspiration and constant criticism of intelligence, applying the best that is available. This is possible only where the would-be teacher has become fairly saturated with his subject-matter, and with his psychological and ethical philosophy of education. Only when such things have become incorporated in mental habit, have become part of the working tendencies of observation, insight, and reflection, will these principles work automatically, unconsciously, and hence promptly and effectively. And this means that practical work should be pursued primarily with reference to its reaction upon the professional pupil in making him a thoughtful and alert student of education, rather than to help him get immediate proficiency. (p. 15)

Learning through practice provides an opportunity for the teacher to continue as a “professional pupil” and continue to develop habits that allow him or her to be an effective educator. It is not realistic to believe teachers will achieve “immediate proficiency” before they experience teaching in classrooms of their own. For this reason, it is necessary to continue to foster teachers’ growth throughout the beginning years of teaching and beyond. Dewey believes teachers cannot grow as professionals unless they are active students.

Dewey (1938) emphasizes the view of teaching and learning as a continuous reconstruction of experience that requires the educator to look ahead and consider every experience as one that influences future experiences. His philosophy of education is
centered on this idea, made obvious by his definition of education which states, “It is that reconstruction or reorganization of experience which adds to the meaning of experience, and which increases ability to direct the course of subsequent experience” (Dewey, 1916, p. 45). When an experience is complete and the learner gains knowledge as result, this is not the “end”. Continuity is a key factor; the learner must use the knowledge gained to direct future experiences. This is why viewing new teachers as finished products without learning needs is a critical mistake.

As Dewey (1938) explains, the principle of continuity of experience is involved in differentiating between experiences that are worthwhile and those that are not. An experience modifies the one who undergoes that experience, and the modification then affects the quality of the subsequent experience (Dewey, 1938). According to Dewey, central to this principle is the concept that an experience both takes up something from previous experiences and modifies the quality of those that come after. The learner is then different as he or she enters future experiences. Therefore, teachers are not simply learning more; they are learning to think about aspects of teaching in new ways.

Dewey (1897) believes “education must be conceived as a continuing reconstruction of experience; that the process and the goal of education are one and the same thing” (p. 13). He states, “The child’s present experience is in no way self-explanatory. It is not final, but transitional. It is nothing complete in itself, but just a sign or index of certain growth-tendencies (Dewey, 1900, p. 14). A key to this component of Dewey’s (1916) experiential learning theory is the ability of the immature individual to adapt in order to grow, which he calls plasticity. He explains that plasticity is not the capacity of one to change based on external pressures, but the ability for an individual to
learn from experience and use that experience to deal with later situations, which includes modifying actions as a result of prior experiences and the ability to develop dispositions. Because of this, Dewey stresses that plasticity is essential for the acquisition of habits. Dewey describes a habit as something deeper than just a fixed way of doing something a habit includes the formation of both emotional and intellectual attitudes (Dewey, 1938). He also indicates that a habit “marks an intellectual disposition” as a result of plasticity (Dewey, 1916, p. 204). Plasticity is vital for teachers to continue to learn through practice because it allows novice teachers to reconstruct their experiences, develop a deeper understanding of how to teach, and grow as an educator.

**Learning progressions.** As explained in the previous section, the view of promoting continued teacher learning is grounded in Dewey’s idea of educative experiences and the reconstruction of those experiences. These educative experiences change the teachers’ ability to participate in a knowledge community, consider how past experiences affect present and future ones, and emphasize the situational influence on one’s experiences. The idea of *learning progressions* is used to determine how these educative experiences should be organized and is grounded in Dewey’s ideas and further developed in Bruner’s (1960) notion of the *spiral curriculum*. As a spiral curriculum develops, it repeatedly revisits basic ideas, building upon them each time and allowing the learner to reconstruct his or her previous experiences. The goal is to challenge the learner as the curriculum becomes progressively more advanced and as time goes on and ideas are revisited. Bruner (1960) asserts, “curriculum ought to be built around the great issues, principles, and values that a society deems worthy of the continual concern of its members” (p. 52). In the case of science teaching, the curriculum for learning to teach
should be built around the core components of what it means to teach science to students in ways that allow them to develop a deep understanding of the content. In this study, these core components are outlined using PCK as a framework and will be discussed further in the following sections.

In addition to the spiral curriculum, Bruner refers to two ideas that are important to think about for continued teacher learning. One is intellectual development, which includes the fundamental ideas and logical structure of a domain. In this study, PCK is the framework in which the knowledge of teaching science is framed. The other dimension of Bruner’s theory is the act of learning. He describes three aspects of the act of learning. One is the acquisition of new information, which, at the very least, is refinement of previous knowledge. Transformation is the second aspect of the act of learning, which Bruner describes as the “process of manipulating information to fit new tasks” (p. 48). The third aspect of the act of learning is evaluation, in which the learner checks to determine whether the way they manipulated the information was appropriate for the task. In this case, the learner must reflect on how he or she utilized the knowledge.

It is important to point out that this study focuses on intellectual development in regard to how science teachers’ PCK progresses throughout their early careers. However, this study does not address the act of learning, as it does not examine how teachers acquire, transform, and evaluate their knowledge throughout the learning process.

The idea of learning progressions is not new, but rather a newer term to refer to the type of learning that occurs within a spiral curriculum and the manner in which
instruction can be planned to promote the reconstruction of experiences. Thinking of teacher learning as a progression allows one to describe a trajectory for learning that allows teachers to engage in successively more sophisticated ways of thinking about their teaching over a broad span of time (Heritage, 2008). This is characterized by progress that is continuous and coherent, an incremental sequence from novice to expert performance that is mediated by instruction (Heritage, 2008). As teachers’ learning progresses, they acquire adaptive expertise when they evolve their core competencies and continually expand the breadth and depth of their expertise (Bransford et al., 2006).

Schneider and Plasman (2011) conducted an extensive review of studies that looked at science teachers’ PCK. The studies reviewed spanned across the various professional phases of science teachers. Schneider and Plasman’s findings support the use of learning progressions to think about science teacher learning. When using PCK as a construct for looking at teachers’ ideas, they found that their thinking did become progressively more sophisticated over a broad span of time, and they were able to identify a sequence of changes in teachers’ ideas.

Viewing teacher learning as a continuous process takes on a holistic practice-based approach for learning to teach and becoming adaptive experts (Hollins, 2011). This includes going beyond standards for quality teaching and a focusing on knowledge, skills, and understanding. With this in mind, the goal for teachers is to change over time and to come to know things in a new way, not just know more or meet a prescribed standard. This holistic approach would need to involve a collaborative network, including other beginning teachers and university faculty, to extend upon pre-service education and continue the development of professional knowledge. Previous research indicates that
science teacher learning does progress over time (Lee, Brown, Luft, & Roehrig, 2007); however, it is important to know how it progresses in order to construct experiences to help promote this progression.

**Pedagogical Content Knowledge: What Teachers Need to Know**

When thinking about teacher learning as a progression, it is important to understand which knowledge is progressing and have a clear idea of the knowledge construct. One of the components of knowledge of teaching, as described by Feiman-Nemser, is knowing ones’ content and how to teach it to diverse learners, which is situated within one’s context and gained through practice. This type of knowledge is also known as Pedagogical Content Knowledge (PCK), a term coined by Lee Shulman (Shulman, 1986). PCK has become a widely accepted academic construct (Berry, Loughran, & van Driel, 2008) and a useful framework for science education research (Friedrichsen, van Driel & Abell, 2011). This study aims to examine the nature of teachers’ knowledge of how to teach science; although other types of teacher knowledge are important, PCK is the most appropriate knowledge construct to utilize for this aim.

Examining PCK is one approach to studying teacher knowledge, specifically how they translate their subject matter knowledge into classroom curricular events (Carter, 1990). However, it is important to distinguish between practical teaching knowledge and pedagogical content knowledge when looking at teacher learning because these terms are often used interchangeably. Practical knowledge is considered a teachers’ knowledge of classroom situations and the dilemmas they face teaching in these settings (Carter, 1990). Pedagogical content knowledge is “to a greater extent grounded in disciplines and formulations related to school curriculum and the collective wisdom of the profession.
than practical knowledge” (Carter, 1990, p. 306). However, it is important to point out that even though one aspect of PCK is the enactment of knowledge, the teacher must understand the components of PCK in order for them to be enacted as classroom events (Carter, 1990).

Situated learning is vital for the development of PCK because it is through the authentic activities described by Brown et al. (1989) that PCK is cultivated. Shulman first described PCK as a blend of knowledge of one’s content and knowledge of the teaching process (Shulman, 1986). This type of knowledge is imperative because “mere content knowledge is likely to be as useless pedagogically as content-free skill (Shulman, 1986, p. 8). PCK is not just knowledge of subject matter, but also how that subject matter is taught (Shulman, 1986). While teachers gain more contextualized knowledge of students, they are able to deepen their PCK to enrich their curriculum and deal more effectively with topics and concepts that students find particularly difficult (Feiman-Nemser, 2001a).

PCK includes the most useful forms of representation of topics regularly taught in one’s subject area and the most powerful analogies, illustrations, examples, explanations, and demonstrations that the teacher can use to convey the subject matter so it is understandable to others (Shulman, 1986). Through PCK, particular topics can be adapted for the diverse learners and interests that compose a classroom (Shulman, 1986). Shulman stresses that there is not simply one way to represent subject matter, which requires teachers to have a variety of methods for representing content. Some of these come from research and others come from practice (Shulman, 1986). In addition to knowledge of representing subject matter, PCK includes an understanding of what makes
certain topics more difficult than others and the conceptions and preconceptions students bring to the learning experience (Shulman, 1986). This includes identifying when preconceptions are misconceptions and implementing strategies that change the understanding of the learner (Shulman, 1986).

Grossman (1990) formalized Shulman’s conceptualization of PCK by framing PCK into four central components, which include: 1) conceptions of purposes for teaching subject matter; 2) knowledge of students’ understanding; 3) curricular knowledge; and 4) knowledge of instructional strategies. While these ideas are consistent with Shulmans’ original definition of PCK, Grossman began to develop a framework to categorize and describe its various components. Her ideas will be carried forward and further defined as scholars begin to develop content-specific frameworks for PCK.

**Science PCK.** While similar to Grossman’s conceptualization of PCK, Magnusson, Krajcik and Borko (1999) look at PCK specific to science teaching and add a fifth component to their PCK model. Magnusson et al. added to Grossman’s model teachers’ knowledge and beliefs about assessment in science, which was originated from Tamir (1988). Park and Oliver (2008) developed another widely accepted model of science teacher PCK. While Magnusson et al.’s and Park and Oliver’s models are similar, the focus of each model is different. Magnusson et al. focus on the sources of the PCK components, while Park and Oliver go further and also identify the integrative nature of the components and illustrate the relationships among the five components, which are further conceptualized by Park and Chen (2012) and will be discussed in a later section.
After reviews and analysis of the literature on PCK, Park and Oliver created a comprehensive working definition of PCK. They define PCK as "teachers’ understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment" (Park & Oliver, 2008, p. 264). This definition of PCK mentions both the understanding and enactment of PCK, which highlights the complexity of the knowledge construct.

In the remainder of this section, the following PCK components from Park and Oliver’s model will be described further: 1) orientations to teaching science; 2) knowledge of science curriculum; 3) knowledge of students’ understanding in science; 4) knowledge of assessment of science learning; and 5) knowledge of instructional strategies for teaching science. In addition, the integrative nature, development and importance of the PCK construct will be discussed.

**Orientation to teaching science.** This component includes teachers’ knowledge and beliefs about their purposes and goals for teaching science at a particular level (Magnusson et al., 1999). A teacher’s orientation would guide his or her instructional and curricular decisions as well as the ways they assess student learning (Borko and Putnam, 1996). Several different orientations have been defined for science teachers, each categorized by their goals and the nature of instruction associated with the orientation. Magnusson et al. identified nine orientations, including process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry. While this study does not focus on orientations themselves,
it is important to be aware of the various orientations and understand how the orientations impact the instructional decisions of the teacher.

**Knowledge of science curriculum.** This component of PCK includes the knowledge of curricular goals and objectives and the knowledge of specific curricular programs (Magnusson et al., 1999). Knowledge of goals and objectives includes how the teacher articulates these guidelines across topics (Magnusson et al., 1999) and the teacher’s knowledge about the vertical curriculum, including what students have learned previously and what they are expected to learn in the future (Grossman, 1990). In addition, knowledge of science curriculum includes how individual topics relate to the science curriculum as a whole, which allows teachers to identify core concepts necessary for conceptual understanding (Park & Oliver, 2008). It is also crucial for teachers to know how science standards can serve as a source of goals and objectives (Magnusson et al., 1999). This category also includes knowledge of programs and materials that are relevant to teaching specific science topics (Magnusson et al., 1999).

**Knowledge of students’ understanding in science.** This component involves knowledge of the requirements for learning science content, including knowledge about the prerequisite knowledge necessary for students to learn science and knowledge of variations in approaches to learning based on developmental level, ability level, learning styles, motivation, and need (Magnusson et al., 1999; Park & Oliver, 2008). This component also includes knowledge of areas of student difficulty, including why certain concepts are difficult for students to understand and ways to address common misconceptions (Magnusson et al., 1999).
**Knowledge of assessment of science learning.** This component of PCK was originally proposed by Tamir (1988) and adopted by Magnusson et al. when constructing their model of PCK. Knowledge of assessment of science learning includes knowledge of the dimensions of science learning to assess, which involves aspects of student learning that are significant to assess within a particular area of study (Magnusson, et al., 1999). In addition, this component includes knowledge of methods of assessment, including which methods are appropriate for assessing certain aspects of student understanding as well as knowledge of specific instruments, procedures, or activities to assess student learning (Magnusson et al., 1999).

**Knowledge of instructional strategies for teaching science.** This component of PCK includes the knowledge of subject-specific and topic-specific instructional strategies and is influenced by the teacher’s orientation to science teaching (Magnusson et al., 1999). This includes knowledge of general approaches to instruction such as learning cycles, conceptual change strategies, and inquiry-based instruction (Park and Oliver, 2008), along with topic-specific representations and activities (Magnusson et al., 1999). It is also crucial that the teacher know both when and how to use various instruction strategies.

**Development of PCK.** Various sources of knowledge contribute to the development of PCK. The three main sources of knowledge development when learning to teach science include prior K-12 science learning experiences, teacher education programs, and teaching experiences (Friedrichsen et al., 2009). More specifically, interactions with students during teaching experiences are a vital source of PCK development (Park and Oliver, 2008). As mentioned earlier, Feiman-Nemser (2001b)
noted that regardless of teacher preparation, teachers continue to acquire new knowledge throughout their teaching practice. For this reason, it is logical to suggest that the primary source from which in-service teachers acquire PCK is through experience in their classrooms. Loughran, Berry, and Mulhall (2007) further elaborate on this idea as they explain that PCK is knowledge that teachers develop over time, through experience, and is the “cornerstone of a teacher’s professional expertise” (p. 94).

As a result of their study, Park and Oliver (2008), support the notion that PCK development is a combination of knowledge acquisition and knowledge use. However, this does not mean that knowledge is first acquired outside of practice and then enacted in practice. It means that knowledge acquisition, new applications of the knowledge, and reflection on knowledge use is all embedded within practice (Park & Oliver, 2008). This supports the earlier statement that teachers produce knowledge for teaching through their own experiences; therefore, experiences are the most powerful sources of PCK for practicing teachers (Park & Oliver, 2008).

Not only are there various sources for PCK development, there is also a time factor in which learning progresses. Studies examining beginning secondary science teachers support the idea that PCK develops over time (Lee et al., 2007; Lee & Luft, 2008). It has also been found when PCK was assessed that beginning science teachers had lower levels of PCK than more experienced teachers had, which suggests that PCK is acquired through practice (Lee et al., 2007). Results of these two studies indicate that teachers have diverse forms of PCK that evolve differently at various points of the school year. As a result of their study, Lee et al. pointed out the need to study the PCK of science teachers to develop better induction programs that foster the development of
PCK, including tailoring such programs to the needs of teachers. The findings of these studies collectively support the purpose of the present research and indicate a need to look at PCK development throughout the beginning years of teaching.

**Integration of PCK components.** The interwoven nature of the PCK components contributes to the complexity of the construct (Lee et al., 2007). Loughran (2013) expounds on the integrative model of PCK and explains that PCK components are separate entities, upon which teachers draw in different ways during practice and the entities of which teachers can use and place together in various ways. The merging of the PCK components does not change them; it shows how they can be integrated in several different ways (Loughran, 2013).

Park and Chen (2012) conducted a study to examine the integrative nature of the following five PCK components: 1) orientations to teaching science, 2) knowledge of science curriculum, 3) knowledge of students’ understanding in science, 4) knowledge of assessment of science learning, and 5) knowledge of instructional strategies for teaching science. They modified their original PCK model to illustrate how each of the PCK components influences others. The results of the study support Loughran’s perception that PCK components merge together in a variety of ways. The study found that some PCK components had more connections with other components, and the dynamic nature of the integration can vary among teachers. However, a common pattern across all teachers in the study was the frequent integration of knowledge of student understanding and knowledge of instructional strategies. On the other hand, knowledge of science curriculum had the most limited connections with other components.

Teachers integrate the components of PCK to make decisions during instruction;
this knowledge-in-action includes the dynamic process by which PCK is developed and enacted in practice (Park & Oliver, 2008). This process is vital because effective teaching depends on the integration of PCK components and the manner in which the components are enacted within a given context (Park & Oliver, 2008). While this research was not focused on how teachers integrate PCK components, an understanding of these components is necessary in order to illustrate the integrative nature of PCK. The integrative nature of PCK also highlights its complexity and informs the research design of the present study.

**Value and importance of PCK construct.** Teachers spend most of their school-related lives planning, enacting, and reflecting on instruction (Park and Oliver, 2008). In addition, they assess their performance continually at each stage, based on their interactions with students (Park & Oliver, 2008). As a result, scholars believe the body of knowledge developed by teachers is unique to teaching, and PCK is an essential construct because its development rests “at the heart of the teaching profession” (Park & Oliver, 2008, p. 280).

Each PCK component and its interactions are vital for providing classroom experiences that enhance student learning. For this reason, one might argue that PCK is the most critical type of knowledge to be developed by practicing teachers. Gaining a better understanding of this construct and how it is developed is crucial in creating a shared language around the ideas of teacher learning and providing support for the foundational components of PCK (Loughran, Berry & Mulhull, 2007). PCK can function as a shared vocabulary, a way to convey meaning and understanding of teaching and learning (Loughran et al., 2013). This shared language comprises aspects of professional
knowledge and allows one to move the knowledge of practice out from the individual and into a larger professional community (Loughran, Berry & Mulhull, 2013).

The input from science education scholars makes it clear that PCK is recognized as a central construct of teacher learning. It is necessary to understand the construct of PCK and its components because “it is a construct to aid our thinking about what teachers continue to learn as they study their practice” (Schneider & Plasman, 2011). The aim of this study is to examine teacher knowledge for the purpose of constructing experiences that promote continued teacher learning and expertise. The PCK construct is a vital knowledge construct for this study because it “represents an important tool for defining what it means to be a competent or expert science teacher” (Magnusson et al., 1999, p. 116). Loughran, Berry, and Mulhull (2013) further elaborate on this idea and illustrate the importance of PCK in this study when they state,

“The value of PCK emerges as a powerful way of moving beyond generic descriptors of good science teaching and introduces a more sophisticated approach to unpacking expertise in science teaching. It also creates a way of moving beyond perceptions of exemplary practice as simply comprising familiarity with a range of teaching activities. Therefore, in suggesting that exemplary practice should purposefully involve unpacking and valuing PCK, it is fundamental that opportunities for science teachers to work together to uncover and explicate their PCK be encouraged. (p. 225)

Furthermore, understanding the PCK construct and its importance in teacher learning can allow researchers to continue to learn about the development of PCK and develop trajectories of learning that can support teacher learning (Monte-Sano & Budano, 2013).
**Induction and Mentoring**

Ingersoll and Smith (2004) define in-service teacher induction as “periodic updating and additional training received on the job, during employment” (p. 683). According to this definition, induction is a process that happens with or without appropriate supports to guide the process, and often, teachers are left to figure things out on their own (Feiman-Nemser, 2001a). Mentoring is a common support used during the induction years of teaching, or in many cases, only the first-year. Traditional mentoring generally involves the assignment of a one-on-one mentor within the school, typically a more experienced teacher within the same department. Some indicate that this type of mentoring does not work and call for mentoring that improves classroom teaching, which includes mentors who take on the role of teacher educator, institutions that support the mentors’ work, and induction programs that value new teacher learning (Norman & Feiman-Nemser, 2005).

Even when induction mandates are in place, most lack a curriculum and are not designed based on an understanding of teacher learning or with a broad view of how induction can play a role in new teacher development (Feiman-Nemser, 2001a). Short-term support, limited to the first year of teaching, is the common approach to induction. A combination of short-term support and lack of collaboration with teacher education programs creates a narrow view of induction, limited to reducing stress and addressing immediate problems rather than promoting teacher learning on a continuum (Feiman-Nemser, 2001a). Additionally, the social organization and culture of schooling, along with the lack of mentor preparation, make school mentoring difficult for the mentor and the mentee (Feiman-Nemser, 2001a).
Continuing teacher education through educative mentoring. As an alternative to traditional mentoring, educative mentoring goes beyond addressing situational adjustment, technical advice and emotional support because it exists based on an understanding of teacher learning and a vision for good teaching (Feiman-Nemser, 2001b). Educative mentoring focuses on what teachers need to learn and can help teachers determine how to link their first years of practice with their pre-service education. It is a way to foster the knowledge teachers generate in practice because it is grounded in a developmental view of learning to teach, in which the focus remains on helping teachers interpret the actions of their students and determine how to move their learning forward, in addition to responding to teachers’ present needs (Norman & Feiman-Nemser, 2005).

Norman and Feiman-Nemser (2005) explicitly state that educative mentoring is rooted in Dewey’s educational philosophy. They explain that their article, entitled “Mind Activity in Teaching and Mentoring,” was inspired by Dewey’s (1904) essay, The Relation of Theory to Practice in Education, in which he argues that teachers need the ability to see what is going on in the minds of their students. Dewey (1904) believes that novice teachers should focus on “the interaction of mind on mind, to see how teacher and pupils react upon each other” (p. 19). From this statement, Norman and Feiman-Nemser find it critical that novice teachers pay attention to the ways in which students make sense of what they are learning. They call for a deeper examination of teaching and learning through educative mentoring.

Many mentoring relationships are defined simply by the assignment of a novice teacher to a more experienced one, and little attention is paid to what is occurring and
resulting from those relationships. This proves a need for a shift to a process that encourages beginning teachers to engage in educative mentoring by participating in professional learning communities that contribute to continued teacher learning (Feiman-Nemser, 2012). In order to develop educative mentoring practices that fall on the continuum of teacher learning, collaboration must exist among institutions. It is problematic for mentoring programs to be exclusively school-based with no concern for or connection to pre-service educational programs. To provide educative experiences, programs must build and extend upon the pre-service curriculum. An induction program that enriches pre-service education while addressing the realities of teaching contexts has the basis for providing powerful forms of ongoing professional development (Feiman-Nemser, 2001a). This idea is supported by research indicating that the most successful professional development activities for teachers are those that are ongoing and promote a professional learning community (Committee on Developments in Science Learning, 2004).

**Mentoring new science teachers.** As discussed earlier, teaching experience is a source of developing PCK; however, teaching experience alone is not sufficient for building knowledge for teaching (Friedrichsen et al., 2009). The literature suggests that contextualized learning that includes the guidance of a mentor has the potential to assist in the development of professional knowledge for beginning teachers (Carter & Francis, 2001). Researchers have found that beginning teachers who are involved in a mentoring program perform better on a variety of aspects of teaching, including using effective student questioning practices, adjusting classroom activities to meet student needs, and maintaining a positive classroom atmosphere (Ingersoll & Strong, 2011). Almost all
studies on mentoring programs show that students of new teachers who participated in mentoring programs earned higher scores or showed greater gains on academic achievement tests (Ingersoll & Strong, 2011).

Research was conducted on a project designed to address the disconnect between universities and K-12 schools during the induction phase for new teachers. The project aimed to extend pre-service education through a two-year, university-based induction program in Australia (Crosswell & Beutel, 2013). Results of this study revealed that graduates considered their professional learning to be ongoing, and universities are well situated to play an integral role in the ongoing development of new teachers. While the findings support the ideas of many scholars, researchers call for further investigation into the ongoing learning of new teachers.

The literature indicates that mentoring is beneficial for new teachers, but what role does content play in the mentoring process? Researchers have found that subject-matter concerns pervade the conversations between mentor and novice teachers when discussing the tasks of teaching and that novice teachers need help determining how to engage their students in the content (Feiman-Nemser & Parker, 1990). Due to these findings, the researchers believe that content-related conversations will best benefit novice teachers. It is necessary to consider the interconnections of knowledge of subject, knowledge of students, context, curriculum, and pedagogy when promoting continued learning with novice teachers (Feiman-Nemser & Parker, 1990).

Similar to the suggestion made by Feiman-Nemser and Parker, Luft et al. believe the general experiences of teachers that are often addressed in induction programs are important; however, content specialists need additional training (Luft et al., 2011). They
conducted a study with secondary science teachers over their first and second years of teaching, as they participated in various induction programs, to examine changes in PCK. As a result of their findings, Luft et al. recommend that science teacher educators remain involved with their graduates and work with schools to implement science induction programs. They also suggest that science teacher educators develop and study ways in which beginning science teachers can be supported.

**Review of Methods**

The following sections will address perspectives and approaches that can be utilized when conducting research on teacher learning, specifically when using PCK as a knowledge construct. To accomplish this, a research perspective will be identified and research studies will be examined, looking specifically at the data collection and analysis methods used when studying PCK. Those methods and approaches found to be useful are discussed, as they inform the methodology of this study.

The nature of the research questions in the present study requires a qualitative approach to describing teachers’ knowledge; therefore, quantitative studies were eliminated from the selection of studies that examined PCK. Approaches that used multiple-choice exams, surveys or rubrics to assess teachers’ PCK were not found to be helpful in answering the research questions, as most of these were removed from the practice of teaching. Research that only used lesson plan studies as a form of data collection were also not useful in addressing the research aims of the present study. Despite the popularity among researchers, lesson plan studies have been criticized as a sole source in studies of PCK (Abell, 2007). In choosing which qualitative studies to examine more closely, those that used multiple data sources beyond lesson plans were
selected. This is of great consequence because when trying to capture the complexity of teachers’ knowledge, it is necessary to use multiple data sources such as observations, interviews, and documents to understand and describe PCK (Magnusson et al., 1999; Abell, 2007). Researchers believe studies of this nature provide the richest information (Magnusson et al., 1999; Abell, 2007).

A cognitive perspective to studying teacher learning. Greeno (2006) would consider studying PCK a cognitive science because it focuses on “patterns of information that are hypothesized to be recognized or constructed in activity” (p. 80). Although social interactions can be contexts of individual cognition and learning, this type of research usually focuses on the individual. Central to the individual cognitive approach is the “construction of information structures and procedures that support understanding and reasoning” (p. 81). Due to its cognitive nature, these central components are necessary to consider when studying PCK.

Similar to Greeno (2006), Rex, Steadman, and Graciano (2006) suggest that a cognitive perspective be taken when studying PCK because PCK is considered a theory of learning and knowing. Cognitive researchers view interactional practice as active engagement to forward learning (Rex et al., 2006). They see teachers as those who provide engaging experiences and instruction that allow students to create their own cognitive structures.

According to Putnam and Borko (2000), when researchers concern themselves with teachers’ learning about teaching, it is necessary to look at the research from a situated perspective. A situated perspective focuses the researcher’s attention on how various settings for teacher learning develop different types of knowledge (Putnam &
Among the various contexts for teacher learning, the classroom is the most significant. Considering the cognitive and situated perspectives described above, the following research studies on PCK are examined.

**Methods and approaches for examining PCK.** Not all studies included in this review examined science PCK. However, the focus of this review is on how PCK is studied, which can cut across content areas. While the PCK components vary across the content areas, the methods in which they are studied among practicing teachers remains the same. Additionally, some studies included in this review examine pre-service teachers. While pre-service teachers are not the population on which this dissertation study is focused, it was appropriate to include studies with pre-service teachers that examined PCK within the context of practice as the pre-service teachers were actively teaching.

Four studies were chosen to examine further and discuss. This section of the review will focus on the data collection methods and procedures and the data analysis procedures used in the four studies, along with a discussion of the strengths and limitations of the studies and the implications for the methodology of this dissertation.

**Exploring novice teachers’ PCK over time.** Monte-Sano and Budano (2013) utilized an exploratory multiple-case study approach to examine the development of PCK in secondary history teachers over three years. They began by identifying four key aspects of PCK for teaching history and provided definitions and examples from the literature. The participants in the study included six history teachers during their last pre-service year and the first two years of in-service teaching.
Data collection methods included observations, document collection and interviews. The researchers observed the teachers three times during their pre-service year: at the beginning, middle and end. During the first two years of in-service teaching, the teachers were observed during two units of study, which they identified as units in which they would try to teach historical thinking, reading, or writing. The researchers observed four to six classes for 5.5 hours total during the first year and three to five classes for 4.5 hours total during the second year. Artifacts were collected for the lessons that were observed, including readings, worksheets, lecture materials, assessments, and other teaching materials. Written student work was also collected.

Interviews were conducted during the first and second years of in-service teaching. Each teacher was interviewed six times during the first year: at the beginning of the year, briefly before each observed unit, after each unit, and at the end of the year. The teachers were also interviewed four times during the second year of teaching. The researchers reduced the number of interviews for the second year because they felt six interviews was too cumbersome for the teachers. However, the interviews conducted after each unit were longer in duration than those conducted during the first year. The goal of these interviews was to gather evidence of the teachers’ thinking about their pedagogical choices, history content, and students. During the interviews, the researchers had the teachers analyze students’ work; chart goals, activities, and assessments for each observed unit; and identify influences on their teaching practices, while the researchers probed for instructional decision making.

The researchers analyzed the data by identifying initial themes and applying them to the interviews and observation notes to cluster the data and identify patterns in
teachers’ practices, knowledge, and thinking. They created data matrices using observation notes and artifacts. The researchers looked for changes in instruction from year to year, since the topic remained the same for each of the teachers. They used the components of PCK identified from the literature as a framework for looking at the data. They also conducted a cross-case analysis to compare the practice and thinking of the teachers over time.

**The development of beginning math teachers’ PCK.** Lannin et al. (2013) conducted a study to characterize the development of PCK for beginning math teachers. Similar to Monte-Sano and Budano, they examined the PCK development of two beginning math teachers, starting with their participation in an alternative certification program (ACP) and continuing through their first year of teaching.

The researchers collected data using instructional planning tasks and observations, followed by stimulated recall interviews. The instructional planning tasks were completed at the beginning and end of the teacher education program. Following the completion of the instructional planning task, the researchers conducted an interview and asked questions specific to the four PCK categories in Magnusson et al.’s PCK model, which includes knowledge of students’ understanding, instructional strategies, assessment, and curriculum.

During the fall and spring semesters of the ACP, the researchers collected data during a two-day observation cycle. The observations included two consecutive mathematics lessons. An interview was conducted prior to the observations related to the lesson that would be taught and the knowledge the teacher drew upon when designing the lesson. Questions related to the four components of PCK were also asked. The lessons
were then observed and videotaped, and field notes were taken. After each lesson, a stimulated recall interview was conducted. The researchers probed the participants’ knowledge while they played back specific parts of the lesson. Video excerpts that focused on particular aspects of the participant’s knowledge were chosen.

The data were analyzed and coded using the four components of PCK mentioned above. Two individual researchers coded the data, and discrepancies were discussed until the researchers were in agreement. Individual profiles were created to characterize the PCK development for each teacher. Similarities and differences between the two participants were also determined.

**Experienced secondary science teachers’ PCK.** Lee and Luft (2008) conducted a qualitative research study to examine how mentor science teachers’ PCK impacted their practice. The researchers used a case-study method to represent the descriptions of the teachers’ PCK. All teachers chosen for this study were experienced in-service teachers.

Sources of data for this study included semi-structured interviews, classroom observations, collection of lesson plans and the participating teachers’ monthly reflective summaries. Interviews were conducted three times throughout a two-year period. The first interview focused on collective biographical information, while the second interview occurred after an observed lesson. The purpose of this interview was to clarify the observed instruction and to discuss the knowledge necessary to teach science. The interview protocol included questions that guide the teachers to discuss certain elements of PCK. The third interview was informed by the analysis of the second interview and involved teachers’ construction of diagrams that represent the elements of PCK and how
they interact with one another. During the interview, the teachers were asked to elaborate on their decisions while constructing their diagrams.

Classroom observations were conducted for two class periods or more so the researchers could gain an understanding of the teachers’ teaching practices and the context in which they teach. The researchers felt this was necessary to capture the details of how teachers act in their classroom, which represents their PCK. These observations were used as a basis for following interviews in which teachers were asked to discuss their rationales for what they enacted while teaching. Lesson plans, project flyers, and reflective summaries from the observed lessons were also collected from the participants. This allowed the researchers to understand how PCK was represented, and the reflections allowed them to understand how the teachers conceptualized PCK.

During data analysis, the researchers formulated initial codes from each data source and used the constant-comparative method of analysis to continue to modify their codes. After completing a line-by-line and section by-section analysis, the researchers combined terms to represent the teachers’ PCK. The initial codes were then reconfigured to be broader and more comprehensive.

**In-service teachers’ PCK of genetics and photosynthesis.** Park and Chen (2012) conducted a qualitative research study to better understand the integration of the five PCK components in their model: 1) orientations toward teaching science, (2) knowledge of student understanding, (3) knowledge of instructional strategies and representations, (4) knowledge of science curriculum, and (5) knowledge of assessment of science learning. All participants were in-service biology teachers at the same high school, and their teaching experience varied from two to 43 years.
Like the previous studies, the researchers conducted semi-structured interviews, observed classroom lessons, and collected documents such as instructional materials and student work samples. In addition, Park and Chen also utilized a lesson plan analysis and chose genetics and photosynthesis as the instructional units for their research to keep the instructional units the same among all teachers. The study investigates the interactions between the different components of PCK as well as the strength of individual components.

All instructional sessions were videotaped, but only two class periods for each topic and each teacher were selected for analysis. Selections were made based on the similarity in the ways in which all four teachers dealt with the subject matter (i.e., a laboratory exercise or group discussion). Three semi-structured interviews were conducted, including a background interview, pre-observation interview, and post-observation interview. Lesson plans, handouts, and student work were also sources of data. Handouts included instructional materials provided by the teacher and assessment materials. Lab reports, notes, written assignments, and poster presentations were the types of student work collected.

The data analysis methods used in this study are more complex than the ones used in the previous studies and include an in-depth analysis of explicit PCK, an enumerative approach and the constant comparative method. An in-depth analysis was used to identify specific PCK elements integrated by the teacher. The researchers used Park and Oliver’s pentagon model of PCK as a framework for identifying components of PCK. While watching videotaped sessions, the researcher identified what the students did, what components of PCK were integrated, and evidence of the PCK components. These
observations were complemented by data from interviews and documents relating to the teaching segment.

An enumerative approach was used to map the integration process of PCK in an explicit way. The pentagon model was used as an analytic device to identify connections between PCK components within a specific videotaped episode. This was repeated with other episodes of PCK, and the frequency of the connections was indicated on the PCK map.

To identify common patterns that emerged from the data sources, especially interviews and observations, the researchers used the constant comparative method. There was no pre-established system of categories or codes. The results were then compared and contrasted with the PCK maps created through the enumerative approach. Park and Chen’s research differs from many studies on PCK because its focus on the integration of PCK components utilizes more complex data analysis procedures.

**Strengths of reviewed studies.** One strength of the studies reviewed is the use of multiple data collection methods. This addresses the complex nature of PCK more realistically than studies that simply ask hypothetical questions related to PCK or use one source of data. The utilization of observations and document collection instead of relying solely on self-reports is valuable because it provides a more in-depth look at the components of PCK that teachers enact during practice. The use of multiple data collection methods also allows for the possibility of triangulation during data analysis.

All of the studies except Lee and Luft’s (2008) categorized the components of PCK and identified a PCK framework before they conducted their research. Even though Lee and Luft did not identify a specific PCK model, they indicated that they developed
interview protocols that asked about the various elements of PCK. Utilizing a framework is crucial because it is helpful when identifying points of interest and analyzing and understanding the results of the study.

A strength of Park and Chen’s study is the examination of the individual PCK components as well as the interactions among them. The components of PCK are interrelated parts that work together; therefore, the analysis of the relationships among them is an interesting approach that offers a different perspective on studying PCK in the classroom.

Several of the studies included interviews conducted immediately after the observed lesson. This allowed the researchers to discuss instructional decisions with the teachers while the lesson was still fresh in their minds. This is essential when trying to gather additional information regarding the teachers’ rationales for how they enacted PCK during practice.

Monte-Sano and Budano and Lannin et al. each added another dimension to the interview process by incorporating materials as a way to facilitate the conversation. During the interviews, Monte-Sano and Budano asked the teachers to analyze samples of student work and chart goals, activities and assessments from the observed unit. Having specific artifacts to use when asking questions and/or having participants engage in an activity during the interviewing process provides a connection to the teacher’s teaching activities and instruction. Lannin et al. utilized stimulated recall during their interviews. This allowed the researchers to probe the teachers’ knowledge and focus on specific aspects of PCK during the interviews, while the teacher viewed their own teaching practices. Similarly, Lee and Luft utilized their classroom observations to develop
interview questions that asked about the specific teaching activities that were enacted. These methods are beneficial because they bring the classroom context into the interview and allow teachers to further elaborate on the actions observed during the lesson.

**Limitations of reviewed studies.** The studies had strong designs, which made it difficult to identify limitations based solely on the information provided in the articles. The small sample sizes in several of the studies could be considered a limitation to the ability to apply the findings to other contexts. However, due to the complex nature of the data collection and analysis, a larger sample size might not be a reasonable undertaking for researchers.

Another limitation of the studies is the limited amount of time spent observing instruction and discussing the observations. PCK is a large knowledge construct that includes many aspects of teaching. By only conducting a small number of interviews or observations, a researcher might not get the whole picture. However, it would unrealistic to think a researcher could spend a large amount of time with each participant and have a manageable pool of data. Reviewing the methodologies of these studies provided a structure to create a research design for this dissertation.

**Implications for the present study.** There are many commonalities between each of the studies and the stronger elements of their designs, which provided a solid foundation for considering the design of the present study. A review of the literature highlighted the necessity for multiple data collection methods, including talking to teachers, observing their practice, and examining their teaching artifacts. However, this limited the number of participants, in order to keep the study manageable. The
participants included only teachers who were currently teaching in a classroom, which was central to the goal of studying teacher learning within the classroom context.

It is important to begin a study with well-defined components of PCK. A PCK model served as a framework for conceptualizing PCK and informed the process of determining interview questions and points of focus for classroom observations. Classroom observations, followed up by semi-structured interviews and collection of teaching artifacts, were thought to be the most useful data collection methods for this study. Conducting a follow-up interview after the observed lesson was vital because it allowed the researcher to probe the teachers’ knowledge on the various components of PCK using specific instances from instruction. It was also important to utilize the PCK framework during data analysis to help organize and analyze the various components of PCK.

The following chapter will further elaborate on the methodology chosen to address the aims of this study and provide answers to the research questions.

**Conclusion**

Science teachers need to have advanced knowledge of how to teach their content area to students in a way that allows students to develop a deep understanding. While pre-service teacher education provides a solid foundation for new teachers, certain aspects of teaching can only be learned through practice, which is why the beginning years of teaching are vital for knowledge development. The most meaningful learning context for in-service teachers is their own classrooms. Within the classroom, teacher knowledge becomes more sophisticated over time, as teachers come to know how to teach in new ways.
Pedagogical content knowledge was the chosen construct to define teacher knowledge in this study because many scholars believe knowledge of how to teach one’s content area is at the center of effective teaching. PCK conceptualizes the uniqueness of the body of knowledge needed to teach, and understanding this body of knowledge provides a shared language for the field and allows for the development of learning trajectories. Research indicates that novice teachers have lower levels of PCK and that their knowledge develops over time. For this reason, induction programs with strong mentoring components are necessary to support knowledge development.

Not all mentoring programs are created equal, and traditional mentoring is characterized by short-term, emotional support during the first year of teaching. Mentoring is often limited to the assignment of a one-on-one mentor who conducts occasional check-ins, with little attention given to the broad view of teacher learning. Mentoring programs that take on an educative mentoring approach to extend on the pre-service curriculum support learning progressions. While there is a research base on teacher learning and the effects of mentoring, there is a need for more research examining ways in which novice science teachers can be supported.

PCK is a useful construct for this dissertation because it provided a framework for thinking about teacher knowledge and designing research to study teacher learning. This research utilized PCK as a knowledge construct for determining teacher learning progressions in order to identify how teachers’ ideas became more sophisticated while they learned within their context. Educative mentoring helped the researcher think about the type of support teachers need for knowledge growth. Unlike other research on
learning progressions, this study allowed the researcher to describe trajectories for learning within a university-based mentoring curriculum.
Chapter 3

Methods

An exploratory approach was utilized to examine the nature of new science teachers’ pedagogical content knowledge and the aspects of PCK to which they paid attention and found challenging throughout the year. The descriptive results were used to determine how new science teachers’ learning progresses and to inform the development of learning opportunities to meet the needs of new science teachers. The purpose of this study was to describe teachers’ learning progressions rather than to evaluate the mentoring program or the pre-service program in which the participants were involved.

To explore and describe teachers’ PCK, observations, interviews, and document collection were employed in order to understand teachers’ ideas about teaching. Teachers utilize their PCK when making decisions during teaching, which highlights the dynamic process in which PCK is developed and enacted in practice (Park & Oliver, 2008). The collection of planning documents allowed the researcher to access teachers’ PCK prior to the teaching event. The observations accessed teachers’ PCK during practice, and the interviews allowed teachers share their ideas about why they made particular teaching decisions. The multiple data sources address the complexity of PCK, as described by Park and Oliver (2008).

This chapter details the methodological approach used to answer the following research questions:

1) What is the nature of pedagogical content knowledge of first-, second- and third-year science teachers at various points across the school year?
2) To which aspects of pedagogical content knowledge do first-, second- and third-year teachers pay attention at various points across the school year?

3) Which aspects of pedagogical content knowledge are challenging for first-, second- and third-year teachers at various points across the school year?

In order to answer the research questions, various qualitative methods were utilized, consistent with those used by researchers who study PCK in classrooms.

**Researcher Role and Potential Bias**

The author’s role as a researcher in this study was not one of an outsider. As a member of a team that designed the curriculum for the mentoring program, the researcher led instructional sessions for the on-campus mentoring days. In addition, the researcher’s role was to provide individual mentoring while visiting teachers in their classrooms.

Therefore, the author of the present study was an observer as participant, which occurs when the researcher remains primarily an observer but has interactions with the study participants (Glesne, 2011). This role proved to be helpful when recruiting participants because many of the prospective participants were familiar with the researcher and seemed open to allowing visits to their classrooms. This was also valuable because the researcher had established a rapport with some of the participants prior to the study, which helped the participants feel comfortable during classroom observations and interviews.

The researcher remained conscious of blurring of the roles as a mentor and a researcher while visiting the participants. While interviewing teachers, the researcher was careful to not provide feedback that would lead the participants’ future responses. It was essential that teachers explained their idea about teaching science, not tell the
researcher what they believed she wanted to hear. However, the researcher also fulfilled the role as a mentor and provided support when necessary, and therefore needed to engage in discussion with teachers when appropriate. In addition, because the researcher wanted the teachers to demonstrate growth as they learned through practice, it was necessary to bracket this bias and ensure that the research was only identifying a progression when more sophisticated ideas were shared by the teachers. Peer debriefing, which will be discussed in a later section, was essential in this study to ensure that the researcher’s bias did not influence data collection.

**Participants and Sampling**

As previously stated, this study was not longitudinal; teachers were not followed over the course of three years to examine how their learning progressed individually. Instead, a stratified sample was used, consisting of groups of first-, second- and third-year teachers. The participants in this study were obtained from a population of science teachers who graduated from the Licensure and Master’s Program (LAMP) at a medium-sized, Midwestern public university. LAMP is a one-year, graduate, pre-service program for those preparing to become middle or secondary teachers. LAMP is not a fifth-year program; it a comprehensive program designed to meet the needs of adult learners who have already obtained a degree. The program follows the K-12 calendar, which allows the interns to work with the same mentor teacher for the entire year. The mentoring phase of LAMP functions to keep graduates connected to the university and provide ongoing support with a curriculum that builds on their pre-service education.

Criterion sampling, in which individuals are chosen because they meet specific criteria, was used to obtain participants for this study (Creswell, 2013). The participants
had to be LAMP graduates and current, licensed science teachers in their first, second or third year of teaching middle (grades 4-9) or secondary (grades 7-12) science. Middle and secondary LAMP students take their science methods courses together, so teacher preparation is not different between these two groups. However, because of the large grade span of 4-12, this study focuses on teachers in 7th through 12th grade classrooms.

In addition, the teachers had to have a current relationship with the university by continuing in the learning to teach conversation with the mentoring program coordinators and by sharing their teaching experiences and keeping in contact.

In addition to fitting the criteria, prospective participants were vetted to determine which teachers would be included in the study. LAMP faculty members identified which teachers would be willing to talk and would be open to having a visitor in their classrooms. This was critical for a study that involves observations and follow-up interviews. In addition, faculty members were able to provide insight about participants whom they believed would be performing well in their teaching assignments, which included teachers who did not struggle in the pre-service LAMP program. This was crucial because the study aimed to look at learning progressions, and therefore participants should be ones who were believed to be progressing appropriately. The sampling strategies contributed to choosing participants who could purposefully inform an understanding of the research, which is vital in qualitative studies (Creswell, 2013).

The sample included 13 total participants, five first-year science teachers, four second-year science teachers, and four third-year science teachers. Due to the multiple data collection methods over a span of 7 months, this sample size was reasonable for this study. The goal of qualitative studies is not to generalize; therefore it was more
important to collect extensive detail about each participant than to have a larger sample size (Glesne, 2011). However, in order to determine patterns within the data, it was necessary to have multiple teachers within each group (first-, second- and third-year teachers). Having multiple participants in each group was also essential to protecting the integrity of the study in case a participant dropped out of the study. There was a larger pool of first-year science teachers who were graduates from the LAMP program, so five participants were selected from this group instead of four.

The sample obtained is a realistic sample of the teachers who participate in the mentoring program. As Table 1 demonstrates, the teachers in the sample were diverse in the science subjects and grade levels they taught. While obtaining a sample of teachers who teach the same subjects and grade level might appear to present a more consistent sample, it would not have been a reflection of the population of teachers who would be attending the mentoring sessions that this research set out to inform.

The researcher spoke informally with several prospective participants at the August on-campus mentoring session to determine whether they would be interested in allowing classroom visits, observations and interviews throughout the year. Not all prospective participants attended this mentoring session, so email communications were sent using the preferred email addresses they had shared with the mentoring program. The researcher shared the goals of the study with the teachers, so they were aware that this research was intended to develop an understanding of new science teachers’ knowledge and learning needs in order to improve the mentoring program.
<table>
<thead>
<tr>
<th>First-year Teachers</th>
<th>Second-year teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amanda Urban</td>
<td>Brandon Suburban</td>
</tr>
<tr>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
</tr>
<tr>
<td>Amanda Urban, public high school; astronomy and environmental science; Adolescence to Young Adult (AYA) Integrated Science license</td>
<td>Brandon Suburban, public middle school 7th and 8th grade earth science (same as year one); AYA Earth Science license</td>
</tr>
<tr>
<td>Bachelor’s degree in biomedical engineering and extra coursework in earth and space science; entered LAMP program immediately after completing degree</td>
<td>Bachelor’s degree in broadcast journalism, then meteorology courses and, later, a second degree in geosciences; worked in news and then 7 years as a meteorologist before entering LAMP</td>
</tr>
<tr>
<td>Ben Urban</td>
<td>Brittany Urban</td>
</tr>
<tr>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
</tr>
<tr>
<td>Ben Urban, public high school; physical science; AYA Life Science license</td>
<td>Brittany Urban, public high school; physical science, honors physical science and physics (same as year one); AYA Integrated Science license</td>
</tr>
<tr>
<td>Bachelor’s degree in environmental science; after graduating, spent 6 years in the National Guard before beginning the LAMP program</td>
<td>Bachelor’s degree in political science with a minor in biology; master’s degree in public administration; took additional content courses before entering LAMP program; has experience substitute teaching and as a teaching assistant at the college level</td>
</tr>
<tr>
<td>Bill Urban</td>
<td>Elizabeth Urban</td>
</tr>
<tr>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
</tr>
<tr>
<td>Bill Urban, charter high school; physical science and College Readiness Science; AYA Integrated Science license</td>
<td>Elizabeth Urban, public high school (different school than first-year, but in same district); physical science and honors chemistry (same as year one); AYA Physical Science license</td>
</tr>
<tr>
<td>Bachelor’s degree in history; spent three years in an outdoor education program teaching history and science; took additional courses in biology, physics and chemistry before entering the LAMP program</td>
<td>Bachelor’s degree in chemistry; worked as an analytic chemist in a laboratory for three years before entering LAMP</td>
</tr>
<tr>
<td>Lee Urban</td>
<td>Kathy</td>
</tr>
<tr>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
<td>Teaching Assignment (Past and Present) &amp; Teaching License</td>
</tr>
<tr>
<td>Lee Urban, public high school; physical science and anatomy/physiology; AYA Integrated and Life Science license</td>
<td>Kathy Urban, catholic high school; physical science, biology, and advanced placement biology (first-year, she taught at an urban charter school, all subjects, grades 9-12); AYA Life Science license</td>
</tr>
<tr>
<td>Bachelor’s degree in zoology; currently working towards integrated license (astronomy and geology classes); entered LAMP program following her bachelor’s degree</td>
<td>Bachelor’s degree in biochemistry, eight years working in a laboratory; worked in children’s ministry with Sunday school curriculum; worked nine years in various long-term substitute positions</td>
</tr>
</tbody>
</table>

(continued)
### Participant (Pseudonym) | Teaching Assignment (Past and Present) & Teaching License | Background Information
--- | --- | ---
### Third-year teachers
Doug | Rural, high school; biology, anatomy/physiology and environmental science (same as years one and two); AYA Integrated Science license | Bachelor’s degree in microbiology; after graduation, he completed an additional year of course work needed for integrated license and then entered the LAMP program
Chelsea | Urban, charter school; 6th and 7th grade science (same as years one and two); Middle Childhood science and social studies license | Bachelor’s degree in studio art and art history, also took science courses; for several years, she worked as an artist, had her own design business, and taught after school art classes before entering LAMP
Gary | Urban, charter school; 7th and 8th grade science (same as years one and two); AYA Life Science license | Bachelor’s degree in biology; entered LAMP immediately after graduation
Mariah | Suburban, public school; 7th and 8th grade science (same as years one and two); AYA Life Science license | Bachelor’s degree in human development and family studies; completed an extra year of science credits to get into LAMP

### Data Sources

Data sources for this study included classroom observations, teaching artifacts, and semi-structured interviews. The decision for these data collection methods followed the suggestions outlined in the methods review and is based on other qualitative studies examining PCK. Researchers believe that when seeking to capture the complexity of teachers’ knowledge across components of PCK, it is imperative to use multiple data sources, including observations of teachers in their classrooms, interviews with teachers about their knowledge and practices, and teaching artifacts used during planning and instruction (Magnusson et al., 1999). Some of the complexity of the PCK construct is due to its two dimensions, knowledge and enactment (Park & Oliver, 2008). Therefore, it was important to not only learn how teachers enact their knowledge, but also to access the knowledge that yields the enactments.
**Classroom observations.** It has been suggested that studies of PCK need to occur partially during the teaching event (Abell, 2007). The translation of PCK into teaching practices is a critical component of PCK (Baxter & Lederman, 1999) and supports the use of classroom observations in this study. Three observations occurred over the course of the academic year to address the enactment dimension of PCK.

The researcher took field notes during the observations to record instances of interest and questions that arose as the instruction and interactions were observed. When taking field notes, a form was used to organize the lesson (see Appendix A). The form organized the lesson by segment (lesson launch, main instructional event, and wrap-up), and the instructional events were organized by student tasks, teacher actions, and teacher talk. While some of the October observations were video-recorded, not all teachers wanted to be recorded, and some had students who were not able to be recorded. A recorded lesson was viewed and compared to field notes; the videos did not provide additional data and the decision was made to not record future lessons.

**Document collection.** Document collection is an unobtrusive measure that can provide contextual dimensions to observations and interviews (Glesne, 2011). Teaching artifacts were collected and included teachers’ preparation materials such as lesson plans and any other materials used during the lesson such as handouts or assessments. The artifacts offered another way to access how teachers translated their knowledge into practice. Like the observations, the artifacts provided information about the enactment of PCK. However, in order to access the knowledge behind the enactment, the researcher also asked teachers to discuss their rationales for the content of these documents.
**Interviews.** While observations are valuable when studying PCK, they only provide a limited view; therefore, interviews are necessary because they provide a means to allow teachers to articulate their knowledge (Baxter & Lederman, 1999). The interviews are essential when examining pedagogical content knowledge, because PCK is partially an internal construct; therefore, researchers must not rely solely upon observational data (Baxter & Lederman, 1999). In this study, follow-up interviews accompanied observations in order to allow teachers to share their understandings, explain their instructional choices, and share what they do in other lessons (Baxter & Lederman, 1999). This allowed for a broader view of the teachers’ PCK.

When constructing the interview questions and determining what to look for during observations and when viewing teaching artifacts, the researcher utilized Park and Oliver’s (2008) science PCK model as a framework. Their model includes the following components: 1) orientations to teaching science, 2) knowledge of science curriculum, 3) knowledge of students’ understanding in science, 4) knowledge of instructional strategies for teaching science, and 5) knowledge of assessment of science learning. Interview questions were specifically developed to answer the research questions, and they included the following:

1. Tell me about what you were thinking about or considering when planning your lesson. (Descriptive)

2. How does the lesson reflect your ideas about the purposes and goals for teaching science? (Reflective)

3. How does this lesson fit into the broader science curriculum (scope and sequence)? (Descriptive)
a. Follow-up questions about standards and curriculum resources

4. How did you think about students’ understanding of science concepts when planning and instructing the lesson? (Descriptive)
   a. Follow-up questions about prerequisite knowledge, variations in approaches to learning, difficult concepts, misconceptions

5. I saw that you […]. Why did you decide on that approach to assess student learning (if an assessment was used)? How do you plan to assess student learning of the concepts in this lesson (if no assessment was used)? (Descriptive/Rationale)
   a. Why is this aspect of student learning important to assess?

6. I saw that you did […]. Why did you decide to use those particular instructional strategies in your lesson? (Descriptive/Rationale)

7. Is there anything you would change when planning and teaching this lesson in the future? (Reflective)

8. In regards to teaching science, what has been difficult for you so far this year? What do you need help with? (Reflective)

The alignment of interview questions and research questions is illustrated in the interview protocol (Appendix B). However, the researcher found that while teachers were answering specific interview questions, they often expanded on their ideas and therefore provided data for multiple research questions.

Semi-structured interviews were chosen because they included pre-determined questions but remained open to following unexpected leads that arose and allowed for depth-probing so points of interest could be pursued (Glesne, 2011). Due to the exploratory nature of this study, it was necessary to allow for open discussions so themes
could emerge. While the interview questions were the same for each teacher, the context of some of the questions was different based on each observed lesson. For example, one teacher utilized an assessment during the observed lesson, while another did not. The one was asked about that particular assessment, while the other was asked about plans to assess student learning in the future.

The interview questions were categorized as descriptive, rationale, or reflective questions. Descriptive questions asked the teachers to describe what happened in their lessons and describe how they planned for the lesson. Rationale questions asked them to explain why they planned and taught the lessons as they did. The reflective questions asked the teachers to explain what they could have and should have done and how they might make changes in the future. Utilizing all three types of questions allowed the researcher to access the teachers’ PCK related to the lessons they taught as well as to past and future instruction.

Interviews questions also asked teachers about where they were focusing their attention on and what they found challenging in regards to teaching at that particular point in the year. Teachers’ responses provided additional data to answer the second and third research questions. These questions were key to understanding the teachers’ learning needs throughout the year so the mentoring curriculum can be adapted to address these needs. The general interview protocol was the same for all three interviews throughout the year. However, the context of the questions was different depending on the specific teaching session observed and particular point in time within the academic year.
In addition to observed interviews, which occurred after observed lessons, unobserved interviews were used to gather data between observations. The interview questions remained the same, but instead of asking teachers about an observed lesson, the teachers were asked to reflect on a lesson they had taught recently (within a day or two). The unobserved interviews were instrumental for gathering data at multiple points across the year in order to determine how teachers’ ideas progressed.

**Data Collection Procedures**

As referred to in the research questions, the researcher looked at teachers’ PCK at various points across the year. To divide the data for analysis, time periods were chosen. The first time period, *late fall*, occurred from October until winter break in mid-December. The second time period, *winter*, occurred during January and February. The third time period, *spring*, occurred during March and April. These time periods were chosen based on natural breaks within the school calendars and to separate the year into beginning, middle, and end.

Observations took place in October, January, and April. These months were chosen because they span the academic year and fall before the on-campus mentoring sessions, so the findings could be used to inform future curriculum development for these sessions. Beginning data collection in October allowed the teachers time to become acclimated to the new school year, especially first-year teachers who were starting in a new environment. The researcher contacted the teachers throughout the month and asked them to select a date and class period for the observations. The researcher also contacted them a few days prior to confirm the date and time and ensure that the selected observation time was still convenient for them. Due to end-of-course exams and other
end-of-the-year commitments, it was logical to end data collection in April. Based on previous experience, teachers tend to be difficult to reach in the month of May, as they are wrapping up the school year and completing required assessments, and they often have a high volume of grading to complete.

Prior to the classroom visits, the researcher asked the teachers to provide lesson plans and/or other related teaching artifacts for the classroom observation. Some provided documents the day prior and some during the lesson. However, not all teachers were willing or able to share their lesson plans for various reasons. Oftentimes, they indicated they would have materials ready and did not, or they explained that they did not create formal lesson plans. The artifacts were reviewed and inquired about during the follow-up interviews. The researcher also used the artifacts as a point of reference during the interviews to aid the conversation when appropriate.

Three observed interviews occurred after each observation in October, January, and April. The interviews were conducted either immediately after the instructional session or later that day, depending on the teacher’s schedule. It was crucial not to allow too much time to pass after the observation because the goal was for the lesson to be fresh in the teachers’ minds so they could easily discuss what happened and provide their understanding. As explained earlier, both instances from the teaching event and teaching artifacts were utilized as points of discussion during the interviews. All interviews were audio recorded.

In between the classroom observations, the researcher conducted unobserved interviews. These interviews occurred either face-to-face, via email or via phone. Due to the busy schedules of participants and the difficulty planning interviews, participants
were given the option as to which manner they would prefer. Attempts for unobserved interviews were made approximately three weeks after the first observation and interview and continued in three-week increments until the next observation.

Table 2 illustrates the data set for this study. The table indicates the number of observations and interviews conducted for each participant across the year.

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Late Fall</th>
<th>Winter</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observations</td>
<td>Interviews</td>
<td>Observations</td>
</tr>
<tr>
<td>First-year teachers</td>
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<td></td>
</tr>
<tr>
<td>Amanda</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Bill</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Ben</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Lee</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Kristy</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Second-year teachers</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Brandon</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Brittany</td>
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<td>1</td>
</tr>
<tr>
<td>Elizabeth</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Kathy</td>
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<td>1</td>
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<td>Third-year teachers</td>
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<td>Chelsea</td>
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</tr>
<tr>
<td>Gary</td>
<td>1</td>
<td>3</td>
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</tr>
<tr>
<td>Mariah</td>
<td>1</td>
<td>2</td>
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</tr>
</tbody>
</table>
Figure 1 below illustrates the data collection procedures explained above.

**Figure 1.** Research design.

**Data Analysis**

The researcher conducted all classroom observations, collected corresponding teaching artifacts and conducted interviews (observed and unobserved) for all 13 teachers during the late fall data collection period and analyzed the data before the next collection period. The same process was followed for winter and spring; all data were analyzed after the data collection period was complete and before the next began. The sequence was significant, not only to keep the amount of data manageable, but to keep the time periods separate. In addition, the researcher analyzed data from all three groups of teachers separately. Analyzing data in this manner is logical, according to the research questions posed. However, after all data was collected, the researcher went back and
reexamined the analyzed data from earlier time periods to ensure consistency across time periods.

Step one of data analysis was transcribing the interviews verbatim. This allowed the researcher to begin thinking about potential patterns. The transcripts were uploaded to NVivo, a data analysis software program. All transcripts were labeled with a pseudonym, data collection time period and specific data source (ex: BillSpringInterview1). The documents were then classified by teacher experience level (first, second, third). This allowed the researcher to group all data sources that belong to each teacher and experience level, which simplified the process of running queries for analysis. Documents were also organized in folders by time period (late fall, winter, spring) and participant pseudonym.

Step two involved coding all transcripts in Nvivo. It is important to point out that the software did not code the data; it simply provided a digital way to organize and code data. With the large volume of data collected in this study, this software program was a valuable tool for data analysis.

Researchers stress that using a model of PCK is a useful heuristic for organizing research on teacher knowledge (Abell, 2007). For this reason, several models were utilized during data analysis. Park and Oliver’s (2008) and Schneider and Plasman’s (2011) models of PCK for science teaching were utilized to create a deductive coding scheme. The PCK models were utilized to identify sub-codes for each of the five components of PCK. A blend of the two models was helpful in determining the coding scheme most appropriate for the data. The coding scheme was finalized after the late fall data was reviewed to determine which sub-codes best fit the data. It was helpful to
operationalize the deductive codes, as shown in Table 3 with descriptions and examples to maximize consistency, while coding. The codes and sub-codes remained the same for all three time periods because they were still appropriate for the data, and new codes did not emerge.

Table 3

*Deductive Coding Scheme*

<table>
<thead>
<tr>
<th>Components of PCK (main codes) and Categories for each component (sub-codes)</th>
<th>Description</th>
<th>Example (quote from participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation to teaching science</td>
<td><strong>Purposes of teaching science</strong></td>
<td>Overarching purpose and importance of teaching science, such as instances when teachers talk about preparing students for beyond the classroom, preparing for college and a desire and interest to pursue science</td>
</tr>
<tr>
<td></td>
<td><strong>Goals for teaching science</strong></td>
<td>Objectives for teaching science, such as instances when teachers talked about what they wanted their students to know, understand and be able to do in their class, including skills, ways of thinking, what they wanted students to learn, how they would like them to think about science concepts, and students’ success on classroom and state assessments</td>
</tr>
<tr>
<td></td>
<td><strong>The nature of teaching and learning science for students</strong></td>
<td>Teachers’ ideas on how students learn and how they should teach, including instances when teachers express their ideas about approaches to science teaching, what types of experiences students should have, student and teacher roles in science learning, and structures and processes conducive for science learning</td>
</tr>
</tbody>
</table>

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<th>Components of PCK (main codes) and Categories for each component (sub-codes)</th>
<th>Description</th>
<th>Example (quote from participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of science curriculum</td>
<td><strong>Curricular resources</strong></td>
<td>The resources teachers utilize to determine what to teach, including textbooks, online materials, state and national standards, other teachers, district curriculum maps, students, standardized tests and their awareness and availability of these resources</td>
</tr>
<tr>
<td></td>
<td><strong>Scope</strong></td>
<td>Which science topics are important and worth knowing, including instances when teachers talk about the concepts that are worth teaching and learning, the necessary depth of concepts, how they determine learning objectives, what students need to know, what concepts are important in understanding the big ideas, what is important beyond the prescribed curriculum, making connections between concepts within the curriculum and across the curriculum (integrations), consideration of previous and future curriculum, addressing concepts within the time allowed</td>
</tr>
<tr>
<td></td>
<td><strong>Sequence</strong></td>
<td>How teachers organize science content for learning, which includes why teachers sequence content in particular ways and the pace at which they move through the sequence</td>
</tr>
<tr>
<td>Knowledge of students’ understanding in science</td>
<td><strong>Initial Ideas and Experiences</strong></td>
<td>Students’ previous experience and knowledge about science concepts (both from school and out of school), teachers’ awareness of misconceptions and how to address these, how students initial ideas vary, how teachers make connections and build on initial ideas, and how teachers help students recall their knowledge</td>
</tr>
</tbody>
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(continued)
<table>
<thead>
<tr>
<th>Components of PCK (main codes) and Categories for each component (sub-codes)</th>
<th>Description</th>
<th>Example (quote from participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning difficulties</td>
<td>Teachers identify what science concepts are difficult, why they are difficult, and ways to address difficult concepts</td>
<td>But I guess to really understand… I guess one misconception, and maybe it’s hard for them to see it in the mathematical model, is that everything that is over there at the beginning in terms of energy needs to show up later on in a different form, but the same quantity, and that goes back to the law of conservation of energy. So if anything, I have been able to bring that in from a different angle, where they can actually see it quantified, and I think that has helped some students understand that more. I’ve realized students still don’t understand that idea yet.</td>
</tr>
<tr>
<td>Motivation &amp; interest</td>
<td>Teachers’ ideas about appealing to students’ motivation and interest by finding ways to address science concepts that students find enjoyable, making content important to students’ everyday lives and connecting it to their interest areas, and allowing students to use their own individual talents and preferences during instruction</td>
<td>I guess what I am looking at is what [are] some of the noncritical things, but they are kind of interesting. Fourth hour is very medically driven… so that enhancement stuff I might do differently between the classes. They are very chemical in third hour. It’s funny the way that they have really split. The discussions are very different.</td>
</tr>
<tr>
<td>Development of science ideas</td>
<td>The process and sequence for how students develop science ideas, such as instances when teachers talk about their role or students’ role in the development of ideas, helping students link ideas, breaking the content into smaller chunks, the impact of teacher instruction on development of ideas, addressing various learning styles, an appropriate amount of scaffolding for students to gain understanding, reinforcement of ideas, multiple ways to present or have students experience the content, adapting for students’ needs</td>
<td>Because when I was telling them the other day, they were just looking at me like, “Okay” or just writing it down because it was notes, so I was just trying to consider that maybe some type of reinforcement of the notes from the prior day will help them gain or understand the content better, so that's why I did, like, a few little basic… demonstrations just to kind of get them to believe what they were actually writing.</td>
</tr>
<tr>
<td>Expression of science ideas</td>
<td>How students demonstrate their understanding of science concepts, questions, and responses, which occurred in instances when teachers talked about having students provide explanations (oral communication) to the teacher and other students, written responses, reflecting in journals, analyzing situations, allowing for choice/multiple ways students can express ideas such as creating models, drawings, performances, etc.)</td>
<td>I was thinking that it’s always interesting to have a discussion the first day about what they know. Today, I’m doing it a little bit different because I am giving them some information, and then tomorrow they are going to have to explain to me what they learned, and I will also try to ask them what their previous knowledge was, and we will work from there.</td>
</tr>
</tbody>
</table>
## Components of PCK (main codes) and Categories for each component (sub-codes)

<table>
<thead>
<tr>
<th>Description</th>
<th>Example (quote from participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appropriate level of science understanding</strong></td>
<td>What the appropriate level of student understanding of science concepts is, including instances when teachers talk about how they determine the appropriate level of difficulty, making tasks not too difficult but challenging according to students’ abilities, an appropriate level of understanding at certain times throughout the year, unit, or lesson, differences, the differences in students’ appropriate levels and how to differentiate to engage the different cognitive levels</td>
</tr>
<tr>
<td><strong>Knowledge of instructional strategies for teaching science</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Inquiry strategies</strong></td>
<td>How teachers approach inquiry (for a lesson or broader approach) which includes instances when the teachers talk about the inquiry process, their role and students’ role in inquiry, the experimental design process and components of the process such as collecting and analyzing data, utilizing data as evidence, questioning (teachers and students).</td>
</tr>
<tr>
<td><strong>Science phenomena strategies</strong></td>
<td>Strategies to get students involved in science and engage them in science phenomena, including instances when teachers talk about activities or approaches they utilize to get their students involved in the phenomena, which could include multiple ways to present phenomena (lectures, reading text, providing examples, hands-on activities, projects, laboratory activities, predict-observe-explain, demonstrations)</td>
</tr>
<tr>
<td><strong>Discourse strategies in science</strong></td>
<td>Discourse strategies in science include instances when teachers talk about students engaging in discussions about science ideas, interacting with science text (including graphics), argumentation, formulas (how to manipulate and understand), writing, and presenting</td>
</tr>
<tr>
<td><strong>Knowledge of assessment of science learning</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Strategies to assess science learning</strong></td>
<td>Strategies teachers use to assess students’ thinking in science, such as formative and informative methods (tests, exit tickets, projects, etc.), how they develop the assessments, types of questions they ask or tasks students have to do, student self-assessment, use of rubrics, and re-take approaches</td>
</tr>
</tbody>
</table>

(continued)
### Components of PCK (main codes) and Categories for each component (sub-codes)

<table>
<thead>
<tr>
<th>Description</th>
<th>Example (quote from participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of science assessment (how and when)</td>
<td>How to use science assessments, including instances when teachers talked about determining when it was time to progress through the unit or lesson, determining instructional decisions, readiness to take other assessments, determining how to divide the class for differentiated instruction assessments as learning experiences or something &quot;separate&quot; from instruction, assessing different levels of understanding, assessing whole class and individuals; and when to use science assessments, including timing during the unit or lesson, frequency of assessments. Now, when I do grade this, I will be looking at that page. Have we missed the bus on this completely? How are we looking in question 3 here? And if we have completely missed the bus, I am going to figure out another way, and we are going to come back to this because you're not understanding this fossil evidence thing.</td>
</tr>
</tbody>
</table>

Inter-rater reliability was established after the coding scheme was developed and the late fall data was completely transcribed and coded. A fellow doctoral candidate was given numerous quotes from various participants, including quotes from all sub-categories. The researcher also provided her with the coding scheme in Table 3. After she coded the data, the codes were compared with those of the researcher. In instances of disagreement, the discrepancies were discussed and a final decision was made. The inter-rater reliability was 90.5%.

While this study used a model of PCK to separate the five components, the components of PCK interact with each other (Park & Chen, 2012), and therefore it was common to have instances when teachers were discussing or enacting several components of PCK together. For example, a common interaction between components occurred when teachers were discussing their ideas on students’ understanding of science concepts and instructional strategies simultaneously. This required careful coding of the data by extracting the various components from responses and situations in which they were integrated. For this reason, it was necessary to operationalize the coding scheme in
advance, in order to establish and use each code’s definition and examples to properly organize and code the data.

After interviews were transcribed and reviewed, the researcher utilized member checks, which Creswell (2013) suggests as a validation strategy for qualitative research. Member checks involve taking data and initial interpretations back to the participants so they can judge the accuracy. Researchers can conduct member checks in various ways: some show participants the raw data, while others show written analyses of the data. Due to the high volume of data in this study, it was not reasonable to conduct member checks with every participant after every data collection time period. However, member checks were important when something was in question during the initial phase of data analysis, such as teachers’ actions or statements that required further clarification. For these reasons, member checks were conducted on an as needed basis and usually occurred via email after the interview was coded or during a follow-up interview.

Step three occurred after the interviews were coded in NVivo and member checks were conducted. Data was transferred into charts to create profiles for each teacher. The participants each had their own data chart for each time period (see Appendix C for example). The charts organized the data by data collection points within that time period and PCK component. Within each PCK component, the data was organized by the participants’ understanding (nature), attention, and challenges in relation to that component, and the appropriate sub-code was also assigned. The only exception to this structure was for the code, orientation to science teaching, as it did not feel appropriate to identify attention and challenges due to the broad, philosophical nature of this code.
Information from the teaching artifacts and observational field notes were incorporated into the data charts when they provided appropriate context to describe teachers’ ideas. Because the artifacts and field notes were primarily used as prompts and points of discussion during interviews, it did not prove to be beneficial to code these data sources in Nvivo. The teachers discussed meaningful aspects of what occurred during the observation and their artifacts during the interviews. Because the interviews were used to further discuss how PCK was enacted during teaching and planning, interview data was primarily used as the conversations allowed the teachers to elaborate on what they enacted during their instruction and other components of PCK found in their teaching artifacts. Interviews were vital in this study. For example, it cannot be assumed teachers pay attention to or find something challenging by looking at their plans or other teaching artifacts. It also could not be assumed that something is challenging by observing the teachers, unless they stated it verbally. If an aspect seem to attract the teachers’ attention or appear challenging for the teachers based on viewing artifacts and instruction, the researcher would ask the teachers to talk about these things during the interviews.

Step four occurred after the charts were complete for all participants. The researcher used the charts for further analysis of PCK sub-categories. The researcher looked at the sub-categories for the various groups of teachers and created descriptions for each, based on commonalities and differences among the groups of teachers. The descriptions were used to determine patterns and establish vertical progressions. It is important to point out that differences among groups of teachers did not constitute a progression. In order for a vertical progression to be determined, ideas needed to be more sophisticated in nature. During this time, the researcher paid attention to one major
pattern: how the nature of PCK and the aspects of PCK to which teachers paid attention and found challenging varied between first-, second- and third-year teachers (vertical progression). To describe the nature of teachers’ PCK, their enactment of PCK and the ideas they shared in their interviews were examined. For attention, the researcher looked at instances when teachers indicated that they were working on a particular aspect of their teaching or focusing on a specific aspect with their students. In regards to challenges, the researcher considered instances when teachers verbally expressed some sort of concern, challenge, difficulty or struggle with a component of PCK.

After step four was complete for all three time periods and the vertical progressions had been established, step five was initiated. At this point in the data analysis, the descriptions created in step four were used to examine groups of teachers across the year in order to establish the second major pattern. This pattern focused on how the nature of PCK and the aspects of PCK that to which teachers paid attention and found challenging were different at varying points throughout the year, which allowed the establishment of horizontal progressions. As explained earlier, progressions were determined by more sophisticated ideas as the year progressed, not by differences alone. In addition, a central goal was for these teachers to utilize inquiry-based instructional approaches. For this reason, the researcher sought progressions that moved toward more sophisticated ideas of guided inquiry, collaboration, and discourse that allow students to develop a deep understanding of science concepts.

Answering the research questions involved the use of the patterns established in steps four and five. To determine the nature of first-, second- and third-year teachers’ PCK at varying points in the year, the established vertical and horizontal progressions,
organized then by sub-category, were used. To determine the aspects of PCK to which first-, second- and third-year teachers paid attention and found challenging the researcher looked at attention and challenges for each main category of PCK. Because there was not enough data on attention and challenges for each sub-category, it was appropriate to look at the five main categories to answer this research question. This allowed the use of all progressions found across the year to describe teachers’ ideas for each subcategory.

Peer debriefing, which occurs when another individual reviews and asks questions about the research and functions as an external check of the process (Creswell, 2013), was utilized during the analysis process. The same doctoral candidate who established inter-rater reliability served as a peer reviewer. This person checked the researcher’s interpretations and discussed major patterns to ensure that the progressions described were justified.
Chapter 4

Results

The organizational scheme in this chapter was chosen because it aids in determining the patterns necessary to answer the research questions. These patterns include how PCK and the aspects of PCK to which teachers paid attention and found challenging varied between first-, second- and third-year teachers and how the nature of PCK and the aspects of PCK to which teachers paid attention and found challenging were different at varying points throughout the year.

The findings in this chapter are organized by the five major PCK components and sub-categories. Within each component the researcher answers the three research questions by describing the nature of teachers’ PCK for each sub-category. Vertical progressions are described to show differences among the groups of teachers. However, these differences must illustrate a progression toward more sophisticated ideas. Horizontal progressions are also described to illustrate how the groups of teachers’ ideas progress over the course of the year. The researcher also describes teachers’ attention and challenges for each main PCK component, as there was not enough data to suggest attention and challenges for each sub-category. Quotations from participants are provided to illustrate major progressions. In some instances, the data did not indicate a vertical or horizontal progression for certain PCK sub-categories. This occurred when ideas remained consistent or the researcher was unable to establish clear patterns.

Orientation to Science Teaching

This PCK component refers to teachers’ knowledge and beliefs about their purposes and goals for teaching science and their ideas about science teaching and
learning. Teachers’ orientation to science teaching is divided into three sub-categories: *purposes of teaching science, goals for teaching science, and the nature of teaching and learning science for students.*

**Nature of teachers’ orientation to science teaching.** Teachers shared and elaborated on their goals for teaching science and the nature of teaching and learning science for students. However, it is interesting to point out teachers talked little about their purposes of teaching science. Sometimes teachers explicitly stated their orientation to science teaching, and at other times they expressed facets of their orientation while discussing their rationales for how they planned and/or taught their lessons.

**Purposes for teaching science.** Purposes for teaching science refer to teachers’ overarching ideas on the purpose and importance of teaching science. The main purposes discovered were based primarily on first-year teachers’ ideas and included preparing students for the future, such as being successful in college courses, applying scientific thinking to their lives (critical thinking and problem solving) and preparing students to be successful in higher-level science courses.

*Vertical progression.* It was discovered that first-year teachers shared ideas about their purposes for teaching science, whereas second- and third-year teachers did not. This was consistent across the year. For this reason, no patterns suggested a vertical progression.

*Horizontal progression.* While first-year teachers did share their ideas about the purposes for teaching science, these remained consistent across the year. For this reason, a horizontal progression could not be suggested.
**Goals for teaching science.** Goals for teaching science refer to teachers’ objectives for teaching science that influence their teaching decisions. This sub-category included instances when teachers talked about what they wanted their students to be able to do in their classes in relation to concepts, skills, ways of thinking, and specifically what they wanted their students to learn and how they would like for them to think about science processes or concepts.

Teachers shared a variety of similar goals across the year. However, an interesting finding emerged. Third-year teachers had less concept-driven goals than did first- and second-year teachers. They were more concerned about their students being able to engage in scientific thinking. First- and second-year teachers made reference to similar goals as well; however, they were not as consistent as third-year teachers and they remained focused on science concepts, with little elaboration.

*Vertical progression.* First- and second-year teachers’ goals for teaching science were more concept-driven and included ideas about students’ understanding science concepts (not memorizing them), being able to remember science concepts, and applying their knowledge of concepts during tasks. Third-year teachers’ goals were focused on scientific processes and students’ ability to engage independently in discovery in order to develop their own understanding of concepts and think scientifically rather than to understand independent concepts.

*Horizontal progression.* Teachers’ goals remained consistent across the year. For this reason, a horizontal progression could not be suggested.

*The nature of teaching and learning science for students.* The nature of teaching and learning science for students consists of teachers’ ideas on how students
learn and how they should teach. This sub-category includes instances when teachers express their ideas about approaches to science teaching, what types of experiences students should have, student and teacher roles in science learning, and structures and processes conducive for science learning.

Teachers shared various ideas about the nature of teaching and learning science for students. While there was occasional overlap between the ideas expressed by teachers within various groups, there were distinct commonalities that revealed a pattern that described the differences among the groups of teachers. The vertical progression below demonstrates this pattern.

*Vertical progression.* First-year teachers’ understanding of the nature of teaching and learning science included teacher-directed approaches, wherein the teacher provided students with information, structure, and guidance, even during inquiry activities. Second-year teachers shared ideas that were less teacher-focused, such as the idea that students learn by engaging in experiences (project- or problem-based learning) and inquiry. Third-year teachers understood that students learn by engaging in inquiry, which should be student-directed in order to allow students to come to their own understanding independently, without teacher “telling” them. They also believe this allows students to have some control over the learning process.

The progression explained above shows advancement from the idea that the nature of teaching and learning science for students is more teacher-directed to the idea that students learn through exploration and discovery. In particular, Doug provided some context that shed light on this progression. He mentioned his shift in thinking over his years of teaching: “I’m starting to see myself go from the point where I’m focusing on
what I’m teaching to focusing on how they are learning it” (Doug, Late Fall Interview). He demonstrates how he has progressed to thinking less about what he is doing and thinking more about students’ role in the learning process, demonstrating the idea that the nature of teaching and learning science becomes more student-directed and less teacher-directed.

**Attention and challenges regarding teachers’ orientation to science teaching.**
Due to the overarching nature of orientation to science teaching, it did not seem logical to delineate this component further and identify aspects to which teachers paid attention or found challenging. Teachers did not express aspects of this PCK component to which they paid attention or found challenging.

**Summary.** It is clear that first-year teachers were thinking about their purposes of science teaching more than second- and third-year teachers. However, second- and third-year teachers were more explicit with their ideas about their goals and the nature of teaching and learning science. The progression of teachers’ ideas about the nature of teaching and learning moved from a more teacher-driven, guided approach to a more independent, inquiry-based learning approach that is student-driven.

**Knowledge of Science Curriculum**

This main PCK component refers to teachers’ ideas about the science curriculum. Three sub-categories, *curricular resources, scope* and *sequence*, are addressed in this section.

**Nature of teachers’ knowledge of science curriculum.** It was clear throughout the data collection period that third-year teachers’ ideas about the curriculum, in general, were more sophisticated than those of first- and second-year teachers. Third-year
teachers took more ownership in developing a curriculum, utilizing various resources, including themselves, as a primary resource. They also appeared to be thinking critically about the content standards and what they meant for their curriculum, instead of considering the content standards as the curriculum itself.

**Curricular resources.** Curricular resources include any material or resource teachers utilize to determine the scope and sequence of their curriculum, including textbooks, online materials, state and national standards, other teachers, district curriculum maps, students, standardized tests and their own experience and knowledge. This sub-category also includes teachers’ awareness of resources and the availability of these resources. While there were some commonalities across all levels of teachers, such as using standards as a resource and standardized tests as the time approached, there were differences in the resources utilized and how these resources were thought about to develop science curricula.

**Vertical progression.** Some differences emerged across the year in how teachers utilized and thought about curriculum resources, however, one vertical progression remained true for all three time periods. First- and second-year teachers thought the curriculum was limited to prescribed curriculum resources such as the district curriculum map, standards, and textbooks, and they followed these closely. An exception is second-year teacher, Kathy, who aligned with the third-year teachers. The third-year teachers’ ideas about the curriculum were more sophisticated. They took ownership of developing the curriculum, either individually or collaboratively, and considered themselves and other teachers as primary resources. They also understood the importance of utilizing several other resources, such as seasonal factors and other grade-level standards, to
inform their own curricular decisions instead of using the resources as the curriculum itself.

The following quote exemplifies the ideas first- and second-year teachers shared about curriculum resources:

I look at the curriculum map and that is based on the standards, so I look at the curriculum map and see the information that they need, and I'll make the learning targets based on what we're talking about this week. (Elizabeth, Late Fall Interview 1)

While instances occurred when teachers would share ideas about using other resources besides the curriculum map or textbook, Elizabeth’s quote demonstrates a common theme.

The following quotes were chosen to illustrate the sophistication of third-year teachers’ ideas about curriculum resources, use of themselves as primary resources for curriculum development, and their critical thoughts about the curriculum. Gary shares his thoughts about his role as a curriculum developer and the questions he asks himself when thinking about the curriculum:

The curriculum – because I have never had to sort of develop a curriculum and I don’t want you to take the wrong way – I have planned units…. but this larger scale thinking that I have had to do – okay, here is an eighth grade curriculum, holy smokes, how are you going to teach it? Well, how do I want to teach it? I didn’t have to have those thoughts before, until I sat down this summer and said, ‘Oh, a new curriculum; how do I want to teach it? What makes sense? How does it make sense?’ Because I’m doing okay with the day to day, I’ve been a first-year
teacher, and then a second-year teacher, and so I feel like I am finally a teacher in that respect, but now I am a curriculum developer too. (Gary, Late Fall Interview 1)

Chelsea also explains her thoughts about becoming a curriculum developer (creating her own curriculum map) and what considerations and resources she utilized to revamp the curriculum year:

“We do have a curriculum map. It’s called Atlas, and I have been working on that more over the summer and using that more this year because that curriculum map was laid out by the teachers prior to me who really hadn’t taught the Common Core yet. So it was kind of all over the place, it was in their words, and now I am taking it and kind of taking ownership of that. But I do have access to the other… to anybody and their curriculum, and we do a lot of integrations, so I like to see where is language arts, where is social studies, not only my division, but also the senior division; where do I have to lead them in order to…. Because I, for instance, they are not going to see rocks and minerals again until like their sophomore year or something like that, so I have to make sure that I am going to fill in the gaps from before they get to that testing, so we are well aware of everybody else’s curriculum. (Chelsea, Late Fall Interview 1)

This significant progression shows how teachers advanced from thinking of their curriculum as a pre-planned document provided by their districts to something that was carefully planned by them, utilizing several curricular resources.

*Horizontal progression for first-year teachers.* During the late fall and winter, first-year teachers’ ideas about curriculum resources were limited to prescribed
curriculum resources such as district curriculum maps and textbooks. However, toward the end of the year, they began to utilize their students as a resource and shared ideas about determining their prior knowledge and utilizing the information to plan their curriculum. As the year progressed, several teachers began to express their ideas about the curriculum map. For example, in the winter and spring, Ben expressed his uncertainty with the curriculum map and questioned whether it was the best resource for his students. Similarly, Kristy questioned whether the map had an appropriate sequence for her students, and Lee questioned whether the textbook he used for his curriculum was appropriate for the abilities of his students and the way he believes the curriculum for the course should be structured.

The above progression suggests that first-year teachers began to think more critically about the curriculum and the resources provided to them. As the year progressed, they used their experience in the classroom to rethink the resources they were using and began to think of students as a critical curriculum resource. The following example demonstrates the ideas first-year teachers expressed during the late fall and winter and exemplifies how their resources were limited to the prescribed standards: “This lesson fits into the [district] curriculum map, in our unit on electricity. In order to teach the lesson, I simply explored the web for appropriate hands-on projects that aligned with both the state standards and best practices” (Lee, Winter Interview 2).

As spring neared, first-year teachers seemed to be questioning the curriculum map and standards. The following quote illustrates this and shows how the teachers began thinking about utilizing their students’ interests and needs as resources:
At the beginning, I was like, ‘I have a curriculum map and textbook.’ and now I am like, ‘I don’t even like you, curriculum map; I don’t like your content standards.’ I want my students to learn something, and I want the freedom to be able to teach them something meaningful, and I want them to walk away with something that they care about… (Ben, Spring Interview 1)

While the quotes above demonstrate the progression of first-year teachers’ ideas about curriculum resources across the year, there was not a noticeable progression for second- and third-year teachers.

**Scope.** Scope refers to the science topics that are essential and worth knowing. This sub-category includes instances when teachers talked about the concepts that are worth teaching and learning and why, the necessary depth of concepts, how learning objectives are created, what students need to know and what the teachers think they should know, which concepts are principal in understanding big ideas in science, what is significant beyond the prescribed curriculum, and making connections between concepts within the curriculum and across the curriculum (integrations, consideration of previous and future curriculum).

While all teachers who taught courses with state and/or national content standards made sure to incorporate the standards within their curriculum, the way in which they chose to expand upon the standards or teach additional topics varied. Similarly, all teachers who taught courses that were assessed with state standardized tests made sure to include the necessary concepts and skills for these tests within their scope.

**Vertical progression.** Similar to curriculum resources, one major vertical progression illustrates the differences among first-, second- and third-year teachers’ ideas
about the scope of the curriculum. First-year teachers’ ideas about scope were limited to
the standards, fundamental concepts of the content, concepts in the textbook and essential
congcepts and skills necessary for standardized tests. While some created their own
learning targets or objectives, they were derived directly from the standards. Second-year
teachers were similar to first-year teachers, but they understood the importance of
incorporating “extras” beyond the curriculum, going “deeper”, relating content to real-life
applications, and students’ interests. However, they were less explicit about how they
actually did this within their context compared to third-year teachers. Similar to
curriculum resources, Kathy aligns more with third-year teachers who were more explicit
about their ideas of going beyond the prescribed scope of the curriculum to integrate
other science topics or non-science topics, going into more depth about individual
concepts beyond the standards, and integrating students’ interests within the scope of the
curriculum.

In the following quote, Lee demonstrates first-year teachers’ ideas of scope as
being limited to the standards provided to them:

Yes, it does. It addresses the standards insomuch that the lesson plan itself is
directly tied to the curriculum map provided by the district and the Common
Core. The lesson for the week, as a whole, is also tied to the standards for reading
and writing literacy in science and technical subjects. Students are given
assignments that force them to engage with their reading in order to complete it.
(Lee, Late Fall Interview 2)
In contrast to first-year teachers’ ideas, the following quote exemplifies second- and third-year teachers’ ideas on how they enhance the standards and incorporate students’ interests within the scope of their curriculum:

I guess what I am looking at is what is some of the noncritical things, but they are kind of interesting. Fourth hour is very medically driven. You know, one student did a lot of micro work in a lab last year. Another student’s passion is anatomy. So that enhancement stuff I might do differently between the classes. They are very chemical in third hour. What does the molecule do? That’s the group that got A’s in chemistry, and this is group that got A’s in anatomy. It’s funny the way that they have really split. The discussions are very different. (Kathy, Winter Interview 1)

*Horizontal progression.* A horizontal progression was noticed for first-year teachers throughout the year. While addressing the necessary content standards was their primary idea for their course scope (as illustrated in Lee’s quote in the previous section), as they progressed toward spring, they began to share a more advanced understanding of scope. They had realized that their students did not always have the prior knowledge necessary to teach the grade-specific standards, so they felt they needed to go back and address previous standards. First-year teachers also began to incorporate topics of interest to their students. However, this was usually an “extra” or a separate activity, not integrated within the curriculum as most third-year teachers demonstrated. The following quote demonstrates how first-year teachers began to think about the scope of their curriculum in a more sophisticated manner at the end of the year:
So what I want to do for these last weeks is – now that they have an astronomy knowledge base, everything is not completely new to them, they know something about gravity and orbits. Now, it’s all about life application. I feel like we reached this pinnacle where I trust they have enough knowledge, and we can start talking about real-life application. It’s also a hard time of year where all kids want to do is check out, so I’m thinking what better time. We are doing so much real-life relevant stuff, in the news today. I feel like it’s the best time; they have the most knowledge to apply, and they are just tired, so it’s a good time for me to transition out. (Amanda, Spring Interview 1)

While first-year teachers demonstrated progression throughout the year, horizontal progressions were not observed for second- and third-year teachers.

**Sequence.** The sub-category, sequence, refers to how teachers organize science content for learning. It includes the teachers’ rationale for why they sequence content in particular ways and the pace at which they move through the sequence. Similar to the themes found for curriculum resources and scope, first-year teachers followed the suggested curriculum sequence outlined in the curriculum map or textbooks, whereas second-year and third-year teachers either made modifications to the sequence or developed their own.

**Vertical progression.** One vertical progression demonstrated teachers’ understanding of sequence, as their ideas did not change much over the course of the year. First-year teachers’ ideas consisted of following the prescribed curricular sequence outlined in curriculum materials. Kristy mentioned following the sequence even though she thought it was “funky”. In addition, they expressed concern about being behind the
suggested pacing guide. While several second-year teachers had curriculum maps or district objectives to follow, the majority of the teachers determined their own sequence for the objectives or changed the suggested sequence of the curriculum map when needed, based on their own opinions. Again, Kathy’s sophisticated ideas aligned more with the third-year teachers, who understood it was important to determine the sequence of their curriculum based on what they thought was best for student learning. Factors that they considered were student understanding, how concepts build on each other and seasonal factors (which concepts lend themselves to outdoor activities and experiences). Most third-year teachers expressed that they were pleased with the way they chose to sequence the curriculum.

The following series of quotes demonstrates the learning progression described above. When first-year teacher, Kristy, was asked about her curriculum sequence, she stated, “My mentor teacher last year did not follow the map to a tee, but for me, as a first-year teacher, and timing and pacing, I think it’s an awesome tool” (Kristy, Late Fall Interview 1). Second-year teacher, Brandon, demonstrates how he used his own ideas to change the prescribed curriculum:

I got to decide how everything goes. As a matter of fact, I changed the order of the way that the standards are approached. The district recommended that the hydrologic cycle be standard 1. I wanted, instead of starting with the hydrosphere, I wanted to start with the atmosphere, so I switched 1 and 3. And standard 2 is like a marriage of both the hydrosphere and atmosphere, so that is a great spot for being in the middle. You start learning about one sphere and you learn about how it connects to this other sphere, and then you learn about that other sphere
independently, so it’s a nice flow, the way it moves. So I just switched do I start with the hydrosphere versus the atmosphere. (Brandon, Late Fall Interview 1)

Doug illustrates how third-year teachers’ understanding of curriculum sequence considered what they had learned about science content to create a sequence they thought was best for learning, not a suggested sequence from someone else:

I guess well, the order, when I first did it, I actually did evolution last, and this is the first year that I switched it up, and I am doing it close to the front, after the ‘What is Life?’ lesson. And I think that I’m going to like it this way better because it’s… evolution being the unifying concept that it is, it helps explain everything, and everything can be explained by it, so hopefully that will help keep everything consistent throughout the rest of the year with wrapping everything back together toward evolution. (Doug, Late Fall Interview 3)

Horizontal progression. There were no significant changes noticed in teachers’ ideas about the sequence of the curriculum across the year. Therefore, horizontal progressions could not be suggested.

Attention to aspects of science curriculum. For the late fall time period, it appeared that first- and second-year teachers focused little on curriculum in general. Overall, third-year teachers seemed to think more about the curriculum than did first- and second-year teachers, and their development of the curriculum was more sophisticated in regards to how they determined the scope and sequence. A theme that supports this finding comes from three third-year teachers, Gary, Chelsea and Doug, as they describe their view of the third year as a turning point for the curriculum. Doug explained year three as a “turning point” during which he finally felt comfortable with the curriculum.
Gary stated that he finally felt confident in the curricular decisions he was making and that “year three is a good year” for that. Lastly, Chelsea explained that it was time that she took ownership of the curriculum.

**Vertical progressions.** The majority of the teachers paid attention to issues of scope; therefore, scope was the only aspect of teachers’ knowledge of the science curriculum that showed a progression. First-year teachers referred to making sure their lessons were aligned with the standards and objectives. Second-year teachers also talked about alignment to the standards; however, Brittany and Kathy both spoke about building on the concepts to promote depth of understanding. Kathy aligned more with the third-year teachers Doug and Gary, with their focus on going beyond the standards to promote a deeper understanding, expanding on concepts from previous grades (vertical curriculum) and connecting topics across the curriculum.

During winter, the aspects of the curriculum to which teachers were paying attention varied, and there was not enough data to suggest a progression. However, it is interesting to point out that first-year teachers did not seem to focus much on issues of curriculum beyond covering necessary content for the upcoming standardized test. While more experienced teachers focused on the same issue, second-year teachers and third-year teacher, Gary, were thinking of other issues related to scope and sequence and how they could improve upon last year and enhance the learning of their students.

There were no major themes for the spring time period. Similar to previous time periods, first-year teachers were concerned about addressing the content standards and catching up with the suggested pacing guide, and second- and third-year teachers were
more focused on thinking of ways to enhance the curriculum, address process skills, and go into more depth about concepts.

**Horizontal progression.** During the late fall and winter, first-year teachers paid little attention to the curriculum beyond addressing the standards. However, at the end of the year, Lee and Ben were rethinking their curriculum for the next year to address content that was more meaningful, relevant, and appropriate for their students. While there is not enough data to suggest a progression, it is a notable finding to point out.

There was no significant progression for second- and third-year teachers throughout the year. They continued to work on aspects of the curriculum that they felt were necessary and continued to think of ways to enhance the curriculum for their students and improve the curriculum based on previous experiences.

**Challenging aspects of science curriculum.** In the late fall, most first-year teachers did not express challenges in regards to the curriculum, with the exception of Ben and Amanda. They were both teaching outside the content areas for which they felt prepared and passionate. Therefore, their challenges were related to their lack of knowledge of the content and feelings of uncertainty. Second- and third-year teachers appeared to express more challenges in the beginning of the year than later in the year.

**Vertical progressions.** As stated above, the challenges expressed by first-year teachers in late fall were due to their inexperience with the content. Second-year teachers were challenged with finding valuable curriculum resources outside of the district-provided resources, but their struggle indicated their new attempt at finding these resources. Several second- and third-year teachers expressed challenges with addressing all the concepts within the scope of the curriculum in the time provided. It appeared that
they struggled to find a balance between achieving the depth they felt was significant and covering all necessary concepts in the allotted time. This challenge seemed more sophisticated, as it shows they are valuing depth of knowledge over breadth.

In the winter, first-year teachers proved to find aspects of the science curriculum more challenging than did second- and third-year teachers. They expressed challenges with covering all required content in time for the test and maintaining an appropriate pace. Due to the lack of challenges second- and third-year teachers faced in regards to the science curriculum, no vertical progression could be suggested. However, it is interesting to point out that while second- and third-year teachers had a more sophisticated understanding of the science curriculum and paid more attention to aspects of the curriculum, first-year teachers expressed more challenges related to curricular planning, addressing all necessary concepts and staying on pace.

As they did in winter, first-year teachers found aspects of the science curriculum a challenge in the spring, whereas second- and third-year teachers did not. They were challenged by addressing all the concepts they felt necessary in the short amount of time they had left in the year. In addition, Lee appeared to feel uncomfortable with his anatomy class, as there was not a map or provided curriculum for this course, which he understood as having no curriculum. Similar to Lee, Amanda felt uncomfortable with her curriculum as there was no prescribed curriculum to follow, and she expressed that her lack of passion for the content made curriculum development difficult.

Progressions for winter and spring cannot be suggested due to lack of challenges expressed by second- and third-year teachers. However, a key finding is that second- and third-year teachers were feeling more comfortable with the curriculum, and they were
paying attention to it and thinking about it, but they were not finding aspects of curriculum challenging.

**Summary.** When looking at the patterns for knowledge of science curriculum, one major finding is apparent. Third-year teachers have a more sophisticated understanding of using curriculum resources to develop the scope and sequence of their curriculum. They understood the importance of going beyond or modifying prescribed curriculum resources and relied on themselves as a major resource to determine the scope and sequence they felt was best for student learning.

Third-year teachers paid more attention to developing or improving their curriculum and had fewer challenges related to the curriculum, whereas first-year teachers were trying to get through the prescribed curriculum in the time available. Even though only two first-year teachers began thinking critically about the curriculum toward the end of the year, in general, they remained comfortable utilizing the resources provided and followed the curriculum they had available.

During casual conversations (not formal interviews), both Gary and Brandon expressed their desire for more preparation and knowledge on how to develop their own curriculum. Their concern supports the major themes that were found. First-year teachers especially felt uncomfortable taking ownership of the curriculum. On the other hand, third-year teachers did feel comfortable, as they used what they had learned through practice in the classroom to help them develop a curriculum best suited for their students.
Knowledge of Students’ Understanding in Science

This PCK component refers to teachers’ ideas about how students understand science. It is separated into the following sub-categories: appropriate level of understanding, development of science ideas, expression of science ideas, initial ideas and experience, learning difficulties, and motivation and interest.

Nature of teachers’ knowledge of students’ understanding in science. The high volume of interview data indicated that teachers spoke a lot about their knowledge of students’ understanding in science. Ideas about the various sub-categories pervaded the conversation, as teachers explained their thoughts when planning and their rationales for their curriculum, instructional strategies, and assessments. The amount of data varies greatly among sub-categories, but development of science ideas was the sub-category in which teachers shared the most ideas.

Appropriate level of student understanding for students. The sub-category, appropriate level of science understanding for students, included instances when teachers discussed how they determined the appropriate level of difficulty of science concepts for their students and how teachers designed tasks that are not too difficult, but challenging, according to students abilities. It also included teachers’ ideas on the appropriate level of student understanding at certain points throughout the year, unit, or lesson; the differences in appropriate level of understanding among students; and how to engage different cognitive levels.

This sub-category was not discussed as much as some of the other sub-categories, and often times teachers’ ideas were not elaborated upon. However, the data for the
entire year showed some obvious patterns that emerged, which allowed the determination of a vertical progression.

*Vertical progression.* First-year teachers shared an understanding that they should not make the content too difficult for students, often teaching at what they considered a basic or lower level. They also expressed that grade-level content was often too difficult for their students. However, they did not explain how they specifically determined what was appropriate. Second- and third-year teachers were more sophisticated in their ideas and understood that their students were capable of higher-level thinking that goes beyond basic understanding of facts, and they felt it was necessary to encourage them to reach this point. They also felt that appropriate level of understanding can vary between students, and differentiation was necessary to challenge every student properly.

The following quote illustrates first-year teachers’ ideas on appropriate level of science understanding for students:

I use the KISS principle: keep it simple, stupid. I look to find ways to explain it as simply as I can…I look to break down everything I can to the most simple way that I possibly can because they are there, simply overwhelmed by even the slightest challenge, in large part because of the fact that they are very far behind.

(Lee, Late Fall Interview 1)

While Lee found it valuable to make sure his students were not challenged and the content was simple, Brandon exemplifies second- and third-year teachers’ ideas when he states the following:
Whenever we have ‘I Can’ statements like this, we try to come up with ways to extend the learning, and so basically, we differentiated so that it stretches our students in a way that we feel is appropriate, and we felt this ‘I Can’ statement really needed to be stretched. After I decided how I wanted to stretch it, and then I used the Bloom’s web to get me as far into the extended thinking and the creating as possible, so design a model or synthesize information across multiple forces. (Brandon, Winter Interview 1)

While first-year teachers tried not to challenge students and made content simple, second- and third-year teachers found it essential to challenge students to think at a higher level.

*Horizontal progression.* When examining the data across the year, there was no major progression in teachers’ ideas, and therefore no horizontal progression could be suggested.

*Development of science ideas.* Development of science ideas refers to the process and sequence for how students develop ideas about science. This sub-category includes instances when teachers talked about their roles or students roles in the development of ideas, helping students link ideas, breaking the content down into smaller chunks, the impact of teacher instruction on the development of ideas, addressing various learning styles, an appropriate amount of scaffolding for students to gain understanding, reinforcement of ideas, multiple ways to present or have students experience the content, and adapting instruction for students needs.

Within the major PCK component, knowledge of students’ understanding in science, the high volume of data for this sub-category indicated that teachers talked the most about the development of science ideas during interviews. Because of the variety of
ideas and the high volume of data, this sub-category was the most difficult to analyze. Teachers shared several ideas across groups, including the need for students to experience the content in multiple ways, collaborative learning among students to develop ideas, visual representations to help students develop an understanding of concepts, students building upon fundamental concepts that are necessary to understand before subsequent ones, and real-world applications to help students develop an understanding of concepts. However, groups of teachers shared other ideas that illustrated patterns and suggested a vertical progression. While second- and third-year teachers had a shared understanding of some aspects of this sub-category, third-year teachers also had more sophisticated ideas that set them apart.

*Vertical progression.* First-year teachers understood that guidance from the teacher was necessary and therefore believed that the teacher plays a significant role in students’ development of understanding. They also expressed that students need to revisit and review concepts frequently in order to understand them. Second- and third-year teachers shared ideas of students being active, drivers of the learning process through engaging in problem-based, project-based, and inquiry-based learning, and engaging in discourse so they can develop their own understanding with less teacher involvement. In addition, third-year teachers stressed the individuality of the learning process and the differences in student learning styles and abilities. They expressed the importance of providing students with choices for learning experiences, the ability to work at their own pace, and various levels of scaffolding and guidance, depending on their needs.
Ben and Amanda illustrate the understanding of first-year teachers with the following quotes. Ben is referring to a lesson he taught that he considered a teacher-directed presentation, which included teacher questions and guided practice problems:

It’s weird because I never even knew what it was [specific content of the lesson] and I learned it as I taught through it, but it has been going good because I know other students are like, ‘that stuff is hard,’ but my students, more than anything I have taught this year, they seem to be getting it. I think part of it is me understanding that I need to slow down. I think part of it I am just kind of trying to take the pressure off myself in terms of being behind…I just need to make sure they understand. I am more confident, which is weird because it is more of a lecture format than anything. It’s not so much lecture, it’s very interactive, but, like, I’m confident that they know this more than any other topic I have taught.

(Ben, Winter Interview 2)

Another quote from first-year teacher, Amanda, demonstrates the influential role the teachers felt in guiding students through the learning process and helping them develop an understanding of science concepts.

So it was kind of, for me, the process of helping them make the connection – sort of doing it with and for them and then sending them out on their own to do the same thing for themselves. (Amanda, Winter Interview 1)

While Amanda eventually allowed students to work by themselves, she found it critical to begin by making connections for them and “doing it for them,” and then allowing them to think on their own.
The following quote from Gary represents second- and third-year teachers’ ideas on how students develop an understanding:

Doing is learning. Me standing up there telling them is not ideal; it’s not the best way. They are not fully engaged. They have got to do it. They have got to be a part in it happening somehow, some way…it’s making the content close to them. It’s make it like, ‘Guys this is happening.’ And you can see that it makes a difference; you can see the ‘Eureka’ moments happening…Conversations happen in those situations that you don’t get with the kids while you are doing direct instruction sort of a thing. You are very much just telling them information. They don’t know the questions to ask. They don’t have those curiosities when you are just giving them information, but if they are standing there at the stream table, looking at it, saying, ‘Oh well, yeah, but this is happening right here; how does this work?’ It is a much more rich conversation when you have those situations.

Because I could have just taught them for three days, had a quiz on it, and half of them would have passed the quiz and the other half wouldn’t, but they wouldn’t have had that deeper…(Gary, Late Fall Interview 3)

In this particular example, Gary is providing students with experiences that allow them to ask questions, be curious, and discover, which ultimately allows them to develop their own ideas about science concepts instead of the teacher telling them.

*Horizontal progression.* There was not a clear horizontal progression for first-year teachers. Initially, the data seemed to indicate that they were progressing toward an understanding that students need to develop their own understanding with less of a teacher role. However, the teachers always followed up by saying the teacher plays an
important role in guiding and providing structure along the way. Additionally, there was no noticeable difference in how they enacted this in the classroom and how their instructional strategies reflected this idea. Therefore, it was not determined to be a genuine progression.

**Expression of science ideas.** This sub-category refers to how students demonstrate their understanding of science concepts. Descriptions of this sub-category included instances when teachers talked about having students provide explanations (oral communication) to the teacher and other students, respond to teacher questions, ask their own questions, write responses, reflect in journals, and allow for choice/multiple ways for students to express ideas such as creating models, drawings, performances, etc.

Teachers shared a variety of ideas about expression of science ideas. In general, first-year teachers talked less about their understanding of this sub-category, and therefore data for this group of teachers was limited. However, groups of teachers shared several thoughts that allowed the suggestion of a vertical progression for the entire year.

**Vertical progression.** While teachers of all levels understood that there are multiple ways in which students can express their ideas (written, verbal, creating visual representations, etc.), details of teachers’ ideas appeared to differ. First-year teachers considered direct question and answer type strategies, wherein they had students respond (verbally or in writing) to prompts from the teacher, as a way for students to express their ideas and demonstrate their understanding. Second- and third-year teachers felt it was important to engage students in tasks wherein the teacher must interpret their ideas from what they see or hear from students rather than just a student response to a question. Many of these tasks involved students engaging in discourse with each other and
explaining/presenting their ideas to the class, which required the teacher to interpret their understanding from the conversations, arguments and presentations. Second- and third-year teachers also valued students asking questions as a way for them to express their own understanding. Additionally, they understood that students can express their understanding of the same concept in multiple ways, and they allowed them to choose their mode of expression and encouraged students to be creative in the way in which they demonstrate their understanding.

The research does not suggest that first-year teachers do not allow their students to be creative in how they express their understanding or engage in discussions with classmates to do so. However, what they view as an expression of science ideas is limited, and while there were instances when they had their students engage in conversation, they were not demonstrating that this as the way they believe students express their understanding.

The following quotes were chosen to demonstrate the above progression. First-year teacher, Ben, explains his use of questioning to allow students to express their science ideas:

So at first, it looked like me doing the work, and the biggest thing with that is trying to keep them engaged while I’m talking about something, so I would ask questions – simple ones they should already know…It is very much so that they are talking to me. It’s interactive; I like that. I am asking them the questions, and they are answering it, but I would rather be able to do something that they are going to remember. (Ben, Winter Interview 2)
Doug exemplifies a more sophisticated view that second- and third-year teachers shared. He explained the various modes of expression students can utilize and the importance of choice and creativity:

So I scaled it back a little bit so they have to give me two different visual representations of their biomolecule, and we drew cards for what they were going to do, so either drawing it and a model or a digital picture and a model or something. Most made models, so that was the first part. Second part is the talent show; they have to do some sort of a skit, video, something creative about the importance of their biomolecule to the cell or life. (Doug, Late Fall Interview 3)

*Horizontal progression.* The data did not suggest any noticeable patterns of teachers’ ideas across the year, and therefore horizontal progression cannot be suggested.

*Initial Ideas and experiences.* This sub-category included students’ prior knowledge and previous experiences about science concepts, both from school and out-of-school contexts. It also included teachers’ awareness of misconceptions and how to address them, how students’ initial ideas vary, how teachers make connections and build upon initial ideas, and how teachers help students recall their knowledge.

A common theme among all teachers across the year was the importance of building upon students’ initial ideas and experiences with science, either from earlier science education or in the real world. However, teachers did share some different ideas about this sub-category, and second- and third-year teachers expressed a more sophisticated understanding, which allowed the suggestion of a vertical progression.

*Vertical progression.* While first-year teachers discussed the importance of prior knowledge and the impact it has on students’ learning of new concepts, they were not
explicit about how they went about determining this and building upon it. In addition, they shared contradictory ideas when they indicated that they usually assume students have no prior knowledge about concepts when they begin new topics. They also shared little understanding of common misconceptions students might have. Second- and third-year teachers were more specific about the importance of determining prior knowledge to inform their curriculum and instructional decisions. They also understood that they need to determine students’ previous knowledge (via assessments) in order to appropriately build upon the initial understanding and allow their students to explore concepts in a deeper way. Second- and third-year teachers demonstrated their awareness of misconceptions and the importance of incorporating them into their instruction.

In the following quote, Lee illustrates first-year teachers’ basic understanding of students’ initial ideas:

Misconceptions often require the students to have heard the word before. Inertia is one where I don't believe they have much of a misconception. Because they don't really have an initial concept of what it is, they don’t have any preconception, right or wrong... (Lee, Winter Interview 1)

While Lee claimed that students do not have any initial ideas or experiences about inertia, he does not elaborate on how he knows this or ways he could determine whether they have an initial conception; he was making assumptions. On the other hand, the following quote by Kathy demonstrates second- and third-year teachers’ sophisticated ideas on determining students’ initial ideas and using that information to inform instruction:

I take their prior knowledge. First, I have to assess what their prior knowledge is. This was my formative assessment. I could see where the holes were. They are
very strong on plant versus animal [cells] and they are very strong on the nucleus and the mitochondria. Where they don’t have as much strength is the membrane. So that led me to the next day; we examined the parts of the membrane… So it’s pre-assessment, then it’s a adjustment of, you know, finding the holes, plugging those holes, and then I know that the rest of what we do, the analysis part, the evaluative part, will be meaningful for them. (Kathy, Late Fall Interview 2)

While first-year teachers might have used pre-assessments or believed it was important to determine what students know, they did not consistently share these ideas as a group and more commonly assumed student were lacking initial ideas rather than trying to determine their ideas and work from what students knew or had experienced.

*Horizontal progression.* There was no noticeable growth across the year; therefore it was not reasonable to suggest any horizontal progressions.

*Learning difficulties.* Learning difficulties for science students refer to instances when teachers identified which science concepts are difficult for students. Additionally, this sub-category includes why certain concepts are difficult and/or ways to address difficult concepts.

In general, all groups of teachers talked very little about which concepts were difficult for students, why they were difficult, and ways to address the concepts, even when asked during interviews. Due to lack of data in this area, patterns were not obvious. However, an interesting finding is how the teachers determined what would be considered a difficult concept. Two first-year teachers, Bill and Ben, mentioned learning difficulties and referenced what they anticipated to be difficult for their students. Second-year teachers, Brittany and Kathy, developed their understanding of difficult
concepts based on previous experiences with students. Brittany, Kathy, and third-year teacher, Gary, also explained why certain concepts are difficult and elaborated upon specific ways to address these concepts with students. While there was little data on this particular sub-category, it was apparent that second- and third-year teachers were more aware of students’ learning difficulties and instructional moves to address them when compared to first-year teachers. Based on teachers’ comments, it appeared that learning through past experiences with students allowed them to realize what the difficult concepts were and how to approach them.

*Vertical and horizontal progressions.* The data did not suggest a major progression among groups of teachers or across the year.

*Motivation and interest.* This sub-category refers to how teachers appealed to students’ motivation and interest. This included how teachers determine and develop ways to address science concepts that students find enjoyable, making content important to students’ everyday lives, connecting content to their interest areas, and allowing students to use their own individual talents and preferences during science instruction and learning.

Teachers shared several ideas on what they felt would motivate their students to learn science and what would attract students’ interest in the classroom. When looking at teachers’ ideas about motivation and interest across the year, several themes emerged that allowed the suggestion of a vertical progression.

*Vertical progression.* First-year teachers understood that in order to motivate students, they needed to incorporate “cool”, “fun” and “exciting” activities within instruction. They usually considered these to be hands-on activities or demonstrations.
Second- and third-year teachers shared ideas about getting to know students’ interests in order to make instructional decisions that related to their science interests and real-world interests. They also understood allowing for more student-driven discovery learning wherein students could explore their interests and be creative as a means to motivate students to engage in science learning.

The following series of quotes illustrates the vertical progression in the previous paragraph. First-year teacher, Ben, states,

I told you I really want things to be different, and I’ve been kind of doing it, and it’s been much better, but, like, when you hear the kids get excited like, ‘Whoa! Look at that!’ That I’m just like, ‘Ah, yes.’ Kids will come up to you and say, ‘Why don’t we do stuff like this in English?’ or they come in and see the table full of stuff and they are like, ‘See, this is what I like,’ and I’m like, ‘This is what I like, too, and I’m sorry I didn’t give you this experience before’…I realize, too, that everything doesn’t need to be groundbreaking. I always think I need to do giant projects, but you can be very simple, like making a soap bubble with warm water, and kids are like, ‘Cool.’ (Ben, Spring Interview 2)

Ben understood that what motivates students to engage in science is having activities that have an excitement factor for students, which they find cool and engaging. However, later in the interview, he talked about needing to focus on the tasks he has students engage in, specifically needing to think critically about what they are doing and why. Even though he feels the cool and fun activities are important to motivate students, he acknowledges that he needs to think more about what he is actually asking students to do
and the implications for learning. Ben’s ideas demonstrate the understanding shared by first-year teachers.

The following quote from second-year teacher, Brandon, demonstrates more sophisticated ideas about interests and motivation in the science classroom shared by second- and third-year teachers. He specifically expressed his ideas about using inquiry-based projects to motivate students to engage in the science learning process:

So next time, I need to search out and find the computers that are going to work. Then I can say, ‘here are the keys to the kingdom. Go explore,’ and they will actually be able to do it. It lost so much effect when they [students] are like ‘I want to watch the video; I want to go explore this island and get on Google Earth’ and they are like, ‘I can’t. This is so frustrating’. But their frustration tells me they were excited for the project and they really wanted to dive in, and even in defeat, I am like, ‘Okay, they are hungry to do this,’ and I know I have hit a home run with the idea of the project. (Brandon, Winter Interview 1)

The two previous quotes demonstrate the progression from the idea that fun, cool and exciting activities motivate students to the idea that projects that allow students to inquire, explore and discover also motivate students to want to learn science. Oftentimes, the focus for first-year teachers was on the effect of a “cool” activity and not on what the task itself was asking students to do and how that would help them develop an understanding of science concepts. While second- and third-year teachers made similar mention of fun and exciting activities, it was not a common theme, and they utilized students’ interests and preference for student-driven, discovery learning activities as a way to motivate them.
Horizontal progressions. The data did not suggest horizontal progressions for groups of teachers.

Attention to aspects of students’ understanding in science. The aspects of students’ understanding in science to which teachers paid attention at various points in the year varied greatly. However, when looking at the facets of understanding on which they were focusing, interesting results emerged.

During the late fall time period, it was apparent that first-year teachers focused their attention on how to appeal to students’ *motivation and interest* to encourage science learning by finding activities they thought students would find fun and exciting. In addition, they also paid attention to *appropriate level of understanding and development of science ideas*, with a focus on making sure that content and tasks were not too difficult for students and that they were saying and doing appropriate things to structure and guide learning activities. Second- and third-year teachers had more sophisticated areas of focus related to *appropriate level of science understanding and development of science ideas*, as they were thinking of ways to challenge varying levels of understanding and engage students in the content in multiple ways to reinforce understanding.

A similar theme was discovered during the winter. First-year teachers were concerned with *motivation and interest* in regards to making learning activities fun, exciting, and interesting to motivate students to engage with the content. Second- and third-year teachers were more focused on how students *develop an understanding* of the content, specifically with ideas of moving toward more student-directed learning and thinking of ways to differentiate for various levels of learners.
During spring, first-year teachers continued to pay attention to the *motivation and interest* of their students in relation to how to connect to their content interests, allow them to explore their interests and keep them engaged in lessons. However, they also began to express attention to *development of science ideas* in regards to thinking about differentiating for needs and abilities of varying learners. They were specifically concerned about how to get started differentiating instruction, as they did not feel they were doing this appropriately. Second- and third-year teachers’ primary focus was on *development of science ideas*. While first-year teachers were thinking primarily about how to start incorporating differentiation in the classroom, second- and third-year teachers were focusing on how to provide less support and encourage students be more independent and self-directed learners. They were also thinking critically about the tasks in which they asked students to engage and how these tasks would help them develop an understanding of the content and extend on their content knowledge in a deeper way. Several second- and third-year teachers articulated areas of focus related to differentiation as they were working on improving what they had already started implementing and thinking about in their classroom.

An interesting theme was first-year teachers’ concern with motivating students and not making the content too difficult. While they retained that focus, they began to pay attention to differentiation toward the end of the year, specifically how to begin thinking about how to differentiate science instruction for various types of learners and ability levels. Second- and third-year teachers were not focused on motivating students; they were concerned with allowing students to direct their own learning and become
more independent in order to determine their own understanding, while trying to improve upon their ability to differentiate in the classroom.

*Vertical and horizontal progressions.* While the above findings are interesting and highlight the differences in the areas of focus for these groups of teachers at various points in the year, the data did not suggest a strong pattern. For this reason, vertical and horizontal progressions were not determined.

**Challenging aspects of students’ understanding in science.** When looking at the data for challenges related to students’ understanding in science, it was clear that first-year teachers expressed more challenges in relation to this aspect of PCK than did second- and third-year teachers across the year. Second- and third-year teachers shared some challenges in the late fall, but not in the winter and spring.

In the fall, first-year teachers primarily expressed challenges regarding *appropriate level of science understanding and initial ideas and experiences.* They found it difficult to find a balance between teaching content that was not too difficult for students but that also went beyond memorization of facts and extended their thinking. Additionally, several teachers struggled to address students’ lack of prior knowledge of science concepts. It was difficult to identify themes for the challenges of second- and third-year teachers, as they were few and varied. However, similar to where they focused their attention, several second- and third-year teachers’ found aspects of *appropriate level of science understanding* challenging. This included how to challenge various ability levels of students in the same class when the appropriate level of science understanding was different.
In the winter, first-year teachers shared several challenges in regards to students’ understanding in science. However, these challenges varied by individual and addressed many different sub-categories; therefore, themes were not apparent. Second- and third-year teachers did not express major challenges.

As in winter, first-year teachers expressed numerous concerns related to students’ understanding in science in the spring, whereas second- and third-year teachers did not. In regards to development of science ideas, they were struggling to accommodate (via differentiation) varying ability levels in one class to help students understand science concepts. They also struggled to address students’ lack of initial ideas and experiences, as they expressed that their students did not have the basics to build from. Motivation and interest also proved to be challenging for first-year teachers, as they found it difficult to incorporate ways to motivate and engage students in science learning, despite their efforts.

Vertical and horizontal progressions. Because of the diversity in what teachers found challenging, it was difficult to determine major patterns and suggest progressions. However, it was apparent that various aspects of students’ understanding in science were challenging for first-year teachers, whereas second- and third-year teachers generally did not express challenges.

Summary. Overall, the vertical progressions described in this section demonstrated that second- and third-year teachers had a more sophisticated understanding of students’ understanding in science. Additionally, second- and third-year teachers appeared to pay attention to aspects of students’ understanding throughout the year related to improving student learning such as differentiating for various ability levels so
students could attain an appropriate level of understanding while being challenged and allowed to develop their own understanding. These areas of focus appeared to be more sophisticated than those of first-year teachers, who were concerned with motivating students by utilizing fun or exciting activities and making sure the content was not too difficult for students.

While students’ understanding of science ideas proved to be an area of focus for third-year teachers, it was not a challenging area. On the other hand, first-year teachers expressed several challenges. This was interesting because it indicated that second- and third-year teachers were working to improve this aspect of PCK, whereas first-year teachers appeared to be held back by their challenges.

Knowledge of Instructional Strategies for Teaching Science

The PCK component, knowledge of instructional strategies for teaching science, refers to teachers’ ideas about various strategies for teaching science and is broken down into three sub-categories: inquiry strategies, science phenomena strategies, and discourse strategies.

Nature of teachers’ knowledge of instructional strategies for teaching science.

While there were similarities among the levels of teachers in how they thought about instructional strategies and enacted their knowledge, there were also distinct differences. Inquiry strategies was a sub-category in which teachers shared the most varying ideas. Additionally, inquiry strategies also proved to be one of the most challenging for first-year teachers and was the instructional strategy to which teachers paid the most attention.

Inquiry strategies. Inquiry strategies refer to how teachers approached inquiry in their classrooms or for a particular lesson. It included instances when teachers talked
about the inquiry process, their role and students’ roles in inquiry, the experimental design process and components of the process such as collecting and analyzing data, utilizing data as evidence, and questioning. While the majority of teachers found inquiry strategies important and valuable for learning, their understanding, attention, and challenges varied across teaching levels. First-year teachers talked much less about inquiry; therefore, data on their ideas about inquiry is limited compared to the other teachers’, whereas third-year teachers shared many ideas on inquiry and implemented a variety of inquiry strategies in the classroom.

*Vertical progression.* While teachers’ ideas on inquiry varied slightly across the year, the overall progression of their ideas remained the same. First-year teachers had limited use of inquiry strategies, even though they believed it was important for student learning. They expressed ideas about structured, guided approaches to inquiry in which the teacher provided procedures and questions. First-year teachers also appeared to feel less comfortable utilizing inquiry strategies and thought their students were not capable of engaging in open-inquiry with less guidance and structure from the teacher. They shared ideas that inquiry was difficult for them and their students. Second-year teachers’ ideas varied, as some aligned more closely with those of first-year teachers and some aligned more closely with those of third-year teachers. Third-year teachers understood that inquiry should be open-ended and student-led and that students should determine their own questions and determine how to answer them by making their own meaning and developing their own understanding. They explained that students should conduct their own investigations with little guidance from the teacher during investigations.
The following quotes exemplify the progression explained above. First-year teacher, Kristy, explains her thoughts on inquiry, when she states the following:

Obviously, it wasn’t completely. It was kind of like a really guided inquiry where I said ‘Here, just try this,’ but… for the inquiry work, you have to train them, but really, if you train them, is it still inquiry? What is the fun of science and the purpose of science if you are not really thinking like a scientist, like, ‘Let’s try to figure this out.’ so I wanted to give them a challenge and be a problem solver.

(Kristy, Winter, Interview 1)

The quote reflects Kristy’s ideas that inquiry is important, but guided inquiry is what she understands to be helpful at this point in her teaching. Several second-year teachers also shared her ideas, but others aligned their ideas with those of third-year teachers. The following statement by second-year teacher, Brandon, demonstrates the theme that second-year teachers are beginning to think beyond the structured, guided inquiry:

And, like we experienced in high school, the cookie-cutter lab. The lab is focused to get you to one answer, and here is the formula you need to find, so the whole focus is not the inquiry and the discovery... So I have to break them of that cookie-cutter idea, and if you break them of that, it opens up this whole world of, ‘Oh my gosh, I could place the buoys here or here, and they could both work. They could both be right.’ So I find that valuable and breaking them of the whole idea of. ‘There is one right answer. I have to find the one, If I take this risk, I might not find the one right answer.’ That’s tough to do. (Brandon, Winter, Interview 1)
While second-year teachers were beginning to think more sophisticatedly about inquiry and question their practices, third-year teachers appeared to have more sophisticated thoughts on inquiry and implemented these inquiry practices more frequently in their classrooms. The following statement by Doug illustrates third-year teachers’ ideas about the implementation of inquiry strategies that allow students to design and conduct their own experiments instead of following a pre-determined procedure:

Yep, and then the plan was to have them do a little bit of research, come up with testable hypothesis and then start designing an experiment today, and then tomorrow, I would approve a design for experiments that would at least get them on sort of a right track. I don’t mind a couple of them actually failing and having to re-do it and then going ahead with the experiment. (Doug, Winter Interview 2)

A second statement, by Chelsea, demonstrated third-year teachers’ understanding that inquiry involves students developing their own problems and questions and researching to find conclusions based on evidence:

They [students] got to choose the problem, some problem that the Earth is experiencing. I want them to research the effects, so what happens because of this problem? And pick a solution, and if there are lots of solutions, pick which one you think is best. Turn it into a story that a human could connect with, and do that through whatever choice of art form or medium that speaks to you and that can express these ideas. So the art component is really going to tell that story and hopefully connect to that human experience and be a little bit more impactful than just a research paper or something, but they have to do the research, and they have to include the scientific evidence. (Chelsea, Spring Interview 1)
The previous quotes show the clear progression of a teacher-guided inquiry approach to a student-driven inquiry approach.

**Horizontal progressions.** When analyzing first-year teachers’ ideas on inquiry, a horizontal progression was not apparent. Similarly, third-year teachers’ ideas remained consistent throughout the year. While they tried to refine and tweak certain aspects of inquiry and encourage students to become more independent, their understanding and enactment of inquiry strategies did not show substantial progression.

Second-year teachers did show a progression of their understanding of inquiry strategies throughout the year In late fall, there was little implementation of inquiry strategies, and those who did utilized pre-made laboratory activities with step-by-step instructions for students to follow or with pre-determined data for student to analyze. As the year continued, they began to share ideas similar to those of third-year teachers about student-led research that would allow students to discover and explore on their own to develop their own understanding.

**Science phenomena strategies.** Science phenomena strategies refer the strategies teachers use to get students involved in science and how they engage them in science phenomena. These included instances when teachers implemented and discussed activities or approaches they utilized to get their students involved in the phenomena, which could include multiple ways to present phenomena such as lectures, providing examples, hands-on activities, projects, predict-observe-explain, demonstrations, etc.

A variety of ideas about science phenomena strategies were shared by teachers, and the enactment of these ideas was observed during classroom visits. Teachers from all levels shared similar ideas, and understood that it was important to employ a variety of
different strategies so students can see, hear, read, and experience the phenomena in multiple ways. The teachers mentioned the implementation of similar strategies such as demonstrations, examples, physical models, pictures, videos, descriptions of and experiences with real-world applications, and hands-on activities. However, the differences in teachers’ ideas suggested a vertical progression.

*Vertical progression.* In addition to the various strategies listed above, a theme that emerged among first-year teachers was their ideas that science phenomena strategies included teacher-led presentations/lectures and student practice activities, usually in the form of worksheets. Lectures and worksheets were not a common practice for second- and third-year teachers during observed lessons and interview conversations. They shared ideas about the need for real-world examples and experiences and more student-developed products such as models and projects.

To illustrate the vertical progression, the following two quotes were chosen. The first is from a first-year teacher who explained why he presented students with information and provided examples before allowing them to complete the practice worksheet:

I wanted to model it first so they could see a couple examples, and then there were more examples on the sheet, so that if they didn’t remember how I had done something… I’ve starting putting snippets of the notes, the most important parts of the notes and examples, on their worksheets now because they don’t all take notes, and if they do they might lose them or forget to take them home when they do the assignment, so I’m trying to get the highlights and some examples there so it’s a self-contained piece of paper…. And then I made it that grid so that they
could do lithium with a minus one ion, a minus two, a minus 3 and a minus, 4 and see how it changes the number of lithiums because we are changing the other element, and then the same way so that they got to see it change as they had different numbers, plus they have every combination of charges so that I know they have done them all. (Bill, Spring Interview 2).

The instructional strategy explained by Bill, wherein teachers present information, practice problems with students and then allow them to complete practice worksheets, was a common strategy explained by first-year teachers to engage their students with the phenomena. They often felt it was necessary to present information first and then allow students to engage in guided practice activities. The following quote from a second-year teacher exemplifies how second- and third-year teachers’ ideas are different:

…. I wanted so much to shy away from a PowerPoint presentation, [I] really did. I don’t find that an effective way of introducing something to this age group, especially when you can drive the point home that everybody lives in a watershed, even the school. So why not go see it? And if the weather cooperates, why not go see it? So it was an experience; it is something they can draw back to as well as being able to see it for themselves and go, ‘Oh!’ … and then when they are at the tree line looking back at the school, they can realize we just went downhill, oh, because water is going to go this way and that makes sense, and even though we felt this, we actually did go downhill. So it’s experiential, it’s – I feel like it’s an authentic lesson because they are really living the lesson, they are taking what they might not realize yet, hopefully they did, is that they just took the same path
water takes through the watershed. They walked it themselves. (Brandon, Late Fall Interview 1)

As Brandon illustrated, second- and third-year teachers shared ideas about utilizing real-world, experiential-based examples in class, in which students were actually able to experience the phenomena they were talking about in class in some way.

*Horizontal progressions.* When looking at the data across the year, there were no significant patterns to suggest a horizontal progression.

*Discourse strategies in science.* The last sub-category, discourse strategies in science, refers to language use in science. Discourse strategies included instances when teachers talked about students engaging in discussions about science ideas, including the use of argumentation, interacting with science text (including graphics), interpreting and manipulating formulas, and writing and presenting science ideas.

Teachers across all levels shared ideas about discourse in a variety of ways, from scientific language, reading and writing scientific text, engaging in discussions and argumentation, and having students present ideas orally. An overarching theme across the school year was third-year teachers’ sophisticated understanding of discourse strategies and their more frequent use of the strategies compared to first- and second-year teachers. In particular, they shared ideas about the importance of incorporating argumentation into the classroom. Despite the various ideas within each teaching level, themes emerged to determine a vertical progression for the entire year.

*Vertical progression.* First-year teachers understood discourse as having students read science texts and write about science through summaries and reflections. Their ideas on discussions among students appeared to be casual, used as an introduction to
class, a conclusion of an activity, or on an as-needed basis when students were struggling with concepts. Second-year teachers shared an understanding that discourse should be integrated into their other learning activities, such as when they had students engage in discussion or written reflection after a learning activity or as part of the research process (reading science texts, writing science text and verbally presenting information to classmates). When sharing their ideas, they appeared to purposefully plan for discussion. While third-year teachers shared similar ideas with second-year teachers, they showed more sophistication with their ideas about discourse, especially with their continued ideas about having students engage in argumentation to discuss their claims and provide support with evidence. They viewed argumentation as a valuable learning strategy. Third-year teachers viewed discourse as a learning activity in itself, not an “extra” or casual conversation. They also considered discourse an integral part of inquiry, as students need to discuss the research process and their findings to develop their own conclusions and share them with one another.

The following statement demonstrates first-year teachers’ ideas about discourse strategies:

Things that I would change… we could have discussed so much more. Maybe a richer discussion, I would say – more time to reflect on actual learning as opposed to, ‘Okay here’s this, male/female, but let’s have a conversation on what does this mean? Why do we care?’ I would say a richer discussion, for sure. (Kristy, Spring Interview 1)

This statement from Kristy reflects much of what was observed and heard from first-year teachers about discourse. Discussions were always at the end of an activity, appeared to
be rushed, and didn’t promote rich conversations that allowed students to learn from one another. Second-year teachers appeared to be more purposeful with the use of discussions for learning, as Elizabeth states the following:

Well, they had to work together to organize the trends, even though they were all their individual elements. They had to work together to decide how they were going to organize themselves…so I like the idea that they had to discuss….but they had to work together to decide how they were going to put them into trends, which is like what scientists do: work together to try to decide what is best…even though it was a simple activity, that’s the same way things work in science. You have to make observations, analyze the situation, and then decide how can we best assess this after making all the observations. (Elizabeth, Winter Interview 1)

Elizabeth was purposefully promoting discussion so students could interact, like scientists do, and discuss what they were working on with the purpose of coming to a conclusion.

Third-year teachers discussed the value of argumentation in the classroom, specifically having students verbally engage in argumentation by making claims and supporting them with evidence so multiple perspectives could be shared and students could learn from one another. The following quote exemplifies third-year teachers’ ideas about discourse:

This is an activity that allows them to discover on their own how that moment and that discussion with their partner, wait a minute, it seems like….so they are having that argument. At the end, when we bring it back together, it is going to be like, ‘Okay, so how did the argument go? Who won? Did you get the right answer
or the wrong answer? What was it like?’ And so those conversations are the key…. That’s what it is about. It’s about them figuring it out. They had no idea, and I think at the end, they still didn’t know that they all had an organism that did both; they don’t know that yet. But it is all about discovery. It’s all about them figuring it out on their own, having an experience with it and not me telling them it. It’s all about them coming to the conclusion; it means a lot more to them.

(Gary, Winter Interview 1)

Third-year teachers understood argumentation as a means for students to engage with the content in a way in that allowed them to come to their own understandings and conclusions. Discourse was often used as the primary instructional strategy or to enhance inquiry. They expressed ideas about purposefully planning for discourse and for students to learn how to engage in argumentation in ways that required them to use their knowledge of the content and learn from each other at the same time.

**Attention to aspects of instructional strategies for teaching science.** The aspects of instructional strategies for teaching science to which teachers paid attention varied, which made determining patterns difficult. An overarching theme discovered was that first-year teachers appeared to pay more attention to instructional strategies in general. This included creating or finding effective demonstrations, activities, etc. Second- and third-year teachers’ attention was more varied and specific, as they were working on refining and improving instructional strategies of interest to them at that point in the year. Due to the large volume of data on teachers’ attention to instructional strategies for teaching science, vertical progressions for each time period are explained, as well as several horizontal progressions.
Vertical progressions. In late fall, teachers appeared to pay attention to inquiry strategies. First-year teachers were focused on getting started with inquiry and figuring out how to develop guided inquiry activities. On the other hand, second- and third-year teachers were focused on figuring out how to allow students to drive the inquiry process and take a lead during investigations. It is also clear that first-year teachers paid attention to all three facets of instructional strategies for teaching science, discourse, inquiry, and science phenomena strategies, while second- and third-year teachers were more focused on one particular strategy at that time.

In the winter, teachers paid attention to varying aspects of instructional strategies; however, an interesting progression emerged. First-year teachers paid attention to inquiry in regards to how to get students started with the process, beginning to scaffold them into inquiry by providing a lot of structure, guidance, and modeling. They were also interested in getting away from teacher-directed instructional strategies and into more interactive experiences. Second-year teachers’ attention varied, but they were focused on trying out new science phenomena strategies that they felt would benefit students’ learning and improve their own teaching. Third-year teachers were focused on utilizing discourse in various ways (argumentation as a way for students to learn from one another, read, interpret, and write informational text) and engage students in more open inquiry with less structure and guidance from the teacher. It is interesting that inquiry was a focus for both first- and third-year teachers, but the emphasis was different, as first-year teachers were figuring out how to begin using these strategies with their students with a lot of guidance from them, and third-year teachers were focused on doing the opposite.
During the spring, third-year teachers paid less attention to instructional strategies than did first- and second-year teachers. As in the previous time period, first-year teachers were still thinking about how to get started implementing various instructional strategies in their classroom (inquiry, discourse, demonstrations, etc.). Second-year teachers were focused on fine-tuning their strategies and implementing less teacher-directed and more student-directed strategies or more advanced strategies such as problem and project-based learning and “flipped” instruction. As a group, third-year teachers did not seem to be paying attention to instructional strategies. However, some teachers expressed a desire to take strategies to the next level, include more real-world involvement, higher-level inquiry, more “rich experiences,” and use of technology to enhance existing strategies.

**Horizontal progressions.** First-year teachers paid attention to becoming familiar with *inquiry strategies* in the fall. Specifically, they were focused on making them structured and guided for their students. In the winter, they were still focused on this, but they also were expressing a desire to move away from teacher-directed instruction such as lectures to incorporate more interactive learning experiences for students. In the spring, first-year teachers’ attention varied as they were trying out new strategies, whether because of their own interests or because of suggestions by the district. These included various strategies related to inquiry, discourse, demonstrations, etc.

A progression was more difficult to determine for second-year teachers across the year, as their focus was individual to their personal thoughts and experiences at that time. They were focusing on incorporating specific strategies of interest to them, working to improve upon a strategy they found effective, incorporating what they felt were more
“advanced” strategies and student-driven strategies such as problem-based and project-based strategies.

Third-year teachers did not appear to pay attention to instructional strategies as much as first- and second-year teachers did. However, when they did indicate a focus, it was similar to those of second-year teachers in that they were working to refine a strategy or promote more student-driven inquiry or more advanced strategies.

**Challenging aspects of instructional strategies for teaching science.** An overall theme that emerged was the lack of challenges expressed by second- and third-year teachers when compared to first-year teachers. Because of this, vertical progressions were not appropriate. First-year teachers’ challenges were primarily related to engaging students in inquiry and developing instructional strategies in general. While second- and third-year teachers weren’t challenged by inquiry, they were paying attention to refining and improving their strategies.

For the same reason vertical progression could not be suggested, horizontal progressions could not be suggested either. First-year teachers’ challenges were fairly similar throughout the entire year. Several teachers shared concerns about their instructional strategies not aligning with their orientation of science teaching. While many first-year teachers believed science teaching and learning is centered around allowing students to engage in inquiry so they can discover and come to an understanding on their own, they also acknowledged that their teaching practices did not reflect this orientation in the classroom. This validates the reason first-year teachers express more challenges related to instructional strategies than second- and third-year teachers, as they were struggling to enact the teaching practices they found effective.
Summary. First-year teachers had the most limited understanding and implementation of inquiry strategies. While they were focused on inquiry, they were also challenged by it and found themselves incorporating very guided, structured inquiry, even if they did not believe this was best for science learning. Second- and third-year teachers did not express this challenge, but third-year teachers ultimately had the most sophisticated understanding, as they implemented student-driven, open-ended, inquiry strategies that allowed students to discover concepts on their own through investigations.

While first-year teachers were thinking about how to incorporate more interactive and less teacher-directed learning strategies, second- and third-year teachers already possessed these ideas and were working to improve these strategies. In regards to discourse strategies, second- and third-year teachers were more purposeful with planning discourse around tasks, and third-year teachers found discourse important for student learning, especially the use of argumentation practices in the classroom.

Overall, first-year teachers had the most limited understanding of instructional strategies, especially inquiry. They also paid the most attention to and expressed the most challenges related to instructional strategies. The themes indicate that attention and challenges lessened from year to year, as teachers began to refine aspects of instructional strategies significant to them.

Knowledge of Assessment of Science Learning

This main PCK component refers to teachers’ ideas about assessment of science learning. There are two sub-categories associated with assessment: strategies to assess science learning and use of science assessments.
Nature of teachers’ knowledge of assessment of science learning. Teachers shared many similar ideas about assessment of science learning. While progressions can be suggested for both sub-categories, teachers’ ideas about the use of science assessments demonstrated a more profound progression.

Strategies to assess science learning. This sub-category refers to strategies teachers use to assess students’ thinking in science. This includes both formal and informal formative methods, summative methods, how teachers develop the assessments, the types of questions they ask or tasks they have students do, student self-assessment, and use of rubrics.

Teachers described a variety of ideas about the formative and summative assessments they utilized their classroom. Among the most common were ideas that tests and quizzes are primary summative assessments, and student discussions and written assignments are helpful formative assessments. While there were many commonalities among the strategies the teachers used, the way they expressed their understanding about these strategies provided insight that allowed the suggestion of a progression.

Vertical progression. All teachers found it valuable to use tests and quizzes as summative assessments, along with various forms of formative assessments such as exit slips and practice worksheets, to assess student learning. First-year teachers indicated utilizing laboratory activities and projects too, but did not view these as having an assessment role, as second- and third-year teachers did. Second- and third-year teachers found it important to use informal discussions and observations as formative assessments. While first-year teachers utilized discussions as informal assessments as well, they appeared to be less purposeful about these as an assessment strategy and indicated
gathered data as an afterthought. Third-year teachers also expressed that projects and laboratory activities allowed them to have students engage in tasks that required higher-level thinking, in a way that quizzes and tests cannot.

The following quote by Lee demonstrates first-year teachers’ understanding that test and quizzes are the primary summative assessment strategy in the classroom:

Summative is all quizzes and tests. I mean, tomorrow they have a vocabulary test. The thing about anatomy is it’s ridiculously dense. There is so much vocabulary, and so I’m constantly quizzing them on that, but to really get a complete anatomy class, there’s a lot of concepts and things they need to understand: the way things function and interact with each other. And with that, that’s where I’m going to hit them with short-answer questions, and that’s where I’m lenient on those things.

(Lee, Winter Interview 1)

The vertical progression for strategies to assess science learning indicates that second- and third-year teachers share similar ideas on strategies to assess science learning and utilize projects, activities, and laboratory experiments as assessment strategies. The following quote from Doug illustrates this understanding:

You can’t model what actually happens in real life on a test. The highest you are going to get to on a test is have them apply to some sort of scenario, so this [project] actually gets them to model what it would be like. They are creating different situations between different countries and solving the problems that come up. So, in my opinion, it is much higher-level than what you could ever do with a test. (Doug, Spring Interview 1)
This major theme indicates the more sophisticated level of understanding of how to assess students’ understanding among third-year teachers, as compared to first-year teachers.

*Horizontal progression.* Teachers’ ideas about strategies to assess students’ science learning did not appear to change across the year; therefore, horizontal progressions were not discovered.

*Use of science assessments.* This sub-category addresses how and when teachers used science assessments. Use of science assessments included instances when teachers discussed using assessments in the following manners: as a means to determine when it was time to progress through the unit or lesson; to determine instructional decisions, readiness to take other assessments, how to divide the class for differentiated instruction, assessments as learning experiences or something “separate” from instruction, assess different levels of understanding, and assess the whole class and individuals; when to use science assessments, including timing, during the unit or lesson; and frequency of assessments.

Teachers expressed a variety of ideas on how and when they used their science assessments. A commonality among all teachers was utilizing assessments to assign students’ grades and determine whether students understood science concepts. However, there were differences in the ideas teachers expressed about the use of assessments, and these differences suggest a vertical progression.

*Vertical progression.* First-year teachers did not appear confident in the quality of their assessments to help them determine what students actually knew about science concepts. They shared ideas that assessments were used as a means to determine basic
understanding and whether students were retaining information. Overall, second- and third-year teachers were more sophisticated in their understanding of the use of assessments. They understood that formative assessments should be used to determine students’ understanding and struggles so they could modify instruction and determine which concepts needed more attention and re-teaching, both on an individual and whole-class level. Second- and third-year teachers also talked about using summative assessments to determine whether students had a deeper understanding (beyond basic recall) of the content and were able to apply their knowledge to analyze and solve problems during higher-level tasks. They expressed an understanding that assessments should be used as learning tools, not something separate, as well as a way to provide effective feedback to students.

The following quotes demonstrate the progression explained above. Lee states, “I will do something [formative assessment] that we talked about late the last week, and it gives me a chance to see what have they retained over the weekend, so it just varies, depending on the day” (Lee, Winter Interview 1). This indicated that he views the use of assessments as a means to determine what students simply remember, not specifically what they understand. He also doesn’t explain that he uses this information to inform his teaching or help students. Additionally, Ben expresses his understanding of the use of science assessments when he states the following:

But individuals [assessing them]… I haven’t figured out how to do it efficiently with the amount of time I have, and for 100-plus students. How are you supposed to do that? It seems so tough. One thing I’ve learned about assessment is to build a good assessment that is really useful, it takes a lot of time, and it takes a lot of
time to evaluate the students’ work, so how could I do that? The grade is supposed to relate to what they know in terms of the concepts, and I just know that mine does that…it’s my first year of teaching; it’s not like I’m going to have it all figured out, but what I’m worried about is I’m setting a trend or a habit for myself. (Ben, Winter Interview 1)

Ben’s quote demonstrates his lack of understanding of how to effectively utilize assessments to determine what individual students understand; however, he is still using the assessment to assign students a grade. He is aware that he needs to figure out how to make better use of assessments but isn’t sure how to do this.

Second- and third-year teachers shared ideas about using science assessments as a way to determine whether students had a deep or higher-level understanding of the content, beyond recall, as demonstrated by Doug’s quote in the previous section. Other ideas expressed by second- and third-year teachers were about the use of formative assessments to evaluate prior knowledge and inform instruction and as learning activities, not something separate or isolated. Kathy illustrates these ideas when she states the following:

I learned from last time when I did discovery with them and they were lost for the first period. I didn’t assess their prior knowledge well enough. This time, we did with the Rube Goldberg video I was able to assess did they understand force? Did they understand why a ball fell from the third floor to the first floor? Gravitation, someone said, ‘Gravitational potential energy’… Bam! Explain that. So I learned better way to assess their prior knowledge, and by doing it as a group rather than as a pre-assessment on paper, they learned from each other, and it’s almost like I
can watch their faces when this information was activated again. (Kathy, Winter Interview 2)

*Horizontal progressions.* The data did not suggest a substantial change in teachers’ ideas across the year; therefore, horizontal progressions were not noticeable.

**Attention to aspects of assessment of science learning.** While there was not enough data to suggest a full progression for the aspects to which teachers’ pay attention in regards to science assessments, there were some interesting findings. In late fall, there was a small amount of data related to what the teachers pay attention to in regards to assessment of science learning. However, when taking a broad look at the data, it appeared that second- and third-year teachers paid more attention to assessment in general than did first-year teachers. They proved to be thinking about assessment more as they shared ideas about discovering more manageable strategies to assess students’ readiness for summative assessments, creating assessments that allow students to learn about their own understanding, utilizing personal interviews as a means to diagnose individual problems, and creating rubrics that allow for subjectivity for projects that encourage creativity. While the specific aspects of assessment on which second- and third-year teachers focused differed, they were more focused and thoughtful about their assessment strategies than were first-year teachers.

In winter, the first-year teachers who indicated a focus on assessment were feeling the need to figure out a strategy to assess students in an effective way, while second-year teachers were working on other forms of assessments, such as performance or activity-based assessments. While little data was available for third-year teachers on this issue, Gary did share an important thought that this year, he felt he could really analyze his tests
and revamp them to go beyond having sufficient test items and re-create them to focus on really assessing what he set out to assess: his learning goals for students.

Similar to late fall’s results, first-year teachers indicated little focus on assessment in the spring. Second- and third-year teachers did indicate aspects of assessment to which they were paying attention, but they varied; therefore, it was difficult to determine themes. However, it was clear that second- and third-year teachers were concerned about improving their practice and worked to focus on aspects of assessment they found important at that time, such as finding new ways to provide feedback on assessments, making more detailed rubrics, etc.

Gary exemplified the finding that second- and third-year teachers seemed to be thinking more critically about their assessments and working to improve them when he stated:

I think I’ve never had time or been comfortable enough to not think about how I’m teaching – well, not how, but thinking about the content of the lesson of the day takes so much thought in the first couple years and so much planning that I think when you get to test day, you get to assessments, it’s like a day off; we are just going to have a test today. It’s not that it’s not connected at all, but I think I would agree that my tests are getting better. If you pull up a test from last year and you are looking at it and you are like [whistle], ‘Wow!’ I think that is all related to time and experience. I don’t think you can be that thoughtful about your assessments when you first begin. Yeah, you just got out of assessment class, and you just had research and measurement, and you have all of that, but you have got bigger fish to fry like making sure your classroom is being run
properly, making sure you’re teaching the standards and you have a plan for the day and are surviving. Assessment is one of the things that is most important, but it’s one of those things that just sort of gets lost in the mix, I think. And it’s not that you can’t write a good item and the level of Bloom’s you are assessing, but it’s not necessarily the content you are assessing. (Gary, Winter Interview 2)

Gary’s statement sheds light on a possible reason first-year teachers were paying less attention to assessment, as they might have been more concerned with other components of teaching science, and assessment was not a point of focus.

*Vertical and horizontal progressions.* While the findings explained in the previous paragraphs are interesting and important, the data did not suggest specific vertical or horizontal progressions relating to aspects of assessment to which teachers paid attention.

*Challenging aspects of assessment of science learning.* While analyzing data, it became a common theme that oftentimes, the aspect of PCK to which a teacher was paying attention was also an aspect the teacher found challenging. However, in the case of assessment, it appeared that first-year teachers paid little attention to assessments when compared to second- and third-year teachers but found more aspects challenging than did second- and third-year teachers.

Across the year, all five first-year teachers found aspects of assessing students’ science learning challenging, specifically in regards to developing assessment strategies. Examples include finding strategies that allow students to assess themselves, formative assessment strategies to assess individuals (not just the entire class), using formative assessment to determine what students know, pre-assessment strategies, ways to assess
students during lab activities, more effective ways to utilize “opener questions” as assessments, and strategies for utilizing assessments to divide students into ability groups.

*Vertical and horizontal progressions.* Specific vertical and horizontal progressions cannot be suggested, due to the variety of challenges expressed by first-year teachers and the absence of challenges from second- and third-year teachers. However, an important finding is that first-year teachers do express challenges regarding assessment across the year, while second- and third-year teachers do not.

**Summary.** Teachers of all levels employed similar assessment strategies, used for similar purposes. However, first-year teachers’ understanding of assessment strategies included the use of tests and quizzes as primary sources of summative assessments and practice worksheets and other written forms as formative assessments. While second- and third-year teachers also utilized these strategies, they had an understanding that projects, laboratory reports and other activities were important to implement as they assessed students’ knowledge in a different way. Their formative assessment strategies, such as discussions, also appeared to be more purposeful and better thought out for use as both learning tools and assessment tools.

All teachers used assessments to assign grades; however, first-year teachers referred to using assessments for the purpose of determining whether students gained a basic understanding of science concepts and whether or not students could recall or retain information. Second- and third-year teachers understood assessment as a way to inform instruction, as a way to assess student’s understanding on a deeper level, and as a learning tool as well as an assessment, not always an isolated event.
It appeared that second- and third-year teachers, especially, were beginning to improve their assessment strategies and think more sophisticatedly about how they were using science assessments. Additionally, an interesting finding was that first-year teachers paid little attention to assessment but found it challenging, and second- and third-year teachers showed the opposite.

**Conclusion**

The previous sections presented descriptions and various patterns that demonstrate the nature of first-, second- and third-year teachers’ science PCK and the aspects of PCK to which they paid attention and found challenging. The themes discovered within the data allowed for various vertical and horizontal progressions to be determined. The following tables provide a summary of the progressions described in this chapter. Table 4 organizes the various vertical progressions, and Table 5 presents the three horizontal progressions that were uncovered. The aspects of PCK to which teachers paid attention and found challenging across the year are organized in Tables 6 and 7.

When examining Table 4, it is noticeable that second- and third-year teachers’ ideas about various aspects of PCK are similar in many instances. These ideas were also more sophisticated than those of first-year teachers and indicated a substantial progression of ideas from first to second year. However, while second- and third-year teachers’ ideas were often similar, their enactment of these ideas in the classroom varied. This is supported by anecdotal evidence observed and heard during the visits. While second-year teachers shared sophisticated ideas, they were not as comfortable enacting these ideas as were third-
Table 4
Teachers' Vertical Learning Progressions

<table>
<thead>
<tr>
<th>Goals</th>
<th>Purposes</th>
<th>Nature</th>
<th>Curriculum resources</th>
<th>Scope</th>
<th>Sequence</th>
<th>Assessment strategies</th>
<th>Use of science assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-year teachers</td>
<td>Students learn through teacher-directed/guided approaches</td>
<td>Curriculum resources are limited to prescribed curriculum materials (district curriculum maps and textbooks)</td>
<td>Scope is limited to the standards, concepts in textbook and essential concepts/skills necessary for standardized tests</td>
<td>Curriculum sequence is prescribed (curriculum map or textbook)</td>
<td>Assessment strategies include tests and quizzes (primary summative assessment); exit slips and practice worksheets are used as formative assessments</td>
<td>Use assessments to determine basic understanding of concepts and retention of information; not confident their assessments allowed them to truly determine what students know</td>
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<tr>
<td></td>
<td>Goals are concept-driven</td>
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</tr>
<tr>
<td>Second-year teachers</td>
<td>Students learn through engaging in experiences (project/problem-based learning and inquiry), less teacher-directed</td>
<td>Prescribed scope should be enhanced by going “deeper” into the concepts, incorporating students interests and real-life applications</td>
<td>Curriculum sequence, from prescribed curriculum map, can be revised when needed based on how it would be best taught for students</td>
<td></td>
<td>Assessment strategies include tests and quizzes, but laboratory activities and projects have an assessment role in addition to being a learning tool; student discussions and observations are used as formative assessments</td>
<td>Use formative assessments to determine students' understanding, inform instruction and determine students needs; used to determine whether students have a deeper understanding of content and can apply their knowledge; assessments are used as learning tools, not something separate, and to provide useful feedback to students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Goals are related to scientific processes and thinking</td>
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</tr>
<tr>
<td>Third-year teachers</td>
<td>Students learn through student-directed inquiry; students should drive their learning, less teacher-directed approaches</td>
<td>Curriculum resources include the teachers themselves as the primary source to develop their own curriculum; it is important to utilize other teachers and curriculum resources to inform curricular decisions</td>
<td>Scope is beyond the prescribed content, other science topics and non-science topics should be integrated; must go into more depth (beyond standards), and integrate students interests within the scope</td>
<td>Curriculum sequence is determined by the teacher, considering conceptual building and seasonal factors related to instructional strategies</td>
<td>Assessment strategies include laboratory activities and projects, in addition to being a learning tool; they allow higher-level thinking to be assessed in ways that quizzes and tests cannot; student discussions and observations are used as formative assessments</td>
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</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Knowledge of students' understanding in science</th>
<th>Knowledge of instructional strategies for teaching science</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appropriate level of science understanding</strong></td>
<td><strong>Development of science ideas</strong></td>
</tr>
<tr>
<td>First-year teachers</td>
<td>Students need guidance, teacher plays a significant role in students’ development of understanding; frequent review of concepts</td>
</tr>
<tr>
<td>Students should not encounter content that is too difficult for them; appropriate level for their students is basic or lower level</td>
<td>Students express their understanding during direct question and answer type strategies, which allow students to respond verbally</td>
</tr>
<tr>
<td>Prior knowledge is important to build on but unsure how to determine it; assume students have no prior knowledge; little understanding of student misconceptions</td>
<td>Inquiry strategies</td>
</tr>
<tr>
<td>Students are motivated by cool, fun, and interesting activities/demonstrations</td>
<td>Engage students in science phenomena with teacher-lead presentations/lecture and student practice activities (usually worksheets)</td>
</tr>
<tr>
<td></td>
<td>Discourse strategies</td>
</tr>
<tr>
<td>Discourse includes students reading science texts and writing about science through summaries and reflections; discussions are casual and on an as needed basis</td>
<td></td>
</tr>
<tr>
<td>Second-year teachers</td>
<td>Students are active drivers in constructing their own understanding of science concepts through engaging in experiences and discourse with less teacher involvement; differentiation is important</td>
</tr>
<tr>
<td>Students are capable of higher-level understanding of concepts, beyond a basic understanding; students’ appropriate levels of understanding differ</td>
<td>Students express their understanding through discourse and the teacher must interpret understanding from what they hear or see from students; understanding can be expressed in multiple ways including creative ways</td>
</tr>
<tr>
<td>Prior knowledge is important to build on, but no ideas of how to determine it; also assume students have no prior knowledge; little understanding of student misconceptions</td>
<td>Inquiry should be open-ended and student-led, students should determine their own questions and how to answer them through inquiry; inquiry involves students conducting their own investigations with little guidance from the teacher</td>
</tr>
<tr>
<td>Students are motivated by discovery learning because it allows them to explore interests and be creative, which motivates them to engage in science learning; it is important to get to know students’ interests (science and real world) to incorporate into the curriculum</td>
<td>Engage students in science phenomena with real-world examples and experiences and allow students to develop their own products such as models and projects (supporting claims with evidence)</td>
</tr>
<tr>
<td>Third-year teachers</td>
<td></td>
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</tbody>
</table>
year teachers. This evidence came from conversations with teachers about what they were doing in other classes, in previous lessons, and plans for future lessons. This evidence also supports several third-year teachers’ claims that they felt their third year was a turning point and they were feeling more confident about their teaching. Gary shares this idea when he states, “I just feel like I am in the groove. I feel like I am finally thinking like a teacher. I think I am finally confident in the curricular decisions I’m making. I feel like year three is a good year” (Gary, Late Fall Interview 3).

While third-year teachers enacted more of their ideas than did second-year teachers, first-year teachers expressed the greatest divergence between their orientations to science teaching and their instructional strategies and methods for addressing student understanding in the classroom. However, first-year teachers indicated that this divergence lessened as the year progressed.

As Table 5 highlights, first-year teachers proved to show more progression across the year than did second- and third-year teachers. However, when looking closely at the data, second- and third-year teachers did have horizontal progressions, but these progressions were individual and, therefore, patterns within the groups of teachers were not noticeable.

Aspects of PCK to which teachers paid attention varied among groups of teachers. First-year teachers expressed and focused on multiple aspects of PCK throughout the year; however, attention to instructional strategies appeared to be a dominant theme compared to second- and third-year teachers. While second- and third-year teachers paid attention to various aspects of PCK, they appeared to focus more attention on students’
understanding in science. Kathy demonstrates this theme with the following quote from the end of her second year:

I just want to keep getting better at this, and I guess what I corrected after the first year: I painted with a broad paint brush. I wanted to be better at my entrance into class, my procedural stuff, and now I want to get better at figuring out how to get into their heads. How do I help them learn what I am teaching them? And it’s more of an investment now, since this is the first time I’m going to be at a school for more than a year where I get to design the department too, who is teaching what. (Kathy, Spring Interview 2)

Another major theme was third-year teachers’ attention to the development of the curriculum. While other teachers paid attention to various aspects of the curriculum throughout the year, they were not concerned about developing a new curriculum with themselves as a primary resource. An interesting pattern was that first year-teachers paid little attention to aspects of assessment compared to second- and third-year teachers; however, they expressed challenges regarding assessment. Lastly, it was more difficult to determine themes for attention for third-year teachers, as their areas of focus were individualized for their needs at that moment in the year.

Overall, second- and third-year teachers expressed fewer challenges compared to first-year teachers, as illustrated in Table 7. With the exception of curriculum challenges in late fall, second- and third-year teachers shared few challenges. In addition to curriculum, several teachers did express other individual challenges, but they did not appear to be of major concern. First-year teachers did share a variety of challenges throughout the year, and many commonalities were discovered.
### Teachers' Horizontal Learning Progressions

<table>
<thead>
<tr>
<th>PCK Component &amp; Sub-category</th>
<th>Late Fall</th>
<th>Winter</th>
<th>Spring</th>
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</thead>
<tbody>
<tr>
<td><strong>First-year teachers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge of science curriculum: <strong>Curriculum resources</strong></td>
<td>Prescribed curriculum resources are used to guide curriculum</td>
<td>Prescribed curriculum resources are used to guide curriculum</td>
<td>Students are utilized as a resource by determining prior knowledge and interests and utilizing the information to plan curriculum</td>
</tr>
<tr>
<td>Knowledge of science curriculum: <strong>Scope</strong></td>
<td>Scope of the curriculum is limited to the content standards</td>
<td>Scope of the curriculum is limited to the content standards</td>
<td>Scope of the curriculum cannot be determined by the standards alone because students do not always have the necessary prior knowledge, sometimes it is necessary to address prerequisite knowledge; it is important to incorporate topics of interest to students within the scope</td>
</tr>
<tr>
<td><strong>Second-year teachers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge of instructional strategies for teaching science: <strong>Inquiry</strong></td>
<td>Inquiry is pre-made laboratory activities with step-by-step instructions and teacher guidance</td>
<td>Inquiry can be student-led, students think scientifically by engaging in discovery learning to develop their own understanding, not “cookie-cutter” labs</td>
<td>Inquiry can be open-ended and student-driven with less teacher guidance; students can ask their own questions and conduct their own investigations</td>
</tr>
<tr>
<td></td>
<td>Late Fall</td>
<td>Winter</td>
<td>Spring</td>
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<tr>
<td><strong>First-Year Teachers</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td>aligning lessons with standards and objectives</td>
<td><strong>Motivation &amp; Interest</strong>: making learning activities fun, exciting and interesting to motivate students</td>
<td><strong>Scope</strong>: thinking of ways to enhance the curriculum for next year to address content that is more meaningful, relevant and appropriate for students</td>
</tr>
<tr>
<td><strong>Appropriate level of science understanding &amp; Development of science ideas</strong>: making sure content is not too difficult and structuring learning tasks to guide students</td>
<td><strong>Inquiry strategies</strong>: how to begin engaging students in inquiry, how to structure, guide and scaffold them into the process</td>
<td><strong>Motivation &amp; Interest</strong>: how to connect to students’ interests and allow them to explore these and keep them interested in the lesson</td>
<td></td>
</tr>
<tr>
<td><strong>Instructional strategies (general)</strong>: paid attention to all facets of strategies</td>
<td><strong>Science phenomena strategies</strong>: trying to move away from teacher-directed strategies toward more interactive strategies</td>
<td><strong>Development of science ideas</strong>: thinking about how to start differentiating for needs and abilities of varying learners</td>
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<tr>
<td><strong>Inquiry</strong>: thinking of how to get started with inquiry and developing guided inquiry activities</td>
<td><strong>Development of science ideas</strong>: thinking of ways to challenge varying levels of understanding and engage students in content in multiple ways</td>
<td><strong>Development of science ideas</strong>: providing less support, students become more independent and self-directed learners; thinking critically about the tasks students engage in and how they will help them develop an understanding and extend their content knowledge; improving their differentiation strategies</td>
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<tr>
<td><strong>Second-Year Teachers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Appropriate level of science understanding</strong>: thinking of ways to challenge varying levels of understanding and engage students in content in multiple ways</td>
<td><strong>Development of science ideas</strong>: moving toward more student-centered learning so students are thinking for themselves; differentiating for various levels of learners</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focused on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
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</tr>
<tr>
<td><strong>Inquiry strategies</strong>: allowing students to drive the inquiry process and lead investigations</td>
<td><strong>Science phenomena strategies</strong>: trying out new strategies they felt would benefit students’ learning and improve their teaching</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: finding manageable ways to assess students’ readiness to move through curriculum, creating assessments for student use, utilizing personal interviews, and creating rubrics</td>
<td></td>
</tr>
<tr>
<td><strong>Assessment strategies and use of science assessments</strong>: finding manageable ways to assess students’ readiness to move through curriculum, creating assessments for student use, utilizing personal interviews, and creating rubrics</td>
<td><strong>Assessment strategies</strong>: utilizing other forms of assessment such as performance- or activity-based</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focusing on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
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<tr>
<td><strong>Third-Year Teachers</strong></td>
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<tr>
<td><strong>Scope</strong>: going beyond the standards to promote deeper understanding, expanding on concepts from previous grades</td>
<td><strong>Discourse strategies</strong>: utilizing argumentation as a way for students to learn from one another; having students engage in reading, interpreting and writing informational text</td>
<td><strong>Development of science ideas</strong>: providing less support for students during the learning process, students become more independent and self-directed learners; thinking critically about the tasks students engage in and how it will help them develop an understanding and extend their content knowledge; improving their differentiation strategies</td>
<td></td>
</tr>
<tr>
<td><strong>Appropriate level of science understanding</strong>: determining ways to challenge varying levels of understanding</td>
<td><strong>Inquiry strategies</strong>: incorporating inquiry strategies that are more student-lead, with little guidance from the teacher</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focusing on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
<td></td>
</tr>
<tr>
<td><strong>Development of science ideas</strong>: engaging students in content in multiple ways</td>
<td><strong>Inquiry strategies</strong>: utilizing inquiry strategies that are more student-lead, with little guidance from the teacher</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focusing on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
<td></td>
</tr>
<tr>
<td><strong>Inquiry strategies</strong>: allowing students to drive the inquiry process and lead investigations</td>
<td><strong>Assessment strategies and use of science assessments</strong>: finding manageable ways to assess students’ readiness to move through curriculum, creating assessments for student use, utilizing personal interviews, and creating rubrics</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focusing on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
<td></td>
</tr>
<tr>
<td><strong>Assessment strategies and use of science assessments</strong>: finding manageable ways to assess students’ readiness to move through curriculum, creating assessments for student use, utilizing personal interviews, and creating rubrics</td>
<td><strong>Assessment strategies</strong>: utilizing other forms of assessment such as performance- or activity-based</td>
<td><strong>Assessment strategies &amp; Use of science assessments</strong>: focusing on improving practice and working on aspects of assessment they found important at the time. Specified varied</td>
<td></td>
</tr>
<tr>
<td>First-year teachers</td>
<td>Late Fall</td>
<td>Winter</td>
<td>Spring</td>
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<tr>
<td><strong>Curriculum:</strong> challenges varied, due to inexperience with curriculum</td>
<td>Scope &amp; Sequence: covering required content in time for the test and maintaining an appropriate pace when moving through curriculum</td>
<td>Scope: covering required content before the end of the year</td>
<td></td>
</tr>
<tr>
<td><strong>Motivation &amp; Interest:</strong> ways to motivate students and appeal to their interests</td>
<td>Development of science ideas: struggled to accommodate, via differentiation, varying ability levels in the same class</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Appropriate level of science understanding:</strong> determining what an appropriate level of understanding is for students</td>
<td>Inquiry strategies: engaging students in inquiry and developing <em>instructional strategies</em> in general</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Initial ideas and experiences:</strong> struggled to address students’ lack of prior knowledge</td>
<td><strong>Initial ideas &amp; experiences:</strong> how to address students who do not have the basics to build from</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Assessment strategies and use:</strong> challenges varied but included issues related to developing formative and summative strategies that were useful in determining what students really know, pre-assessing their knowledge, assessing students during laboratory activities, effective questioning for assessment, and using assessments to determine ability groups</td>
<td>Assessment strategies and use: challenges varied but included issues related to developing formative and summative strategies that are useful in determining what students really know, pre-assessing their knowledge, assessing students during laboratory activities, effective questioning strategies, and using assessments to determine ability groups</td>
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</table>

<table>
<thead>
<tr>
<th>Second-year teachers</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope:</strong> addressing all the concepts necessary in the time allowed, struggled to address concepts in the depth they found to be important</td>
<td></td>
</tr>
<tr>
<td><strong>Appropriate level of science understanding:</strong> how to challenge various ability levels of students in the same class when the appropriate levels of understanding are different</td>
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</tbody>
</table>

| Third-year teachers | |
|---------------------| |
| **Scope:** addressing all the concepts necessary in the time allowed, struggled to address concepts in the depth they found to be important | |
Teachers also shared several challenges and areas of focus that were not related to science PCK. First-year teachers expressed concern about classroom management issues throughout the year. Challenges related to classroom management were shared frequently during interviews. It pervaded many conversations and was often considered when they were making instructional decisions. First-year teachers shared that they felt their classroom management improved as the year progressed, but it still remained a challenge and area of attention.

Third-year teachers expressed attention and challenges regarding requirements for Ohio’s teacher evaluations for new teachers. Specifically, they felt overwhelmed with completing the required tasks over the course of the year. They felt the tasks were consuming the time they felt they needed to spend working on aspects of their teaching and planning their lessons.

The themes and patterns that emerged during data analysis allowed a description of first-, second- and third-year teachers’ ideas about various aspects of science PCK as well as a determination of the areas to which they paid attention and found challenging. Determining these progressions will allow a discussion about the implications these findings have for continued teacher learning and the university-based mentoring program.
Chapter 5

Discussion

The vertical and horizontal progressions described in the previous chapter shed light on the nature of new science teachers’ knowledge growth and learning needs. The vertical progressions uncovered show teacher learning from year to year, but the lack of horizontal progressions indicates little growth throughout the year. In addition, the aspects of PCK to which teachers pay attention and find challenging indicate the complex nature of supporting continued learning for new teachers. Contextual matters such as classroom management and state induction programs and evaluations proved to be of concern for new teachers. All of these major findings have implications for continued teacher learning and university-based mentoring programs.

Vertical learning progressions

An overarching pattern found in this study was the increasingly sophisticated ideas about teaching science demonstrated by the teachers across levels. A vertical progression was apparent for fifteen of the seventeen PCK sub-categories. In two situations, first- and second-year teachers shared similar ideas, and third-year teachers expressed more sophisticated ideas. However, in the majority of cases, two patterns emerged. For seven sub-categories of PCK, second- and third-year teachers shared similar ideas, which were more advanced than those of first-year teachers. For six sub-categories of PCK first-, second- and third-year teachers sequentially shared more sophisticated ideas. In instances in which second- and third-year teaches shared common ideas, third-year teachers appeared more confident in enacting their ideas in the classroom. It is reasonable to consider that while their ideas are similar, third-year
teachers’ ability to connect their ideas to their context was more advanced than that of second-year teachers. For example, many second- and third-year teachers shared sophisticated ideas about inquiry strategies. However, third-year teachers spoke more about their ability to connect these ideas with their classroom contexts and elaborated on what this meant for their instruction and their students’ learning.

The vertical progressions described in this study demonstrated the difference between Feiman-Nemser’s (2008) ideas of the knowledge for teaching, which is learned outside of practice, and knowledge of teaching, which is gained in the context of teachers’ work. The progressions uncovered illustrate the knowledge of teaching, which is gained as teachers utilize their existing knowledge and beliefs as a lens for interpreting new knowledge and experiences (Feiman-Nemser, 2008). The vertical progressions described in the results embellished what was expected, as teachers’ ideas became successively more sophisticated as they gained knowledge of teaching and utilized their knowledge base to encounter new pedagogical situations in the classroom.

Certain aspects of teaching can only be learned in conjunction with practice, such as making decisions about what and how to teach over time and responding to students’ thinking (Feiman-Nemser, 2001a). Interpreting students’ ideas and making pedagogical decisions as a lesson develops is something teachers will gain knowledge of as they teach within their context (Feiman-Nemser, 2001a). The aspects of teaching described by Feiman-Nemser were encompassed in the various PCK sub-categories, and it was clear that teachers were developing a deeper knowledge of teaching. As explained above, the evidence demonstrated vertical progressions for the majority of the PCK sub-categories, indicating the advancement toward a deeper knowledge of science teaching.
The vertical progressions described in this study fall in line with Heritage’s (2008) definition of learning progressions as progress that is continuous and coherent as one develops more sophisticated ways of thinking over time. Learning progressions suggest a trajectory for learning in which teachers acquire adaptive expertise as they evolve their core competencies and continually expand the breadth and depth of their expertise (Bransford et al., 2006). While the research does not suggest that third-year teachers are experts, they are more advanced than first-year teachers are, and the vertical progressions described in this study demonstrate noticeable sequences of teachers’ ideas toward a more sophisticated nature as they learn through practice.

The vertical progressions uncovered through this research indicated a substantial change in teachers’ ideas from year to year. This demonstrates the importance of staying in the profession for multiple years. It is also reasonable to consider that teachers spend a lot of time reflecting at the end of year, when they are less immersed in the day-to-day duties of teaching. During the final interview, many teachers were thinking forward to summer or the following year and expressed attention to improving certain aspects of their teaching. It makes sense that at this time, they were able think about their teaching over the year and develop ideas for improvement for the following year. Ben pointed this out when he stated,

I honestly need some time to just think about it, and I think that time is going to be in the summer after my first year where I can… But I think the biggest thing lately is I know what I want my classroom to look like and I know that I’m capable of having it look more like that, and I want it to look more like that, so how do I get there? (Ben, Spring Interview 1)
It is logical for teachers to feel they have the opportunity to reflect at the end of the year and during the summer. This could explain the noticeable vertical progressions.

Most of the research on learning progressions has been on students’ learning of science content. However, Schneider and Plasman (2011) analyzed multiple research articles on science teacher PCK and developed progressions for various PCK sub-categories. Their study involved five levels of teachers, which included pre-service teachers, teachers with zero to three years of experience, teachers with four to 10 years of experience, teachers with more than 11 years of experience and leader science teachers who have taken on mentoring roles. The PCK model used in their study was similar to the one used in this dissertation, with some variations in sub-categories.

When comparing the progressions discovered in this study to those in Schneider and Plasman’s study, some similarities were noticed, despite the differences in teacher experience levels in each study. Most of the similarities occurred when first-year teachers’ ideas in this study aligned with the most basic level of understanding in the Schneider and Plasman study. Second-year teachers often aligned with second-level ideas, and third-year teachers with more advanced ideas. For example, one of the sub-categories in which similarities were found was inquiry strategies. The progression found in this study was the following:

*Vertical progression.* While teachers’ ideas on inquiry varied slightly across the year, the overall progression of their ideas remained the same. First-year teachers had limited use of inquiry strategies, even though they believe it was important for student learning. They utilized a structured, guided approach to inquiry wherein the teacher provided procedures and questions. First-year teachers also
appeared to feel less comfortable utilizing inquiry strategies and thought their students were not capable of engaging in open inquiry with less guidance and structure from them. Second-year teachers were a split group. Some of the teachers’ ideas aligned with those of the first-year teachers, while the others aligned with those of third-year teachers. Third-year teachers understood that inquiry should be open-ended and student-led and that students should determine their own questions and determine how to answer them by making their own meaning and developing their own understanding. They explained that students should conduct their own investigations with little guidance from the teacher during investigations.

Schneider and Plasman described the following progression for inquiry strategies:

Progression. Inquiry strategies are activities that are hands on or that lead to “discovery,” are difficult to enact, and may be inappropriate for students → Inquiry strategies are primarily opportunities to collect data through observations or experimentation and can be teacher centered → Inquiry strategies are opportunities for student to pose questions or collect and work with their own data, and traditional lessons can be converted to inquiry → Inquiry strategies include students posing questions, designing investigations, collecting evidence, and making claims (with instruction). (Schneider & Plasman, 2011, p 550-551)

The progressions are similar in how teachers think about inquiry as they learn through practice, and their ideas become more sophisticated. It was interesting to point out that first-year teachers in this study were at a very basic level, and second- and third-year teachers often aligned with more advanced ideas. Based on this evidence, it seems that
first-year teachers almost regress from the pre-service year, while second- and third-year teachers advance quickly.

There were several other progressions in which similarities were noticed. In some instances, the teachers in this study were thinking more sophisticatedly than the teachers in Schneider and Plasman’s study, as second- and third-year teachers’ understanding often aligned with advanced ideas. However, as stated earlier, there were many instances in which first-year teachers in this study aligned with the most basic ideas. A reason for this could be the survival mode feeling many first-year teachers alluded to during our conversations. Second-year teacher Kathy reflected on this feeling she had had as a first year teacher when she stated, “Before, I was just trying to survive until the end of the year, and I feel like I can slow that down and not worry about that as much…” (Kathy, Spring Interview 2). It appears that once the teachers feel they are out of survival mode, they are able to focus on their teaching and learn through practice.

The similarities found between the two studies validated the findings in this study. Using the progressions uncovered in this study is a valuable framework for thinking about how to develop curriculum and instruction for new teachers that promote continued learning through practice. However, this study adds to the understanding of how learning progresses for a specific group of teachers who graduated from the same teacher preparation program. In some cases, this study was able to provide more specific progressions for PCK components. For example, in the case of science curriculum, this study was able to provide a progression for each sub-category (curriculum materials, scope and sequence), whereas Schneider and Plasman provided one progression for curriculum in general. The multiple progressions allowed for a more specific
understanding of teachers’ ideas about science curriculum. In addition, this study also examined horizontal progressions for which aspects captured teachers’ attention and what they found challenging, which will be discussed in later sections. This adds to the understanding of teachers’ knowledge growth and learning needs.

**Horizontal Learning Progressions**

Only three horizontal progressions could be suggested to illustrate how teachers’ ideas develop across the year. However, of the three, two were first-year teachers’ progressions. This is not to suggest that second- and third-year teachers did not progress throughout the year, because when looking at the data, there was some evidence of progressions among individual teachers; however, these were not apparent when looking at themes among groups of teachers. While there were some individual progressions, they were considered minimal and suggest a lack of growth throughout the year.

First-year teachers showed a progression of their ideas related to the nature of curriculum resources and scope. It is reasonable to suggest that because first-year teachers are entering the profession with a basic level of understanding and are experiencing that particular teaching context for the first time, there would be some horizontal progression from the beginning of the year to the end. In regards to curriculum in particular, this was the first time several of these teachers taught these courses; therefore, it makes sense that it took time for them to develop ideas about the new science curriculum.

As stated earlier, evidence also shows that there was not much substantial change across the year for individuals. It is reasonable to suggest that teachers are so engrossed in the act of teaching throughout the year that it is difficult for them to reflect on their
practice. Scholars have expressed the importance of reflection in teaching but have also acknowledged that this thoughtful deliberation is difficult to engage in and can pose a challenge for all teachers (Zeichner & Liston, 2014), especially novice teachers (Yost, Sentner, & Forlenza-Bailey, 2000). However, at the end of the year, the teachers shared aspects of their teaching that they wanted to think about more and work on during the summer and at the beginning of the following year. This could explain why teachers demonstrated little horizontal progression throughout the year but noticeable vertical progressions across teaching levels.

It would also be reasonable to consider that another explanation for why horizontal progressions were lacking while vertical progressions were prevalent was that teachers taught the same courses for the entire year. Therefore, teachers did not come back to specific topics again until the next year. Considering this, it was not surprising that teachers did not progress substantially throughout the year, as revisiting the topics again the following year would allow their ideas to grow and become more sophisticated.

The noticeable vertical progressions and lack of horizontal progressions are an essential finding in this study. They indicate teachers’ growth in understanding from year to year, but a lack of growth across the year. It is also important to point out that this study only measured PCK, and it is possible that the teachers progressed in other aspects of teaching.

**Attention to Aspects of PCK**

An overarching theme across the year was first-year teachers’ attention to instructional strategies for teaching science. However, second- and third-year teachers primarily expressed attention to aspects of students’ understanding in science and science
curriculum. They also focused on aspects of assessment, which was rarely expressed by first-year teachers.

One reason for the shift in attention from instructional strategies to student understanding might be the feeling of urgency teachers had to create lesson plans with effective instructional strategies. The focus was on themselves as the teachers and what they were going to do or have students do in class each day. As teachers begin to feel comfortable with their strategies and learn through practice, they are able to direct their attention to other aspects of PCK. In addition, it is reasonable to consider that gaining knowledge of students’ understanding in science as very contextual and requires teachers to gain knowledge through working with students and discovering how they develop and understand science concepts; therefore, it took time to develop more sophisticated ideas.

The majority of first-year teachers were provided with prescribed curriculum materials. It is likely that for this reason, curriculum was not an aspect to which first-year teachers paid attention because it was a facet of teaching that was already developed for them. However, second- and third-year teachers who had prescribed materials available to them were found to modify or create their own curriculum. Thus, in this case, it makes sense that teachers felt more comfortable with other aspects of their teaching, such as instructional strategies, and they were able to look at the bigger picture of curriculum and begin to think critically about it and take ownership.

Another interesting finding was the variation in the aspects to which third-year teachers paid attention. While a small number of obvious commonalities existed, third-year teachers also shared very individual aspects of science teaching to which they were paying attention. For example, one teacher was paying attention to revamping his
science assessments, while another was focused on implementing more student-directed inquiry strategies in class, and another teacher was dedicated to addressing the various student ability levels. This can be attributed to third-year teachers having more time to learn through practice and work on aspects of their teaching. For this reason, they were able to think of specific areas of focus to improve their teaching.

Awareness of where teachers are placing their attention is valuable when considering what will motivate and interest teachers who are involved in a mentoring program. Looking at where teachers place their attention across the year and across teaching levels will inform the mentoring curriculum to appeal to the needs of teachers as learners and can be used to consider how instruction might be individualized for various teachers. Examples will be expanded upon in a later section.

**Challenging Aspects of Teaching Science**

Second- and third-year teachers expressed fewer challenges related to teaching science compared to first-year teachers, whose challenges spanned various PCK components and were numerous across the year. Second- and third-year teachers did indicate challenges; however, they were not as numerous. It was not surprising to discover this, as it seems logical that first-year teachers would express more challenges.

While second- and third-year teachers expressed fewer challenges, their challenges were more refined. For example, first-year teachers often expressed broad challenges such as engaging students in inquiry or motivating students. On the other hand, second- and third-year teachers explained more specific challenges such as challenging all students within the same class, even when their appropriate level of
understanding differed, and formatively assessing students to determine readiness to move through the curriculum and inform instruction.

It is important to recognize the patterns of teachers’ challenges, as they will have implications on the suggestions for the mentoring program. As explained in the previous section, utilizing what we know about teachers’ challenges will allow a curriculum to be developed that responds to these challenges at particular points across the year and can be individualized for various levels of teachers when appropriate. It is important to consider the varying challenges of second- and third-year teachers, as this will have implications for the support provided.

Classroom Management: The Distraction

First-year teachers were primarily concerned with issues of classroom management, including discipline, and expressed these challenges throughout the year. Classroom management issues pervaded the conversations, and teachers expressed the impact their struggles had on their instruction and student learning. While classroom management is not a component of PCK, it was important to discuss this finding, as it impacts teachers’ ability to develop and pay attention to other aspects of PCK. First-year teachers’ attention and struggles with classroom management could also explain their alignment with basic-level ideas in Schneider and Plasman’s study and apparent regression to pre-service ideas during the first year. On occasion, a second or third-year teacher brought up a concern related to classroom management; however, it was not a recurring theme across the year for these groups of teachers.

Finding that new teachers, first-year teachers in particular, struggle with classroom management is consistent with the literature. The literature has shown for
decades that novice teachers feel more challenged when it comes to classroom management and discipline procedures (Berliner, 1987). Despite the fact that classroom management was woven through the teachers’ pre-service curriculum and they had the opportunity to learn about it through practice during student teaching, the school and classroom contexts affect how the teacher manages the classroom (Emmer & Stough, 2001). School and classroom contexts vary, and that has implications for how the teachers develop effective management strategies for their students (Emmer & Stough, 2001). For this reason, teachers need opportunities to learn about their new contexts and adjust their procedures.

Based on what is known about classroom management concerns among new teachers, it was not surprising to find that first-year teachers expressed many challenges about this aspect of teaching. While classroom management is not an aspect of science PCK and therefore not a main focus for the curriculum of the mentoring program, it is necessary to recognize classroom management as a component of the teaching context and to be aware that this challenge could prevent teachers from progressing in other areas. It is important to think about what this distraction means for the curriculum and instructional support developed for new teachers. These ideas will be expanded upon in the implications section.

**Ohio’s Beginning Teacher Evaluation Program: The Roadblock**

First-year teachers mentioned little about Ohio’s new teacher induction and evaluation program in general or about its requirements. However, second- and third-year teachers did mention the program in several instances throughout the conversations. Primarily, third-year teachers discussed the negative effects of program, in particular the
effects the teacher evaluation system had on their teaching. They expressed concerns with the amount of work required to complete the assessment tasks and how this was deterring their focus from their classrooms and students. Doug even shared his frustration with how the assessment was forcing him to focus on himself and not focus on his students, which he felt he was beginning to do in his third year. In addition, all third-year teachers shared disappointment with the program overall and the lack of support it was providing. They did not feel the assessment was helpful with providing opportunities for reflection on their teaching, and the lack of feedback from the assessment was a concern for them. They were also disappointed in the lack of support they were being provided during the program. However, it is interesting to point out that third-year teachers did demonstrate sophisticated ideas, and the data did not indicate a regression. While they did not feel the induction program was beneficial and indicated that the evaluation caused stress, it is possible that it was still helpful.

Second-year teachers did not share similar issues about the assessment portion of the induction program, as they are not evaluated during year two; however, they did share their opinions about the program. Most of them expressed that the professional development and support was minimally helpful, as much of it pertained to things they already knew and did not address the concerns they were having in their classrooms at that time.

While these findings are not related to the components of PCK, they indicate that teachers feel as if they cannot focus on the aspects of their teaching and student learning that they find important, as they are occupied with evaluations. Additionally, teachers are not satisfied with the support they are receiving through the program, which indicates that
additional support is needed to continue to advance their understanding of science teaching and learning. It is important to consider the standards and requirements of the induction program and evaluations when thinking about curriculum and instruction for new teachers. Perhaps it is necessary to consider how the university-based mentoring program can provide additional support. Additionally, it would be helpful to align with the program standards, as they are of importance and concern to teachers. These ideas will be further discussed in the following section.

**Implications**

The major points discussed above have several implications for continued teacher learning and university-based mentoring programs. How the findings of this study contribute to the understanding of teachers’ growing ideas and the development of support for new teachers will be discussed in the following sections. Keeping in mind what was learned from the teachers in this study, several recommendations are offered for teacher educators and university-based mentoring programs. These recommendations take into consideration the evidence demonstrating teachers’ development of PCK and their learning needs in the beginning years of their careers.

**Vertical and horizontal progressions.** As stated earlier, much of the research conducted on learning progressions has concerned students learning science content. However, research on how teachers’ learning progresses is lacking. Despite the focus on science learning, much of the literature can be applied to the domain of teaching and teacher education and has guided the author’s thinking about learning progressions.

**Continued teacher learning.** The vertical progressions uncovered in this study and the lack of horizontal progressions indicate that teachers are learning through practice
and developing more sophisticated ideas from year-to-year; however, they have difficulty reflecting on their teaching and progressing throughout the school year. When thinking about learning progressions in teacher education and the complex nature of learning through practice, it is important to think of teaching as an ill-structured domain (Spiro, Coulson, Feltovich, & Anderson, 1994) and that “the task of teaching occurs in a relatively ill-structured, dynamic environment” (Leinhardt & Greeno, 1986, p.75). Because teaching is ill-structured and complex, teacher educators need to be aware of what teachers are learning and how their knowledge is progressing so they can provide appropriate support. In addition, the integrative nature of PCK components adds another complex facet to continued teacher education (Park & Chen, 2012). It is important to remember that while these components can be separated and examined, within the context of teaching, they are intertwined. This means professional learning opportunities must assemble these learning progressions back together. Using the learning progression and PCK framework, professional programs can be designed to promote advanced science teacher learning (Schneider & Plasman, 2011).

While these professional learning opportunities are imperative to promote teacher growth, the reflective dimension of continued teacher learning is also essential. As demonstrated in the literature, it is difficult for teachers in general, and the teachers in this study, to reflect throughout the school year. It would be helpful to have more frequent breaks in the school year to allow teachers time to reflect on their teaching, collaborate with other teachers and educational professionals, and determine plans for improvement. Many teachers in this study, especially first-year teachers, shared overwhelmed feelings throughout the year. Periods of time when they can take a break
from the everyday duties of teaching and work on their professional growth would be helpful in progressing teachers’ learning.

*University-based mentoring programs.* It is important to keep in mind that the goal of learning to teach is to advance teachers’ knowledge about teaching their content area. This study has focused on what Spiro et al. (1994) consider *advanced knowledge acquisition*, which is the learning that goes beyond the introductory stage but comes before expertise. New science teachers begin with a level of knowledge obtained during the pre-service program and, as they learn through practice, they develop expertise. The beginning years of intense learning are when they will begin to develop *advanced knowledge acquisition*. Spiro et al. point out that within an ill-structured domain, advanced knowledge acquisition, wherein the learner attains a deeper understanding of the content and is able to reason with it and apply it within diverse contexts, can pose learning problems and requires certain conditions to advance knowledge. Conditions relevant to the purpose of this research are active participation, tutorial guidance, and adjunct support for the management of complexity. Spiro et al. assert that in ill-structured domains, knowledge cannot be given to the learner. The learner must be actively involved in knowledge acquisition, with guidance by expert mentors, which is essential to handling the complexity of the ill-structured domain. Therefore, it is essential that those who support new teachers be expert mentors and be able to guide teachers to be active learners within their school contexts. These mentors should be teacher educators with expertise in teaching science content and should be aware of the interests and needs of the teachers and understand how to promote continued teacher learning. In particular, teacher educators need to understand how science teachers’ PCK
develops in order to guide them to more sophisticated understandings of how to teach science.

Due to the ill-structured nature of teaching, learning progressions are helpful for thinking about how to advance teachers’ knowledge. Consistent with Shavelson’s (2009) ideas, findings from this study do not suggest that the learning progressions uncovered should function as standards for teacher learning within a mentoring program. Instead, they should be used as a framework through which to think about the curriculum and instructional methods utilized for a mentoring curriculum. The learning progressions were uncovered by examination of actual teachers’ thoughts and actions, which therefore provide a way to look at the paths from novice to more experienced teaching and should inform curriculum and instruction (Shavelson, 2009; Shin, Stevens, Delgado, Krajcik & Pellegrino, 2007; Heritage, 2008). Learning progressions should be based on evidence, not on analysis of disciplinary knowledge (Corcoron, Mosher & Rogart, 2009). This study regards learning progressions as Heritage (2008) does, as a continuum, a trajectory of development that connects the knowledge within a domain.

Armed with the knowledge of how teachers thinking progresses, a curriculum can be efficiently aligned with what teachers need in order to progress (Corcoron, Mosher & Rogat, 2009). Therefore the present study suggests that mentoring programs should utilize the descriptions of teachers’ learning progressions to design a spiral curriculum (Bruner, 1960) that addresses the specific areas necessary to support teachers’ knowledge growth. Knowing how teachers’ learning progresses will allow for the creation of opportunities to accelerate their learning and continue to advance their knowledge acquisition so they will become more sophisticated in their thinking. It is essential that
the mentoring curriculum be an extension of teachers’ pre-service curriculum to ensure that the curriculum is meaningful and will serve to promote growth. To do this, it is imperative that teacher educators understand the knowledge teachers are bringing to the field in order to determine how to build from this knowledge. Utilizing a PCK and learning progression framework will allow for opportunities for continued teacher learning.

When programs involve teachers of various levels, vertical differentiation among groups of teachers is important. While programs with various levels of teachers re beneficial, as teachers can learn from one another, it is important to consider the differences in their learning needs. Teachers’ knowledge, interests, and challenges vary, which should be considered when determining the curriculum and instructional methods for a program.

Due to the lack of horizontal progressions and the difficulty teachers appeared to have with showing development across the year, it is necessary to design a curriculum that considers this struggle. Having a trajectory for learning can inform the support provided throughout the year as mentors assist teachers with moving along that pathway and provide support to minimalize the overwhelmed feelings that prevent reflection and growth.

Reflection is not as easy task, even for experienced teachers. For this reason, this study is aligned with Zeichner and Liston’s (2014) suggestions for enabling teacher reflection. They propose that rich reflection can be prompted with various texts within formal teacher education and professional development contexts. Reflection can occur either individually or collaboratively and in various settings such as study groups,
forums, book clubs, and action research groups (Zeichner & Liston, 2014). Based on the evidence, it is reasonable to suggest a need to enable reflection in various ways as teachers participate in a university-based mentoring program to help progress their learning.

**The nature, disconnect, and fading of teachers’ orientations to teaching science.** Within the orientation to science teaching PCK component, some interesting findings emerged. First-year teachers demonstrated a disconnect between their ideas about the nature of teaching and learning science and how this was reflected in their ideas about the other aspects of teaching and learning. In addition, the researcher was unable to suggest a progression for purposes of teaching science, as second- and third-year teachers shared few thoughts on this aspect of teaching. However, the opposite was noticed for teachers’ goals for science learning.

**University-based mentoring program.** While there appeared to be a fading effect in which second- and third-year teachers thought little about their overall purposes of teaching science, they were more explicit and focused on their goals. It is reasonable to suggest that this was due to their ability to translate their purposes into specific goals for science learning as they learned within their contexts. A recommendation for mentoring programs would be to have first-year teachers think about their goals more specifically, as these are essential for guiding curriculum, instruction, and learning environments.

The divergence between first-year teachers’ ideas about the nature of teaching and learning science and their ideas and enactment of instructional methods and student understanding requires attention in the mentoring program. Teachers need opportunities to identify and consider why there might be a misalignment and how they can remedy the
issue and enact teaching strategies that reflect what they believe teaching and learning science should be. During the visits, many teachers made comments about how the conversations forced them to reflect and realize issues about their teaching that they wouldn’t have otherwise considered, which brought attention to the disconnect. For this reason, it is essential that mentoring programs follow the suggestions above and enable teachers to reflect both individually and as groups on their teaching and on the alignment of their teaching practices and their orientations.

These suggestions for university-based mentoring programs are consistent with Friedrichsen and Dana’s (2005) recommendations that teacher education programs support teachers in examining the nature of their orientations. Group discussions and activities can support this purpose. The questions that were asked during the visits compelled teachers to reflect on their teaching, think about their rationales for their decisions and explain how they reflected their orientations. For this reason, opportunities for one-on-one mentoring in the teachers’ schools is an essential component of a university-based mentoring program.

**Attention to PCK and challenging aspects of PCK.** Teachers expressed variety in the facets of PCK to which they paid attention and found challenging. As explained earlier, first-year teachers shared more challenges than did second- and third-year teachers, and second- and third-year teachers were more refined with the aspects of PCK to which they paid attention and found challenging. These findings have implications for thinking about teacher learning needs in a university-based mentoring program.

**University-based mentoring programs.** Mentoring programs for which attendance is not a requirement face a challenge. It is important that the support
provided, including the on-campus sessions, online community, individualized school visits, and/or other support structures, consider what teachers need and are interested in so they find value in their participation. This includes focusing on areas of teaching to which teachers are paying attention and finding challenging throughout the year. Not only will this help with teacher attendance, it will promote active participation.

As explained in the results, first-year teachers appeared to pay little attention to several aspects of PCK compared to second- and third-year teachers. For example, first-year teachers paid little attention to assessment of science learning, both strategies and how to use them, but focused on motivation and interest and instructional strategies. While it is not certain why this pattern occurred, based on the data and a statement made by Gary, it is reasonable to think it is due to first-year teachers’ attention to other aspects of science teaching and learning that they found more immediate, and therefore they pushed assessment aside. A suggestion for an instance of this nature would be for mentoring programs to bring attention to aspects of PCK that teachers appear to be neglecting. While it is impossible to address all aspects of PCK at every mentoring session throughout the year, the use of the online support communities and individual mentoring visits could aid in bringing attention to various aspects of PCK. This would encourage teachers to think about components of their teaching that they otherwise would not and help them progress in those particular areas.

As pointed out earlier, second- and third-year teachers’ attention and challenges were often more specific than those of first-year teachers. For this reason, second- and third-year teachers within a mentoring program would benefit from engaging in more specific activities that relate to their needs while first-year teachers engage in more
reflective practice to refine the aspects of PCK that they feel need attention or improvement.

Both collaborative learning experiences and individual experiences are important for a well-rounded program. Teachers can learn from one another and can offer insight that the mentor might not be able to offer; however, teachers have individual interests and needs that warrant individual support as well. It is important to get to know these areas and use this information as a tool for designing experiences that promote individual growth. In addition, first-year teachers prove to have more challenges and could therefore benefit from additional support within the program. This could include more frequent instructional sessions, additional individual mentoring visits, or a pairing with a more experienced teacher to provide more frequent, ongoing support, as needed.

Dealing with distractions and roadblocks. Classroom management and Ohio’s beginning teacher induction and evaluation program are not components of PCK and were not the focus on this study, however, teachers’ thoughts on these issues pervaded conversations. Both of these aspects of teachers’ contexts are important to consider when thinking about how to continue teacher learning and provide support for new teachers.

Continued teacher learning. As mentioned earlier, first-year teachers focused on and found classroom management challenging throughout the year. For this reason classroom management could be viewed as a major distraction from other aspects of their teaching. It is important to be aware of this distraction when working with new teachers. While classroom management is not one of the components of PCK, it is important to consider it when thinking about continued teacher learning, as it is a high priority for beginning teachers.
State induction programs and evaluations also proved to be an issue for teachers. While third-year teachers described year three as a good year, a year in which they felt they had a handle on teaching, they described Ohio’s teacher evaluation program and its requirements as a roadblock. They felt as if it was time consuming, took away from their ability to instruct effectively and pay attention to their students needs, and failed to provide effective feedback. In addition, both second- and third-year teachers felt the professional development opportunities were minimally helpful, if at all. The teachers’ comments also suggest that if induction and evaluation programs are not fully supported, they can be stressors to teachers. Based on this evidence, it is reasonable to suggest that teacher induction and evaluation programs nationwide should consider this issue when developing programs for new teachers.

A component of accelerating the learning process and helping teachers acquire advanced knowledge in an ill-structured domain is removing the distractions and roadblocks that will delay their learning progressions. Providing support that coincides with these issues will appeal to teachers’ interests and needs while promoting continued teacher learning.

*University-based mentoring program.* The issues of classroom management and new teacher evaluations have implications for university-based mentoring programs. This is not to suggest that classroom management be a particular focus for the mentoring program; however, it is important to focus on-campus sessions on instructional strategies and methods to address student understanding as a way to engage students in the content at a level that makes them less susceptible to cause classroom management issues. This will help teachers to focus on how they can improve their classroom management by
addressing other aspects of science teaching. A valuable method to address this issue is having teachers share ideas from their own classrooms. Challenges related to classroom management faded across the teaching levels; therefore, it makes sense that more experienced teachers would be able to help first-year teachers think about this issue.

The results of this study stressed the importance of considering teachers’ concerns with new teacher induction and evaluation programs on a broader scale. However, based on the evidence from this study, it would be helpful for university-based mentoring programs to align their curricula with the various tasks required by state induction programs and evaluations. For example, the standards for the Ohio assessment were aligned with several PCK sub-categories, and the assessment tasks are due to be completed at various points throughout the year. To help teachers receive support in these areas and to appeal to their interests at various points in the year, alignment between state and university-based programs would be beneficial for new teachers.

Limitations

While many vertical progressions were discovered in this study, it is important to point out that one limitation of this study is that it was not longitudinal in nature. The participants were not followed for three years; instead a stratified sample was used. A longitudinal study would have allowed the researcher to track teachers’ progress over the course of three years and suggest learning progressions for individual teachers.

An advantage of this study was that it followed a sample of teachers who came from the same teacher education program, all of whom were adult learners who had already obtained a degree. Many of these teachers were well motivated as they participated in an ambitious, one-year teacher education program. However, not all
teachers participated in the university-based mentoring program consistently or at all. While the population of teachers was an advantage, it was also a limitation. The findings of this study are not necessarily applicable to teachers from other preparation programs.

A final limitation of this study was that it examined teachers’ PCK across topics within the domain of science to make inferences about progressions. While some teachers were teaching the same courses or topics, others were not; therefore, topics varied. However, a sample of science educators who teach various courses within the domain of science is reflective of both the population of teachers found in districts and schools and the population that would be probable in university-based mentoring programs.

**Future Research**

To extend upon this research on teacher learning progressions, it would be interesting to think about the types of continued learning opportunities that would impact the teachers’ knowledge growth. Determining which teachers learn from support during the early years of teaching would be helpful to illustrate which aspects of university-based mentoring program are helpful and what could be improved.

The teachers in this study were not followed for three years, but it would be interesting to continue to collect data from the first-year teachers for two more years. To address the previous suggestion for future research, teachers’ learning progressions could be compared based on their attendance and involvement in the mentoring program.

It might also be helpful to look at more experienced teachers, to determine the nature of their knowledge and to use this information to add to the progressions uncovered in this study. Understanding how expert teachers think about various aspects
of teaching and learning might allow for a more advanced trajectory for learning to be developed.

As explained in the review of literature, this study focused on Bruner’s idea of intellectual development in regards to how science teachers’ PCK progresses throughout their early careers. However, this study did not attend to the act of learning for these teachers, as it did not examine how they acquired, transformed, and evaluated their knowledge through the learning process. A future line of inquiry could look specifically at how teachers inquire and reflect on their teaching and consider whether there is a progression for the act of learning.

Conclusion

This study was grounded in several theories that guided the researcher’s thinking about continuing to learn to teach. Dewey’s (1938) ideas about the reconstruction of experiences were the anchor for the theoretical framework. He believed that reconstructing experiences adds meaning to prior experiences and that new experiences must take up something from the previous experiences as well as modify future experiences. A spiral curriculum (Bruner, 1960) provides opportunities for ideas to be revisited and experiences to be reconstructed. The reconstruction of ideas through a spiral curriculum allows for learning progressions to occur wherein learners develop successively more sophisticated ways of thinking over time, which allows one to describe a trajectory of learning (Heritage, 2008). This framework allowed the researcher to think about the importance of understanding teachers’ learning progressions and what the progressions mean for continued teacher learning experiences.
Educative mentoring guided the researcher’s thoughts about the nature of the support provided to new teachers during the beginning years of their careers. Educative mentoring views induction as a way to link the first years of practice to pre-service education (Feiman-Nemser, 2001b) and is a way to think about induction as moving teacher learning forward (Norman & Feiman-Nemser, 2005). In order to develop educative mentoring practices that promote learning opportunities for new science teachers and allow them to reconstruct their experiences and progress their learning, it was important to have an understanding of how teachers’ knowledge develops. The trajectory of learning was missing in the ideas about learning to teach, and this research fills the gap. By understanding how learning progresses, a spiral curriculum can be developed for an educative mentoring program that allows teachers to reconstruct their experiences and continue to develop successively more sophisticated ideas as they learn through practice.

Thinking of university-based mentoring as described in the previous paragraph is rare. Most policy mandates lack consideration of beginning teachers’ learning needs, provide short-term emotional support to retain teachers, and fail to provide the necessary experiences to guide the intense learning that occurs in the first years of teaching (Feiman-Nemser, 2012). Induction mandates are often not designed based on an understanding of how induction can play a role in teacher development (Feiman-Nemser, 2001a). The research in this study can inform a university-based mentoring program that addresses the shortfalls of many traditional programs.

Researchers have stressed that the framework teachers develop in pre-service education is emergent (Adams & Krokover, 1997), and the induction phase should
include genuine support to develop knowledge about teaching and learning science (Loughran, 2007). Educative mentoring is powerful because it considers this and enriches the pre-service education while addressing the realities of teaching contexts (Feiman-Nemser, 2001a). In addition, research has indicated that induction should be content-focused (Luft et al., 2011) and should involve universities, as they are well situated to play an integral role in mentoring (Crosswell & Beutel, 2013). However, despite the literature about what makes a good induction program, very few have a carefully developed curriculum that extends from the pre-service program to support teachers in continued growth and development.

The findings of this study contribute to an understanding of how teachers’ learning progresses and allows for a trajectory of learning to be described. The trajectory can be used to design the curriculum for a university-based mentoring program. Because the learning progressions were developed from research, not assumed from the knowledge of the domain, they provide an effective tool for thinking about the curriculum and instruction of a university-based mentoring program. A mentoring program that includes essential components of what it means to teach science content and a curriculum that is research-based is a powerful means of progressing the learning of new teachers. Armed with the understanding of how learning progresses, support can be provided to advance teachers’ knowledge so they can be effective practitioners and impact the learning of their students.
References


Journal of Teacher Education, 41(2), 144-158.


### Observation Field Notes Form

<table>
<thead>
<tr>
<th>Participant:</th>
<th>Date:</th>
<th>Class period observed:</th>
<th>Lesson topic:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lesson launch</strong></td>
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<tr>
<td><strong>Student tasks</strong></td>
<td><strong>Teacher actions</strong></td>
<td><strong>Teacher talk</strong></td>
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<tr>
<td><strong>Lesson Wrap-up</strong></td>
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<tr>
<td><strong>Other comments</strong></td>
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Appendix B

Interview Protocol

New Science Teachers’ Learning Progressions Interview Protocol

The interview will take place after I have observed the teachers. Prior to the interview, I will also examine the teachers’ lesson plans and any other teaching artifacts related to the lesson. The interviews will take place the same day or the day after the observation.

Research Questions
1. What is the nature of pedagogical content knowledge of first-, second- and third-year science teachers at various points across the school year?
2. To which aspects of pedagogical content knowledge do first-, second- and third-year teachers pay attention at various points across the school year?
3. Which aspects of pedagogical content knowledge are challenging for first-, second- and third-year teachers at various points across the school year?

Interview Questions
1. Tell me about what you were thinking about or considering when planning your lesson. (RQ2)

2. How does the lesson reflect your ideas about the purposes and goals for teaching science? (RQ1)

3. How does this lesson fit into the broader science curriculum (scope and sequence)? (RQ1)
   a. Follow-up questions about standards and curriculum resources

4. How did you think about students’ understanding of science concepts when planning and instructing the lesson? (RQ1)
   a. Follow-up questions about prerequisite knowledge, variations in approaches to learning, difficult concepts, misconceptions

5. I saw that you […] Why did you decide on that approach to assess student learning? (if an assessment was used) How do you plan to assess student learning of the concepts in this lesson? (if no assessment was used) (RQ1)
   a. Why is this aspect of student learning important to assess?

6. I saw that you did […] Why did you decide to use those particular instructional strategies in your lesson? (RQ1)

7. Is there anything you would change when planning and teaching this lesson in the future? (RQ2)
8. In regards to teaching science, what has been difficult for you so far this year? What do you need help with? (RQ3)
### Appendix C

#### Example of Data Chart

<table>
<thead>
<tr>
<th>Gary – Late Fall</th>
<th>Data Collection Point 1*</th>
<th>Data Collection Point 2</th>
<th>Data Collection Point 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orientation to science teaching</strong></td>
<td>Nature of teaching and learning: Science teaching is making students think about evidence they have for something and what that means, not just telling students what the evidence might be, because that is not teaching science. Having students exploring the evidence through experiments and thinking critically about what it means; Goals: Getting students used to taking the type of assessments he gives (no study guide, very application-based, not focused on memorization)</td>
<td>Nature of teaching and learning: Science involves students thinking, not the teacher telling them. Students need to think critically. Even if it means they have a wrong idea, that is okay as long as they are thinking. He will get them back on track when needed; Goals: Getting students to think critically</td>
<td>Nature of teaching and learning: Doing is learning. Therefore, it is not ideal for the teacher to be standing up in front telling students, because the students are not fully engaged. They have got to be a part of it happening somehow, some way. Whether is it having a real-life experience or crunching data, it has to be real to them, and the content needs to be relevant to them; students need to be engaged in opportunities that allow for conversations to happen and for students to ask questions. This promotes a deeper understanding; instruction needs to be altered (his nature of teaching) slightly for each class based on the students;</td>
</tr>
<tr>
<td><strong>Science curriculum</strong></td>
<td>Understanding: Curriculum materials &amp; Scope &amp; Sequence: In the previous two years, he followed a curriculum map</td>
<td>Understanding: Sequence: tries to sequence concepts so he can make transitions that make sense for the students;</td>
<td>Understanding: Scope: He was previously spending too much time and going too deeply into the concepts, so he</td>
</tr>
</tbody>
</table>
provided to him by his mentor teacher (from student teaching), but now he is becoming a curriculum developer himself and is doing more “large scale thinking” about the curriculum by creating a new curriculum map this year, which was determined based on the standards. He created his own sequence that makes sense to him and his students (did not like the order of the standards or book)

**Attention: Scope:** For this topic, he made sure to go more in depth than what students learned about the structure of the earth in earlier grades to build upon earlier curriculum

**Challenges: Scope & Sequence:** Acting as a curriculum developer on a larger scale, deciding how long to spend on concepts and how deep to go (with the new 8th grade standards, he decided to develop his own scope, sequence and pacing for the standards)

**Scope:** he considers what they should have already learned in previous grades and goes further and deeper to prepare them for what they need to know for science courses in the future

**Attention: Scope:** Likes to connect concepts into culminating lessons so students can see how the concepts fit together; **Sequence:** Thinking about which concepts to address and when, what would make the most sense

**Challenges: Sequence:** Struggles with developing the curriculum: he had the year planned out, but now the way that it makes sense to teach is changing for him. He questions where he should go; he doesn’t think curriculum is something that somebody can teach you. He thinks you just have to do whatever makes sense to you; **Scope:** finds he is spending too much time on concepts. Maybe he is going too deep, but he is behind based on where he should be

**Challenges: Scope:** Finding time to address all the content standards before the state test; making curricular connections between physical science and earth and life science

had to adjust the curriculum to make sure he addresses all concepts before the state test. He is getting better at developing the curriculum and is learning from his earlier mistakes with the scope and pacing; it is necessary to make connections across topics and three branches of science for 8th grade

**Attention: Scope:** Having a culminating unit to wrap up the earth science portion of the course and make connections between the concepts, planning out the curriculum for when students get back from Christmas break and making sure he is only focuses on the necessary topics so he doesn’t run out of time

**Challenges: Scope:** Finding time to address all the content standards before the state test; making curricular connections between physical science and earth and life science

**Attention:** Scope: for this topic, he made sure to go more in depth than what students learned about the structure of the earth in earlier grades to build upon earlier curriculum

Challenges: Scope & Sequence: Acting as a curriculum developer on a larger scale, deciding how long to spend on concepts and how deep to go (with the new 8th grade standards, he decided to develop his own scope, sequence and pacing for the standards)

Scope: he considers what they should have already learned in previous grades and goes further and deeper to prepare them for what they need to know for science courses in the future

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Challenges: Sequence: Struggles with developing the curriculum: he had the year planned out, but now the way that it makes sense to teach is changing for him. He questions where he should go; he doesn’t think curriculum is something that somebody can teach you. He thinks you just have to do whatever makes sense to you; Scope: finds he is spending too much time on concepts. Maybe he is going too deep, but he is behind based on where he should be

Challenges: Scope: Finding time to address all the content standards before the state test; making curricular connections between physical science and earth and life science

**Attention:** Scope: for this topic, he made sure to go more in depth than what students learned about the structure of the earth in earlier grades to build upon earlier curriculum

**Challenges: Scope & Sequence:** Acting as a curriculum developer on a larger scale, deciding how long to spend on concepts and how deep to go (with the new 8th grade standards, he decided to develop his own scope, sequence and pacing for the standards)
for the standardized test; because he is trying to go deep and get kids real-world experience using raw data, it takes time and there is not enough of it; feels state standards are set up for direct instruction, and he doesn’t think it is possible to cover everything for the test if you go deeply into the content

| Students’ understanding in science | Understanding: Development of science ideas: Scaffolds processes for students and adds more or less scaffolding (support) for certain classes. It is important to allow students to work in groups and then on their own to develop ideas; Initial ideas: considers the necessary prerequisite knowledge for topics and makes sure they have an understanding of that before he moves into new concepts; tries to consider what misconceptions he might have had when he was their age; Learning difficulties: Addressing the difficult concepts, which are often those that the students cannot see and | Understanding: Development of science ideas: adapts his lessons every period based on the understanding of the students in that class and decides when they can move forward on a topic based on their conversations and understanding; wants students to think critically (by themselves). Even if they are wrong, he can then get them back on track; feels these students needed to have whole group discussion in this lesson to keep the students working together and on one path, which allows students to quash their misconceptions as a whole group; Expression of ideas: finds discussions are | Understanding: Development of science ideas: Students gain a better understanding of a concept if they are experiencing it themselves; you see the “Eureka” moments when kids understand something while they are doing or seeing a concrete example of the concepts; making sure students understand how concepts fit into the bigger picture, not just understanding the concept by itself; providing an opportunity for students to see and experience the concepts they are talking about so they can gain an understanding; Initial ideas: there are a lot of engrained |
therefore lead to misconceptions; 
*Expression of ideas:* asking students to explain why and how they knew something instead of just giving the right answer because he wants to understand how they know something, how they are thinking about something and not necessarily just giving the right answer

helpful to gauge student understanding; the discussion questions were not the same for every class, but determined based on the concepts to be discussed and the students’ understanding about the concepts; adapted questions as the conversations went on and let them discover ideas on their own and think for themselves; *Initial ideas:* considers students’ prior knowledge in science from earlier grades and other subjects

misconceptions students have, and he constantly has to practice “myth busting”; makes sure to assess topics that are common misconceptions on the test, readily identifies misconceptions students have with the topics; 
*Appropriate level of science understanding:* the questions he asks students vary from class to class, based on their understanding of the topic and the level of students; *Expression of science ideas:* having students draw visual representations to demonstrate their understanding of the lab activity; 
*Learning difficulties:* focusing more attention on the concepts that are difficult for students to understand; knows which are more difficult than others 
*Interest and motivation:* Adjusts instructional activities based on the interest and needs of his students and different classes

<table>
<thead>
<tr>
<th>Instructional strategies for science</th>
<th><strong>Understanding:</strong> Inquiry: likes to utilize instructional</th>
<th><strong>Understanding:</strong> Discourse: likes whole-group</th>
<th><strong>Understanding:</strong> Science phenomena strategies: When</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching strategies that have a real-world application and have students focus on real data as evidence; Science phenomena strategies: visual representations that make abstract concepts concrete allowed for “eureka” moments; Discourse: group activities are important because it is important for students to have interactions with one another to share their thoughts, have discussions and work through data analysis together (data analysis calls for group work to him)</td>
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<td>Attention: Inquiry: Having lessons that focus on evidence and having students collect their own data and think about what that evidence means, real-world applications</td>
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<tr>
<td>Discussions because it allows them to address misconceptions together as they talk about their ideas and monitor their progress more easily; Discourse: Utilizing group discussion to make this a culminating lesson that brings the topics they have been talking about together, having discussions to tie everything together and make connections as they talk</td>
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<tr>
<td>Rushed to cover topics in a short amount of time, he utilizes more direct instruction but always makes sure to incorporate some sort of interactive experience because it is necessary for understanding concepts; pictures and animations are good ways to represent concepts, but students also need to have a real-life experience with concepts so they can actually see and experience the concepts they have been talking about; this type of interactive activity engages students; Inquiry &amp; Discourse: activity was open-ended and unstructured so students could direct the process and ask questions, but he also guided them through it so they would notice the important things happening; this type of activity gets students curious and asking questions for discussion that would not have happened otherwise</td>
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<tr>
<td>Attention: Inquiry: Having the time and money for supplies to do more inquiry activities and getting</td>
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### Assessment of Science Learning

**Understanding: Strategies and Use:**

- Does a lot of formative assessing by having whole group conversations to see where students are and determine whether they need to come back to something if they are not understanding; his written tests are not monotonous and regurgitated; they assess how students can apply their knowledge of the concepts and reasoning skills, such as having students analyze data;
- **Strategies:** Checking in during the labs (discusses lab questions) to formatively assess as students participate in the lab

**Understanding: Strategies and Use:**

- His culminating formal assessments (tests) are developed to address the particular standards for those concepts (makes sure questions address standards – that is how he determines what is important to assess content-wise) because he needs to make sure that if the state said they need to know something, his students know it, can apply it; discussions often serve as formative assessments because the discussions allow him to determine where his students are and where he should go with them; the questions he asked allowed him to determine their understanding

**Understanding: Strategies and Use:**

- A lot of frequent and informal assessments are necessary to gauge the understanding of the class and to direct instructional decisions; a lot of this is done through discussion;
- **Strategies:** Formatively assesses students by having them draw and label what they were experiencing in the lab so they could demonstrate their understanding and will assess students in a similar way on the summative test by providing pictures that model the stream table lab

### Additional notes:

*Denotes observed lesson