2016-07-01

A High School Biology Teacher's Development Through a New Teaching Assignment Coupled with Teacher-Led Professional Development

Lorien Young Francis
Brigham Young University

A High School Biology Teacher's Development Through a New Teaching Assignment Coupled with Teacher-Led Professional Development

Lorien Young Francis

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Arts

Stefinee Pinnegar, Chair
Leigh Smith
Janet Young

Department of Teacher Education

Brigham Young University

July 2016

ABSTRACT

A High School Biology Teacher's Development Through
a New Teaching Assignment Coupled with
Teacher-Led Professional Development

Lorien Young Francis
Department of Teacher Education, BYU
Master of Arts

This self-study examined the learning that emerged from a change in teaching assignment coupled with self-initiated, teacher-led professional development in order to understand a high school science teacher's development as a teacher. The two participants in the study were the teacher/researcher, an experienced high school biology teacher who was taking up a new assignment teaching biotechnology, an advanced science course; and a first-year teacher assigned to teach biotechnology, who served as collaborator in the professional development and critical friend in the study. In order to uncover the teacher/researcher's learning and thinking, self-study of teaching practice methodology most clearly met the demands of the study. Data emerged from three research conversations and included transcripts of the conversations, artifacts from the participants' practices, notes from meetings, and memos. Data were analyzed using constant comparative methods and the understandings generated are grounded in the data. The study reveals shifts in teacher identity as the expert teacher takes up novice roles, the challenges encountered when teacher knowledge is insufficient for the teaching task, and the experienced teacher's need to return to a place of expertise when faced with a new teaching context. The study finds that (a) teacher identity shifts and develops in new teaching contexts, and teaching expertise facilitates expert identity development in such contexts; (b) expert teacher knowledge mediates novice-ness when experiencing new teaching contexts such as new teaching assignments; and (c) teacher-led professional development is a viable model for professional development experiences and can lead to increased teacher knowledge. The author suggests that (a) teachers are capable of determining what they need to learn and how they might best learn it in a professional development setting; (b) teachers' specific contexts should be honored when designing professional development, which should be practice-centered, and special attention should be given to developing specific subject matter knowledge, pedagogical content knowledge, and science knowledge for teaching; and (c) capable others should be included in collaborative professional development teams.

Keywords: qualitative research, professional development, professional identity, knowledge base for teaching, secondary school science

ACKNOWLEDGEMENTS

Thanks to the many beautiful people who have helped me along my path. Stefinee Pinnegar, thank you for your hours of generous help, your encouragement, your kindness, and your expressions of confidence in my abilities. Leigh Smith, thank you for your patience and guidance throughout this long process. Janet Young, thank you for your example of tenacity and hard work, for your coaching, and for your constant, unconditional love. Brent Young, thank you for teaching a small girl many years ago that she was smart, strong, and capable. Natalie, thank you for your friendship, time, and insight. Hugh Baird, thank you for your caring mentorship as I began the process of becoming a teacher. Calvin, Samantha, Madeline, and Max Francis, thanks for being amazing children and for hanging in there. And Guy Francis, thank you for your humor, creativity, and support, and for being a fabulous father and husband.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1: Introduction

Since World War II there has been a continuous focus in the United States on science education. During the 1950s, the aim of science education was to prepare the nation's future scientists and engineers; the primary focus was on the few who were adept at or interested in science and mathematics. In the late 1980s and early 1990s the goal of science education shifted to helping all students, "regardless of their social circumstances and career aspirations," develop scientific literacy (American Association for the Advancement of Science, 1990, p. xviii). More recent science education reform documents, such as *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2012), hereafter called "the Framework," and *Next Generation Science Standards: For States, By States*, reaffirm the importance of science education for all students (NGSS Lead States, 2013).

Because of the increasingly technological orientation of our society, authors of the Framework reasoned that to be competitive in this environment, all U.S. students should be able to understand science and scientific reasoning better (NRC, 2012). Additionally, in light of increased dependence on technology, more people also need to be prepared as professionals in science-, technology-, engineering-, and mathematics-related careers (STEM; Gonzalez & Kuenzi, 2012). Assuming that all citizens need an understanding of science, whether they are the general populace or specialists in STEM fields, it follows that successful science education in public K-12 schools is critical.

In addition to advocating for science education for all, the writers of current science education reform documents also emphasize the importance of the integration of STEM in education (NGSS Lead States, 2013; NRC, 2012). The Framework (2012) elucidates the need for science teachers to have knowledge of more than science alone in order to integrate science, technology, and engineering in their teaching. In fact, the Framework recommends teachers teach science and engineering practices, as well as concepts common to both science and engineering. It includes engineering, technology and current applications of science as one of four disciplinary areas to be taught by science teachers. Clearly, as a result, science teachers must know more than isolated scientific information in order to effectively teach science courses.

A science teacher prepared to meet the challenge of teaching science integrated with engineering and technology to all students has a wide range of knowledge and skills (NRC, 1996). She is current in her knowledge of the rapidly changing field of science, or science *subject matter knowledge* (SMK); her knowledge about effective teaching practices, or *general pedagogical knowledge* (GPK); and her specific knowledge about how to teach science, or *pedagogical content knowledge* (PCK). Shulman (1986) specifies these as categories of potential teacher knowledge growth for teaching content. Because knowledge in science disciplines is continually expanding and changing, and students must be prepared to live in a science and technology-rich society, "teachers will need ongoing science professional development opportunities" (Luft & Hewson, 2014, p. 889). In the literature, researchers sometimes use the term *professional development* to refer to the continual learning and development of the teacher (e.g., Luft & Hewson, 2014), and sometimes to the activity or event in which the learning occurs (e.g., Desimone, 2009). In this study, *professional development* refers to the activities in which teachers participate that result in their learning and development as teachers.

In addition to needing support to meet the rigorous demands of science teaching, science teachers also need support when they experience shifts in their teaching careers (Fessler & Christensen, 1992). Among the many changes teachers encounter during their careers, it is not uncommon for teachers to be assigned to teach a new subject outside of their area of expertise. When seasoned teachers experience such a change, they exhibit some features of novice teachers (Sanders, Borko, & Lockard, 1993). These "experts-turned-novice" (p. 734) lack experience in a specific teaching context. Although they bring with them other teacher knowledge, such as GPK, as novices in some respects, they must learn again how to teach that particular subject or course. Thus, professional development for those teaching science within or outside of their expertise plays a critical role in supporting teacher learning, not just in terms of SMK, but also in all the types of teacher knowledge essential for science teaching.

Professional development designed to support teacher learning can take many forms. While activities along the continuum of formal to informal learning experiences have the potential to create change in a teacher's knowledge and practice (Desimone, 2009), the most typical form is formal professional development that is mandated by those in leadership positions. Bullough and Smith (2016) described these learning opportunities as systemically driven, and influenced by social, cultural, political, and economic factors. This is consistent with the top-down approach of traditional professional development programs described by van Driel, Beijaard, and Verloop (2001). They explained that first, policy makers, state departments of education, or administrators determine what curricular changes or educational innovations teachers should implement. Next, a professional development program is devised to train the teachers to implement the change or innovation. Often this training is a single event or workshop. Finally, after receiving training, teachers are expected to simply take up and implement these practices with fidelity and little additional support.

As van Driel and his colleagues (2001) asserted, teachers do not always enact new practices taught in this form of professional development, nor do the practices persist over time.

In this top-down approach, "the role of teachers in the context of curriculum change usually has been perceived as 'executing' the innovative ideas of others," (p. 140) and the failure of such programs is generally "attributed to the failure of teachers to implement the innovation in a way corresponding to the intentions of the developers" (p. 137). Teachers often see these sorts of mandated programs as irrelevant, imposed, and privileged over their own judgment of improvements needed in their teaching (Bullough & Smith, 2016). In this model, the *personal practical knowledge* (PPK) of teachers, defined by Clandinin (1985) as "knowledge which is experiential, embodied and based on the narrative of experience" (p. 363), is neither valued nor employed. Borko (2004) acknowledged that researchers have made much progress toward understanding how teachers learn in order to address the problem of ineffective professional development, but she maintained that more work needs to be done "in order to provide high-quality professional development to all teachers." She further asserted, "it will take many different types of inquiries and a vast array of research tools to generate the rich source of knowledge needed to achieve this goal" (p. 13).

Formal professional development programs imposed on teachers are not the only type of experience in which teachers have the potential to learn. Research demonstrates that teacher learning is situated (Brown, Collins, & Duguid, 1989), occurring in a variety of contexts within a teacher's practice. Less formal experiences that are part of normal teaching practice, such as conversing with a fellow teacher during the school day, reflecting on a lesson, co-teaching, or working in a teacher mentoring situation create the potential for teacher learning (Borko, 2004; Desimone, 2009). In other forms of professional development, teachers may participate in and serve as leaders of professional learning communities, often determining what should be learned and how to learn it. In a study of professional learning communities facilitated by teacher-leaders, Hargreaves (2013) found that teachers stayed more committed to the professional development when the needs specific to their school and class contexts were acknowledged and addressed. She also found that positive teacher outcomes were undermined when the learning community was imposed on teachers, inflexible, or neglected to respect teachers' other school commitments. Whether formal or informal, mandated or teacher-initiated and led, events that occur in a teacher's practice provide opportunities for learning, and have the potential to lead to the professional development of the teacher.

As stated previously, although various types of professional development provide opportunities for teachers to learn, teachers do not always enact the new practices. In response to this problem, researchers have studied features of professional development that increase the likelihood that teachers will use the ideas learned in the professional development and, consequently, change their practice. Features of such effective professional development include (a) extended duration of the professional development, (b) teacher collaboration, (c) focus on both content and teaching strategies, (d) active learning time built into the professional development, (e) alignment of the aims of the professional development with teachers' goals, (f) providing supports for implementation, and (g) attending to barriers to the implementation of the innovation (e.g., Desimone, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Professional development that includes on-going interventions, peer coaching, reflection, networking, and co-learning through talk and observation provides the kinds of experiences that have greater chance of success at creating lasting change (e.g., Avalos, 2011; van Driel et al., 2001). Evidence of this emerged in a 2007 study conducted by Penuel et al. This study of a multi-site, longitudinal professional development focused on a particular aspect of science education. Professional development in any form—formal or informal, systemic or personally driven—is intended to support teacher learning and development. Accordingly, such efforts should have many of the features of effective professional development, particularly if change in teacher learning and practice is to emerge from them (Bullough & Smith, 2016).

Many studies have been conducted documenting the viability and success of efforts to improve formal, mandated, teacher professional development (e.g., Avalos, 2011; Borko, 2004; Desimone, 2009; Hargreaves, 2013; Penuel et al., 2007; van Driel et al., 2001). However, there are few studies specifically focused on changes in teachers' knowledge that occur when opportunities for professional development and teacher learning are fashioned by these teachers as part of their natural, every day experiences in preparing lessons. There is a need to study such teacher-led professional development, to examine more fully what the characteristics of such professional development experiences are, what teachers learn, and what changes teachers make as a result.

The purpose of this self-study was to investigate a teacher-led professional development experience to uncover understandings about teacher learning and development. This study was about me, a high school biology teacher with 11 years of teaching experience, and about my collaboration with a first-year teacher. I examined myself as expert-turned-novice, as I developed as a teacher while taking up a new assignment teaching biotechnology, an advanced science course that integrates STEM disciplines. The study uncovered who I was before the assignment, as a biology teacher who felt secure in my teaching and teacher knowledge and practices. It also explored my lived experience as I became unsettled by the new assignment to teach an unfamiliar course. Finally, it examined how collaboration in the teacher-led professional development began bringing me back into equilibrium, leaving me secure once again in my role as a high school science teacher committed to lifelong learning and growth.

The following research question guided this study: What does an examination of the learning that emerges from a change in teaching assignment, coupled with collaborative, teacher-led professional development, reveal about a high school science teacher's development as a teacher?

Chapter 2: Review of Literature

This chapter is a review of areas of the literature relevant to the study. The chapter includes the following topics: teacher knowledge, the learning-to-teach process, professional development, teacher career cycles, and natural opportunities for learning and growth in teachers' careers.

Teacher Knowledge

Researchers have extensively studied and described the complex landscape of teacher knowledge, exploring the different types of knowledge that teachers hold, and studying knowledge constructs from different theoretical perspectives (e.g., Clandinin, 1985; Lee & Luft, 2008; Munby, Russell, & Martin, 2001; Reynolds, 1995; Shulman, 1986; van Driel, Berry, & Meirink, 2014; van Driel, Verloop, & deVos, 1998). Van Driel et al. (2014) defined teacher knowledge as "the total knowledge that a teacher has at his or her disposal at a particular moment that underlies his or her actions" (p. 848). Decades earlier, Shulman (1986) created a framework to classify both categories of teacher knowledge and forms that teacher knowledge takes in an effort to guide the construction of a "knowledge base for teaching." Some types of knowledge Shulman identified include SMK, GPK, and PCK. Other researchers have further explored teacher knowledge and have established alternative, yet related, ways to conceptualize the integrated, embodied nature of teacher knowledge, such as PPK (e.g., Clandinin, 1985).

Teacher knowledge comes from many sources, including schooling, teacher preparation programs, professional development, and teaching experience, and is "embedded in teachers' personal and professional contexts" (van Driel et al., 2014, p. 849). Because secondary science teachers, like other secondary teachers, teach subject matter specific to their content area, science teachers have a very specific kind of teacher knowledge. Munby et al. (2001) explained that effective secondary science teachers have a sophisticated knowledge set that is highly domain-specific, organized, and often tacit.

Subject matter knowledge. Science teachers need a deep and current understanding of science content, or subject matter, in order to "foster students' conceptual understanding" (Borko, 2004, p. 5). SMK, one type of teacher knowledge sometimes referred to as content knowledge (see NRC, 2012), is not limited to knowledge of scientific facts and ideas. Borko (2004) described teachers' SMK as a "rich and flexible knowledge of the subjects they teach. They must understand the central facts and concepts of the discipline, how these ideas are connected, and the processes used to establish new knowledge and determine the validity of claims" (p. 5). The Framework (NRC, 2012) echoed Borko's (2004) ideas within the context of science education, explaining that SMK includes not only scientific facts and ideas but also "an appreciation of how scientists collaborate to develop new theories, models, and explanations of natural phenomena" (p. 256). Some researchers have explored SMK, referring to it as *science knowledge for teaching*, and described three domains of this knowledge: *core content knowledge*, which includes the scientific concepts of the discipline; *specialized content knowledge*, or the knowledge the teacher needs in order to teach the content and understand student comprehension; and *linked content knowledge*, the awareness of knowledge that connects concepts within the discipline (Nixon, 2015; Nixon, Campbell, & Luft, in press). They explained that these knowledge bases are foundational for a teacher's PCK, discussed later in this chapter, and that linked content knowledge is particularly important in curriculum sequencing because it includes an explicit awareness of what topics are essential to learn before learning others. In order to teach science effectively, science teachers need an extensive, integrated, flexible understanding of the body of scientific knowledge, how that knowledge came to be, and how scientists work and communicate within the discipline.

Although prospective science teachers learn science content as K-12 students and as part of their preservice preparation programs, science SMK continues to develop as teachers teach. Van Driel and colleagues (2014) concluded that the studies they reviewed "seem to confirm that teachers' SMK increases with teaching experience" (p. 854). Classroom experience alone, however, is not the only way teachers can develop richer SMK. "Professional development programs that include an explicit focus on subject matter can help teachers develop these powerful understandings" (Borko, 2004, p. 5). In these experiences, activities in which teachers are actively involved seem to be most effective.

In her comprehensive review of research on science teacher knowledge, Abell (2007) found that the relationship between science teacher SMK and science teaching is complex, yet tends to be a positive one. She found that collectively, early studies of SMK were inconclusive about the relationship between teacher SMK and classroom practice and teacher effectiveness. However, Abell continued, more recent studies of SMK have become more sophisticated in their methods and asserted that overall, recent studies show a positive relationship between SMK and teaching. For example, some teachers with low SMK use textbooks and seatwork in their instruction more than those with higher SMK. They also tend to question students less and talk more. Abell also suggested that part of the complexity of the relationship between SMK and teaching may be due to mediating variables, including other types of teacher knowledge. In fact, van Driel et al. (1998) found that in some contexts, SMK appears to be a prerequisite for developing PCK. In their update of Abel's (2007) review of the literature, van Driel et al. (2014) agreed with Abell's assertion of the positive relationship between the SMK and science teaching, concluding that “a higher level of SMK is typically associated with more confidence and more interactive and adventurous ways of teaching.” They also noted, “there still have been relatively few studies on the development of SMK in the context of teaching” (van Driel et al., 2014, p. 854).

One interesting aspect of SMK is people’s conceptions and misconceptions in science. Conceptions of science are deeply held, and some misconceptions persist into adulthood (Abell, 2007), even among those who study the field as part of their vocation. Researchers have expressed concern about the problem of teacher misconceptions in science. Elementary and secondary science teachers alike may hold misconceptions about both life and physical science, and often carry the same misconceptions as their students (Abell, 2007). Although experience teaching seems to reduce teacher misconceptions in science somewhat (van Driel et al., 2014), this phenomenon is particularly troubling given the amount of research about teacher conceptions since the 1980s and accompanying attempts to address them (Abell, 2007; van Driel et al., 2014).

As teachers take up new curriculum and struggle to plan and teach the new course or topic, they are confronted with their limited SMK (Sanders et al., 1993). These realizations about gaps in their own SMK provide the opportunity to correct misconceptions they may hold and increase SMK.

General pedagogical knowledge. Alongside knowledge of the subject matter they teach, teachers develop understandings about the science of teaching. Knowledge teachers hold about teaching methods, or pedagogy, is referred to as GPK (NRC, 1996; Reynolds, 1992; Shulman, 1986). In a content analysis of reviews of literature, Reynolds (1992) focused on three domains of teacher tasks that are inherent in teachers’ GPK: *preactive tasks*, *interactive tasks*, and *postactive tasks*. These domains include things teachers know and do, regardless of the grade or content they teach. Preactive tasks are activities involving short and long term planning for teaching. Interactive tasks involve interactions with students and content. Postactive tasks are those in which teachers reflect upon the teaching activities and student responses within those activities.

Across a range of studies, researchers found that expert and novice teachers differ in the way they approach the three domains of teacher tasks, and that “beginning teachers often lack an adequate knowledge base of understandings to perform teaching tasks in an effective manner” (Reynolds, 1992, p. 5-8). For example, in preactive tasks, experienced teachers use their SMK and knowledge of students more effectively to create lessons than do beginning teachers. Experienced teachers more often plan instruction that will connect new knowledge to students’ existing knowledge, are better able to explain ideas in ways students can understand, are more selective in their choice of curricular materials they use, create developmentally-appropriate learning activities, and set more appropriate expectations for students. In interactive tasks, beginning teachers may not efficiently manage all the intricate interactions between teachers, students, the physical space of the classroom, and the curriculum. Experienced teachers, on the other hand, are better able to attend to the important details that occur in the classroom setting involving “rapid judgment, chunking of information, and differentiation of important from unimportant information” (p. 11). In postactive tasks, Reynolds noted, novice teachers do reflect on the teaching experience, but their reflections are not as focused as those of expert teachers. Reynolds explained, “the distinguishing feature between expert and novice teachers seems to be the inconsistent focus novices provide concerning their practice and their more intuitive rather than empirical comments about the teaching and learning process” (p. 24). Put simply, new teachers have some tools in their GPK toolkit, but the tools are not usually as diverse, refined, or used as effectively as those of experienced teachers.

When experienced teachers change teaching assignments, many aspects of the new assignment are novel. However, teachers' knowledge of the science of teaching—their GPK—can transfer to the new context, serving as a framework upon which they can build their knowledge about teaching in the new context (Sanders et al., 1993). Teachers' knowledge about planning lessons, methods that are effective when interacting with students, their ability to attend to many details during a lesson, and their ability to reflect on specific instances in their lessons may transfer to the new teaching situation as these understandings are not limited to one context.

Pedagogical content knowledge. In addition to SMK and GPK, an effective science teacher employs PCK. Shulman (1986) first identified PCK as a type of teacher knowledge. More recently, it has been described as the integrated, experiential knowledge, concepts, beliefs, and values specific to teaching particular content, developed in the context of classroom teaching (Lee & Luft, 2008; NRC, 1996). It includes "the most useful forms of representation of [subject matter] ideas, the most powerful analogies, illustrations, examples, explanations and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9). Also central to PCK is understanding of the learner. Lee and Luft (2008) described PCK as "the unique combination of content and GPK that helps teachers transform science content into learning experiences for students" (p. 1344). In summary, "key elements in Shulman's conception of PCK are knowledge of representations of subject matter, on the one hand, and understanding of specific learning difficulties and student conceptions, on the other hand" (Henze, 2006, p. 13-14).

A science teacher with rich PCK is able to design and implement curricula using many methods. The following are some of the tasks included in the Framework (NRC, 2012) that science teachers often perform. These tasks demonstrate the kinds of things science teachers do, often on a daily basis, in which they enact their PCK:

- Support simple and student-designed investigations in the classroom, laboratory, and in field studies
- Organize, prepare, and maintain laboratory equipment and materials
- Follow and teach students to follow laboratory safety procedures
- Organize groups of students
- Aid students in designing investigations that include collecting, analyzing, and representing data, as well as constructing arguments and creating conclusions based on data
- Facilitate scientific discourse in the classroom
- Organize curricula
- Analyze and revise commercially prepared curricula
- Select, create, and use different types of assessment of student learning
- Integrate new reform-based ideas in their teaching

While not comprehensive, this list illustrates the complex and diverse nature of PCK that science teachers must use in order to effectively teach science.

Researchers have explored different aspects of PCK (e.g., Henze, van Driel, & Verloop, 2008; Lee & Luft, 2008; Magnusson, Krajcik, & Borko, 1999). Magnusson et al. (1999) created a model that integrated the following five components of PCK:

> (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. (p. 97)

Henze et al., (2008) used similar components of PCK in their study of teacher knowledge, and noted that this construct of PCK is somewhat broader than Shulman's original conception. Lee and Luft (2008) articulated that one problem with research about PCK is that conceptions of PCK are usually from the perspective of a researcher and often do not reflect "the teachers' perspectives on their existing knowledge, beliefs, and attitudes" (p. 1344). Their research addressed this problem, revealing teachers' conceptions of PCK through the lens of four expert science teachers. All four of the teachers identified knowledge of content, knowledge of students, and knowledge of goals at the core of PCK.

An understanding of science learners, one fundamental aspect of PCK, includes knowledge about what students already know and believe about science, including the "common prescientific notions that underlie a student's questions or models," sometimes known as "misconceptions" (NRC, 2012, p. 256). This knowledge allows teachers to more effectively build on students' prior conceptions (Magnusson, et al., 1999; NRC, 2012; van Driel et al., 2014). Van Driel et al. (2014) further explained the importance of understanding science learners:

> At the heart of PCK lies what teachers know about how their students learn specific subject matter or topics and the difficulties or misconceptions students may have regarding this topic related to the variety of representations (e.g., models, metaphors) and activities (e.g., explications, experiments) teachers know to teach this specific topic.

> These components are mutually related: The better teachers understand their students' learning difficulties with respect to a certain topic and the more representations and activities they have at their disposal, the more effectively they can teach about this topic. (p. 849)

Ideally, effective science teachers with rich PCK draw on their understanding of the way students conceptualize and interact with science content, enabling them to select and design learning activities that make science accessible to students. Although understanding students in this way is important for effective science instruction, van Driel et al. (2014) agreed with Abell (2007), concluding that "science teachers often have limited knowledge of how their students understand and learn science content. However, teaching experience tends to improve teachers' knowledge of student difficulties in science" (p. 856).

Researchers have found that, in addition to knowledge of students, PCK of secondary science teachers in the broader sense is also acquired through classroom experience (Lee & Luft, 2008; van Driel et al., 1998). Because teachers develop PCK through their teaching, beginning teachers' PCK is typically limited compared to experienced teachers' "integrated and developed understanding of teaching" (Lee & Luft, 2008, p. 1345). As previously noted, some studies indicate that a broad and integrated SMK is necessary to develop PCK (Nixon et al., in press; van Driel et al., 1998). However, although there has been considerable research investigating PCK and its fundamental position as a knowledge base for teaching, "little is known about the process of PCK development in relation to other domains of teacher knowledge, especially in the context of educational reform" (Henze, 2006, p. 3).

Like other kinds of teacher knowledge, PCK is disrupted when teachers work with a new group of students, move to a new setting, or teach new content (Sanders et al., 1993). This teacher knowledge develops again as teachers teach students in these new settings.

Personal practical knowledge. While researchers can tease apart various aspects and types of teacher knowledge, it is impossible to isolate that knowledge from the person who knows it. Rather, all knowledge is situated, "being in part a product of the activity, context, and culture in which it is developed and used" (Brown et al., 1989, p. 32). Clandinin (1985) recognized the situated nature of teacher knowledge, integrating multiple aspects of teacher knowledge, adding the highly personal, and called it PPK. In this study, I use Claninin's characterization of PPK. She described it as knowledge that is "imbued with all the experiences that make up a person's being. Its meaning is derived from, and understood in terms of, a person's experiential history, both professional and personal" and is "found in practice. It is knowledge which is experiential, embodied and based on the narrative of experience" (p. 362-363). Van Driel et al. (2001) described knowledge similar to PPK, referring to it as *practical knowledge*, and explained that it "consists of teachers' knowledge and beliefs about their own teaching practice, and is mainly the result of their teaching experience" (p. 138). Practical knowledge and PPK are constructs similar to *craft knowledge,* described by van Driel et al. (1998) as encompassing "various aspects such as pedagogy, students, subject matter, and the curriculum" as well as "knowledge derived from prior education as well as from ongoing schooling activities" (p. 674). Additionally, craft knowledge is "influenced by factors related to teachers' personal backgrounds and by the context in which they work" (p. 674).

Loughran (2007) noted, "much of the teacher as learner literature tends to focus on the development of understanding and knowledge of teaching generally, rather than being content specific," (p. 1044) and emphasized the need for these kinds of studies in science education. Because PPK is situated, action-oriented, person-bound, and "constructed by teachers in the context of their work," integrating "experiential knowledge, formal knowledge, and personal beliefs" (van Driel et al., 2001, p. 137), studying the development of science teacher knowledge within the context of the science content being taught, the way it is taught, and the teacher's understanding of the students to whom it is taught is important and the focus of this study.

The Learning-to-Teach Process

Science teachers must be lifelong learners (Hammerness et al., 2005). Novice teachers do not and cannot know all they need to know when they begin their careers (Hammerness et al., 2005; Reynolds, 1995). Additionally, teachers of any level of experience must learn as new guidelines for teaching science and new curricula are adopted by states, as student populations change, or as teachers experience shifts in assignments (Sanders et al., 1993). Regardless of experience, teachers need to engage in the learning-to-teach process throughout their careers to improve their teaching practice. This process is often gradual and "has been found to be highly implicit and reactive" (Henze, 2006, p. 2).

Learning to teach, whether by novices or by experienced teachers, is situated within the context of teaching (Brown et al., 1989; Loughran, 2007). Teacher learning happens in many contexts and activities within teachers' practice (Borko, 2004). Just as students construct knowledge about science as they do science, science teacher knowledge becomes more rich and integrated as they teach (Munby et al., 2001; Russell & Martin, 2014). Consistent with a fundamental tenant of Vygotsky's sociocultural theory of learning, that learning is constructed in the context of the person's culture and through social interactions within that culture, teacher learning occurs within the context of the school and community culture and through interactions with others within that culture, such as students and other teachers (Russell & Martin, 2014).

In a review of the literature, Loughran (2007) asserted that although the literature treats the learning of beginning and experienced science teachers as distinct, the "distinction between them can be somewhat blurry" (p. 1044). The journey from knowing as a novice to knowing as an expert teacher does not take a neat, linear path. It is a messy endeavor, occurring as an "iterative process of learning, experimenting, and reflecting as [teachers] develop new skills for use in their classrooms" (Hammerness et al., 2005, p. 380). However, an examination of differences in knowledge of novice and experts can sometimes reveal learning that occurs as teachers gain teaching experience.

In a review of research on beginning teachers, Reynolds (1995) identified four main themes about the knowledge and practices of beginning teachers. First, she noted that while novice teachers may be able to detect differences among students, these teachers are unable to use this understanding to inform their pedagogy and subject matter in order to create instruction appropriate to the subject and their particular students. Second, she found that beginning teachers often do not establish classroom rules and routines that create an environment structured for learning. Third, she noted that novice teachers are not able to explain their SMK to students. Finally, Reynolds found that while novice teachers do reflect on their own teaching, their reflections are not as focused as those of experienced teachers.

Munby et al. (2001) echoed the ideas of Reynolds (1995), pointing out that experience in the classroom is central to the difference between novice and expert teachers. They explained that "where novices may focus on surface features or particular objects, experts draw on a store of knowledge that is organized around interpretative concepts or propositions that are tied to the teaching environment" (p. 889). Further, they asserted that the act of teaching, itself, increases SMK in novice teachers. Reflection needs to accompany experience when learning to teach, but reflection alone is not enough. In addition, teachers need to be taught how to reflect (Russell & Martin, 2014). Munby and colleagues (2001) stated that it is not only knowledge about content that increases with teaching experience, but also "in the area of science teaching, at least, the sense is that teaching experience makes a substantial contribution to the richness and interconnectedness of teachers' knowledge" (p. 881-882). As beginners and even experienced teachers teach science to students and develop, design, and implement curriculum in school settings and reflect on teaching experiences, their knowledge about teaching science deepens and becomes increasingly integrated.

Just as science students approach science with prior conceptions, novice teachers enter teaching with prior notions about teaching of which they may be unaware, but that will influence what they learn about teaching (Russell & Martin, 2014). Hammerness and colleagues (2005) described the problem of *apprenticeship of observation,* a term coined in 1975 by Lortie, in which people have observed teaching throughout their elementary and secondary education and have consequently developed certain views about teaching. Hammerness et al. explained that these conceptions are often simplistic, developed by observation through the lens of a student who sees only the actions of the teacher and does not understand the reasons behind the teacher's instructional decisions. These notions about teaching are deeply held, as evidenced by the fact that many teachers teach in ways they were taught and that these practices are difficult to change (Loughran, 2007). Novice and experienced teachers, alike, need to make conceptual changes in their ideas about teaching, and making these changes takes time and varies with individual attitudes toward learning (Borko, 2004; Russell & Martin, 2014).

A problem related to the apprenticeship of observation is that to observers, good teaching appears easy. Expert teachers are able to respond, seemingly automatically, to the myriad of situations that arise at any moment during teaching (Hammerness et al., 2005, Munby et al., 2001). They "possess richly elaborated knowledge about curriculum, classroom routines, and students that allows them to apply with dispatch what they know to particular cases" (Munby et al., 2001, p. 889). Experienced teachers are masters of complexity, able to manage many constantly shifting factors at once, including students' diverse backgrounds and current understandings, the school and community contexts, and the social, intellectual, and affective goals of teaching (Hammerness et al., 2005). The ease with which teachers appear to handle the complexities of teaching is not automatic and is learned as teachers teach.

Loughran (2007) described several insights into secondary science teachers' learning. First, secondary science teachers' teaching is more conceptual and constructivist when teachers reflect on their teaching. Second, teachers' institutional and social context influences how new teachers teach, and whether or not they enact practices consistent with their ideals about teaching. This context also affects their development as teachers. Third, teachers learn about dilemmas and contradictions in teaching theory and practice. Fourth, some teachers learn about their personal connection to the subject they are teaching, while some learn about risk taking in teaching, and others learn that taking risks can make both the teacher and students uncomfortable at first. Fifth, teachers learn to be more flexible in their teaching as they learn to respond to students' diversions from planned topics. Finally, some teachers learn to articulate their understandings about teaching through developing language to describe their teaching, often accomplished through graduate programs and other professional development. Loughran's work demonstrates the complicated nature of secondary science teachers' learning.

Sometimes shifts in teaching assignments disrupt teacher knowledge and require teacher learning in order to bring the teachers' understanding back into equilibrium (Hammerness et al., 2005). In a study comparing experienced science teachers' teaching in and out of their areas of certification, Sanders et al. (1993) found that in some ways, expert teachers behaved as novice teachers. When comparing the teachers' teaching in and out of areas of their expertise, teachers showed more differences during interactive teaching than during preactive or postactive tasks. For example, their ability to keep lessons flowing smoothly, to create clear explanations for students, and to anticipate student prior knowledge was more like that of novices when teaching out of their areas of expertise. These experienced teachers also exhibited behaviors similar to novices in their planning when teaching out of their area of certification. For example, they struggled to know which were the salient ideas that needed to be taught, and how to sequence and integrate those ideas in their instruction. However, these experts-turned-novice were able to rely on some aspects of their teacher knowledge, such as their GPK and general science PCK, to facilitate their learning in other areas. In this way, these teachers' learning was different than novices'. Because learning to teach is situated within the context of teaching, and beginning teachers enter their careers with limited knowledge of teaching, it is important that novices have support as they continue developing as teachers. Similarly, when seasoned teachers experience shifts in their teaching contexts, such as leaving one school setting, grade level or district for another, experiencing changes in their student populations, or receiving new teaching assignments, their teacher knowledge is impacted and they are faced with opportunities to learn. In such situations, experienced teachers remember teaching from their framework of experience and find themselves seeking out the knowledge that will enable them to return to their earlier position as experts in their new situations.

There are challenges to the learning-to-teach process. Hammerness et al. (2005) described several of these challenges. First, they explained, teachers bring with them to their practice prior expectations about what it means to teach. They pointed out that learning to teach differently than the way one has been taught is a difficult process. Russell and Martin (2014) also described this phenomenon, noting that "logic alone cannot change teaching practices that were initially learned indirectly and unintentionally from one's own teachers" (p. 872). Second, Hammerness et al. (2005) asserted, it is difficult to enact new understandings about teaching. A teacher may understand reasons behind certain methods, but changing practice to actually implement the methods is more difficult. Further, teachers are sometimes hesitant to enact practices suggested by research (Russell & Martin, 2014). Third, Hammerness and her colleagues (2005) identified "the problem of complexity" (p. 359). Teachers must do many things at once, making immediate decisions, dealing with many people with diverse needs, and responding in ways that facilitate student learning. Because of these challenges and others, changes in teaching practices consistent with reform are often difficult (Russell & Martin, 2014).

Professional Development

In light of teachers' need to continually refresh their knowledge throughout their teaching career, there is ongoing need to support their learning (Borko, 2004; Luft & Hewson, 2014). As discussed earlier, activities in which teacher learning and growth are facilitated are referred to as professional development. Formal experiences, including structured professional development programs such as a course, workshop, or series of classes (Borko, 2004), are often called *in-service education and training* in the literature (Bullough & Smith, 2016). Desimone (2009) asserted that professional development is not limited to formal formats such as these. Rather, it often occurs in everyday teaching practices and is "ongoing, continuous, and embedded in teachers' daily lives" (p. 182). She explained, for example, that professional development can occur in activities such as selecting or designing new curricula, participating in school leadership, teaching a lesson, administering an assessment, having a conversation with a colleague in the hall, or reading professional literature. Luft and Hewson (2014) extended this idea, pointing out that professional development can occur before a teacher ever begins teaching in the classroom, and may continue until the end of the teaching career.

According to Bullough and Smith (2016), over the last 40 years there has been a shift in the way teachers are perceived in relation to their own learning. They explained that in the past, teachers were viewed as professionals capable of choosing professional development that would best serve their needs and interests. They described the factors influencing professional learning as *personal drivers*. In recent years, they argued, school, district, or state educational leaders more often determine teachers' needs, select or design professional development programs, and then impose those programs on teachers. In these forms of professional development influenced by *systemic drivers*, they explained, the teacher is usually not the one in control of what is to be learned and implemented, or how it is to be implemented. Borko (2004) highlighted problems with many of these types of professional development programs, pointing out that each year the US federal government, school districts, and schools spend millions and perhaps billions of dollars on professional development programs that are "fragmented, intellectually superficial, and do not take into account what we know about how teachers learn" (p. 3). Van Driel et al. (2001) asserted that "reform efforts in the past have often been unsuccessful because they failed to take teachers' existing knowledge, beliefs, and attitudes into account" (p. 137). In addition to failing to acknowledge teachers' prior knowledge, teachers' experiential learning is often undervalued (Russell & Martin, 2007). In programs that ignore the local context of individual schools, disregard teachers' knowledge, experience, and position as professionals, and take a "one size fits all" approach, teachers often resent the professional development, viewing it as burdensome rather than an opportunity for learning and growth (Bullough & Smith, 2016; Hargreaves, 2013).

Implementing professional development programs without attending to the quality of the programs is not sufficient. In response to the problem of unsuccessful professional development, researchers have identified certain features of professional development that have the potential to increase their effectiveness and the likelihood that the knowledge taught will be enacted by teachers (e.g., Avalos, 2011; Borko, 2004; Desimone, 2009; Hargreaves, 2013; Penuel et al., 2007; van Driel et al., 2001). Desimone (2009), for example, proposed a "core conceptual framework for studying the effects of professional development on teachers and students" (p. 185). Her framework includes five features of professional development: content focus, active learning, coherence, duration, and collective participation. She determined that professional development that (a) focuses on teachers learning content and how to teach that content to students, (b) gives teachers the opportunity to actively learn in the professional development setting, (c) aligns teacher learning with school, district, and state goals, (d) provides sufficient time and duration of the learning activity, and (e) facilitates interaction between teachers, increases the effectiveness of the professional development. Van Driel and his colleagues (2001) addressed two of the elements in Desimone's (2009) framework, active learning and collective participation, in their assertion that if professional development is to "achieve lasting changes in teachers' practical knowledge…the following strategies are potentially powerful: (a) learning in networks, (b) peer coaching, (c) collaborative action research, and (d) the use of cases" (p. 137).

Loughran's assertions (2007) that teacher learning situations need to be authentic, social, and collaborative are also congruent with Desimone's framework.

Consistent with the features of effective professional development found elsewhere in the literature, the longitudinal, multi-site study conducted by Penuel et al. (2007) revealed that the professional development science teachers experienced influenced the implementation of an educational innovation. These researchers argued that important features of the professional development that improved implementation included (a) focusing on content, (b) adjusting the implementation to the teachers' individual school contexts, (c) providing support by supplying and setting up specialized equipment, and (d) the teachers' perception of the alignment of the aim of the professional development with their own goals and those of their school districts. The findings from this study parallel other research about features that make effective professional development, but emphasize that "the particular aspects of individual programs can make some features more or less important for supporting implementation" (p. 952). When considered together, the work of these researchers make clear the need for collaborative, active, extended, professional development that focuses on the particular content teachers are teaching and the context in which they teach.

In contrast to typical formal, systemically driven professional development, teachers sometimes direct their own learning experiences in order to make changes in their teaching. In such self-initiated, teacher-led professional development, the teacher, or group of teachers, may determine what needs to improve in their practice and decide how to go about improving it. The learning is personally driven, responding to the teachers' own desires and motivation to improve their teaching practice (Bullough & Smith, 2016). These teacher-led situations honor teachers' needs, existing knowledge, and experiences (Hargreaves, 2013). In a study of "participants' experiences of having their own needs respected and valued" in Teacher Learning Communities, Hargreaves (2013, p. 332) found that when teachers participated in teacher-led professional development, selecting and directing their own learning activities, and then received support for implementing their plans, teachers tended to stay more committed to the professional development and felt valued and empowered as professionals. She also found that the positive outcomes of the communities were undermined when the learning communities were imposed on teachers and did not accommodate other school commitments, when the meetings were inflexible and teacher leaders were "too directive," and "where practice was emphasized at the expense of theories" (p. 327). Valuing and respecting teachers' learning needs, thus acknowledging teachers as professionals who are capable of directing their own learning, appeared to have a positive effect on teacher learning.

Possible forms of professional development that are directly related to teachers' work include co-teaching, mentoring, reflecting on lessons, and discussions about artifacts from teaching practice (Desimone, 2009). Artifacts from teaching practice are sometimes called "records of classroom practice," and may include items such as lesson plans, video of lessons, or student work (Borko, 2004). These artifacts bring evidence of teaching into the professional development setting for examination and improvement (Borko, 2004).

Because professional development is a crucial part of teachers' practice and central to improving teaching, there is still a need for studies of effective professional development. Borko (2004) called for more research "in order to provide high-quality professional development to all teachers. It will take many different types of inquiries and a vast array of research tools to generate the rich source of knowledge needed to achieve this goal" (p. 13). This study investigated a teacher-led professional development experience in order to add understanding about teacher learning.

Career Cycles

Throughout teaching careers, teachers' knowledge and learning change, as do their needs. In the 1970s, in response to the realization that teachers have different needs at different points in their careers and that a "one size fits all" approach to supporting teachers' learning is not effective, researchers began to study teacher characteristics in different phases of their careers (Fessler & Christensen, 1992). Fessler and Christensen (1992) proposed a teacher career cycle consisting of the following stages: preservice education, *induction*, *competency building*, *enthusiastic and growing*, career frustration, stability, career wind-down, and career exit. The stages relevant to this study are induction, competency building, and enthusiastic and growing. The authors asserted that in the induction phase (usually the first few years of teaching) new teachers seek acceptance among students, other teachers, and administrators. These beginning teachers also learn to feel secure dealing with everyday teaching situations. In addition to the initial teaching year, "teachers may also experience induction when shifting to another grade level, another building, or when changing districts completely" (p. 41). In competency building, teachers strive to improve their teaching practice by building curriculum, trying new things, and willingly participating in professional development. "Their job is seen as challenging, and they are eager to improve their repertoire of skills" (p. 41). Enthusiastic and growing, Fessler and Christensen continued, is a period of high competence and continued learning and growth. Teachers in this stage take up leadership roles and have "enthusiasm and high levels of job satisfaction" (p. 41).

Importantly, Fessler and Christensen (1992) noted that the career cycle is not rigid and linear, but is characterized by a "dynamic ebb and flow…with teachers moving in and out of stages in response to environmental influences from both the personal and organizational dimensions" (p. 42). They described influences from the personal environment as home or family events or crises that may disrupt a teacher's ability to devote time or focus to teaching. Organizational influences include the supportive—or not supportive—aspects of school culture or leadership, as well as personnel shifts within the organization. The shift that was the focus of this study, a change in teaching assignment resulting in an expert-turned-novice, is an organizational influence that has the potential to affect the stages of the teacher career cycle by causing a teacher to cycle back toward induction before moving forward again.

Ryan and Kokol (1988) also studied phases of teachers' careers and focused on various components of teachers' development. They found that these components have different importance at different stages of the teaching career. The stages they identified were more rigidly defined in years of experience than stages as described by Fessler and Christensen (1992). Ryan and Kokol explained that as novice teachers complete their teaching preparation program and practicum and enter their first year of teaching, by far the most important component of teacher knowledge these teachers need is knowledge of classroom survival skills—the day-to-day management of classroom events and student behavior. The emphasis on these foundational skills peaks the first year of teaching, and then drops off dramatically for the remainder of the career as teachers master these practices. According to Ryan and Kokol, the second most important components to first-year teachers are strategies and skills for teaching particular content. Whether it is socialization in the teaching community, assistance with classroom management, teaching techniques, or some other concern, Loughran (2007) pointed out the importance for science teachers early in their careers to receive support and guidance as they determine what they need to improve their own science teaching practice.

The next stage, which Ryan and Kokol (1988) called the *probationary years*, includes years two through four. Ryan and Kokol argued that, similar to first year teachers, classroom survival skills and skills for teaching particular content are most important to probationary teachers. But unlike first-year teachers, for probationary teachers, the two components hold nearly the same emphasis. In other words, classroom survival skills drop in importance in relation to other components for these teachers.

During years 5–15, the stage Ryan and Kokol (1988) called the *professional years*, a new component emerges as most important: Idiosyncratic teaching style. They defined this as the need for "identifying, developing, and expanding the individual teacher's style" (p. 63). Strategies and skills of teaching particular content are also important to these teachers, and another component rises in importance: Non-classroom professional skills, which include taking up leadership roles in school organizations and professional associations.

The work of these researchers points to the importance of professional development that is specific to the needs of teachers in their particular contexts and at particular places in their career development. As teachers transition from their first year in the classroom through their probationary years to the professional stage, their knowledge about teaching changes, as does the kind of support they need.

Natural Opportunities for Learning and Growth in Teacher Careers

Within the course of a career, a teacher will likely experience changes in teaching assignments. There may be shifts in student populations, mandated curriculum, methods and technology used in the classroom, school assignment, or in the grade or subjects taught. There is evidence that in some respects, experienced teachers become novice again when they experience changes in their teaching context, such as teaching in a new school or an unfamiliar content area (Loughran, 2007). Shifts or disruptions in a teacher's career naturally produce opportunities for learning and growth by the teacher. When this occurs, there is also the opportunity to study the shift and learn from the experiences of teachers in this situation.

This suggests research should examine teacher learning in the various contexts in which it occurs, "taking into account both the individual teacher-learners and the social systems in which they are participants" (Borko, 2004, p. 4). However, there are few studies of the specifics of changes in teachers' knowledge that occur when opportunities for professional development and teacher learning are fashioned by teachers as part of their natural, every day experiences in preparing lessons and learning and teaching new content. There is a need to study such teacher-led professional development to examine more fully the characteristics of such professional development experiences, what teachers learn from them, and the changes they make in such contexts.

The purpose of this study is to explore how an experienced teacher, faced with just such a circumstance, learned and grew as she experienced a change in teaching assignment. The research question framing this study is, "What does an examination of the learning that emerges from a change in teaching assignment, coupled with collaborative, teacher-led professional development, reveal about a high school science teacher's development as a teacher?"

Chapter 3: Methods

In this chapter I will outline the design of the study. First I will overview the methodology that was used and why it was appropriate for the study. Then I will describe the context of the study, including the intellectual and institutional context of the new teaching assignment, and the context of the self-initiated, teacher-led professional development. Next, I will turn to the participants in the study, followed by the data sources, data collection, and data analysis procedures. Finally, I will explain how the design of the study met the criteria of self-study of teaching practice methodology.

Study Design

Because the purpose of this study was to explore the teacher/researcher's learning in a professional development effort motivated by and enacted as a result of changes in teaching assignment, self-study of teaching practice was the methodology that most clearly met the demands of the study (Pinnegar & Hamilton, 2009). A qualitative researcher might have studied the change process by observing my practices, interviewing me about the visible changes, and asking questions about increases in my knowledge. However, only a researcher acting in the role of researcher-and-researched would have access to my internal representations and understandings of teaching. Through the creation and analysis of an empirical tracing of the practices enacted, curriculum developed, and knowledge changes, I had full access to both my thinking as well as the evidence created (Pinnegar & Hamilton, 2009). This means I was more able to construct an accurate account of the growth and development that occurred. In this section I will outline the design of this self-study of practice, including the context of the study, participants, data sources and collection, and data analysis, and then show how this design met the criteria for self-study of teaching practice methodology.

Context of the study. Self-studies are always interactive (LaBoskey, 2004). This was a retrospective study of myself and my learning that emerged from a collaborative, teacher-led professional development.

In the study, I referred to myself in first person, and used the pseudonym Natalie to refer to my colleague. All other names are also pseudonyms. Unlike a typical self-study of practice where two teachers would undertake the study together as co-researchers (Pinnegar & Hamilton, 2009), I was the primary researcher in the study. Natalie was a co-participant in the teacher-led professional development, but in the research study, she served the role of critical friend rather than co-researcher. As critical friend, she provided a conversational space for me to reflect on my teaching experience. I investigated my learning and growth, and controlled the data collection procedures and analysis. Natalie, as a critical friend, provided feedback, helped me uncover bias, and made sure evidence supported assertions. Thus, as a critical friend, she helped establish the credibility of the researcher, and the viability and accuracy of the findings. In this way, Natalie joined me in the analysis, not as a researcher, but as a critical friend who critiqued my analyses, consequently contributing to the trustworthiness of the study (LaBoskey, 2004; Pinnegar & Hamilton, 2009). An expert in teacher thinking and teacher knowledge, with expert knowledge in teacher education, also contributed trustworthiness to the work by pushing my thinking at each stage of analysis, and agreed with my analysis as I created and adjusted codes, and found exemplars for each code.

To help other researchers determine how the results of this study might inform them, I begin by articulating the intellectual and institutional contexts of the biotechnology course. I then describe the teacher-led professional development.

Intellectual context of the course. At the time of this study, my school offered the following high school science courses: Biology, Chemistry, Physics with Technology, Concurrent Enrollment Geology, Concurrent Enrollment Chemistry, AP Physics, Medical Anatomy and Physiology, STEM Rocketry, and Concurrent Enrollment Biotechnology. Concurrent enrollment courses were those in which students simultaneously received both high school and college credit. The biotechnology course in my state was taught as an advanced science course in the high school, and at my school we recommended students complete Biology and Chemistry before enrolling.

The course was a specialized one with unique content. Biotechnology is a branch of science involving technology that uses living things or products of living things to solve human problems (Nature Publishing Group, 2015). Applications of the science can be found in medical, agricultural, and industrial fields and include processes such as genetic engineering and the production of chemicals and antibiotics. The topics included in the course were past and present applications of biotechnology, careers in biotechnology, safety in the laboratory, following laboratory procedures, chemistry and solution preparation, cell biology, bacterial identification and culture maintenance, mechanisms for genetic inheritance and expression, and DNA manipulation techniques (Utah State Office of Education, 2009). The technical content of the course required unique pedagogy that included instruction about the use of technical equipment and in-depth laboratory work. Because of the specialized nature of the content and equipment involved in the course, not many high school science teachers were prepared to teach biotechnology.

Institutional context of the course. My school began offering the biotechnology course about six years before this study and the enrollment in the course up to the time of the study had been small. The counselors at my school, who helped students select courses, initially struggled to understand what the course was about, and consequently the course had been slow in gaining momentum in terms of student enrollment. At my critical friend's school, on the other hand, two sections of the course filled and carried each year, even when the experienced biotechnology teacher retired and a new teacher was hired. At my school, biotechnology was viewed as a newer science course, and its continuing status each year was dependent upon the student enrollment in the course being sufficient for it to carry.

The contrasting way the biotechnology courses were situated within the greater contexts of the two schools was interesting, partly because of the many parallels between the two institutions. Being located in two neighboring suburban cities in the Western United States, the two public high schools had similar community contexts. The two schools shared a boundary, even though they were in two different school districts, and were similar in their demographic makeup. My high school served grades 9-12, with a small Gifted and Talented magnet program for grades 7 and 8, and during the 2014-2015 school year had an enrollment of 1,895 students. Approximately 39% of the students were ethnic minorities, and about 40% of the students participated in the National School Lunch Program (free and reduced lunch). Natalie's school served grades 10-12 and during the 2014-2015 school year had an enrollment of 1,303 students, approximately 34% of the student population were ethnic minorities, and 44% of the students participated in the National School Lunch Program. While the total enrollment of students in the two schools differed by almost 600 students, the number of students in grades 10, 11, and 12 differed by only 24 (Utah State Office of Education, 2014). Despite the demographic similarities of the two schools, the course was positioned differently within the cultures of the two schools. In my school the course's existence was constantly in jeopardy, whereas in Natalie's school the course was deeply regarded and perceived as essential in developing the academic prowess of the student body.

Context of the teacher-led professional development. This study is a self-study of a teacher-led, collaborative professional development co-constructed with my critical friend, Natalie. Our collaboration began when we first met in a weeklong biotechnology workshop involving high school teachers from around the state the summer before we taught biotechnology. At that workshop, I invited myself to a subsequent summer collaboration of biotechnology teachers from Natalie's school district, as I would be the only biotechnology teacher in my school district and I was seeking supportive colleagues. The group of teachers graciously accepted me into their collaborative group. At that subsequent meeting, a few first-year biotechnology teachers, including Natalie and me, began to work more closely. Later, a few months into the school year, Natalie and I decided to meet together monthly in our own professional development.

I engaged with Natalie in this endeavor as we both taught biotechnology for the first time. In the teacher-led professional development, we met together monthly and corresponded with each other regularly. We talked on the phone and interacted in professional settings not specifically focused on our teacher-led professional development. We also communicated by email as we faced challenges or resolved curricular or content issues. We engaged in calendaring, curriculum sequencing, assigning readings and labs to students. We shared labs and other classroom activities and assignments. We used the same assessments as the year unfolded. We resolved difficulties with equipment and lab set-ups. With our students, we engaged in a university-directed collaborative student project. In troubleshooting the project we shared images of student work and lab results. We consulted about difficulty in managing students and equipment. We discussed how to engage each of our 20 students involved in the single presentation of their project at a symposium attended by university students and other biotechnology teachers and their students. These activities comprised the teacher-led professional development of which this project is a retrospective self-study.

Because I was interested in what I learned in this professional development, I determined to use self-study of practice as a way to examine my learning in relationship to Natalie's that emerged in the teacher-led professional development. Of course, articulating our learning, re-examining representations of our curriculum and experience and reflecting on it pushed my learning further; however this study as a self-study of practice looks at that learning as a more formal and explicit account and documentation of the embodied, tacit knowledge that emerged from the teacher-led professional development. Therefore, in this account I am reporting the analysis of the artifacts, conversations and data that came from the study of the teacher-led professional development but not in the midst of the teacher led-professional development. This study grew out of our collaboration.

Our collaboration exhibited the features that Desimone (2009) and Penuel et al. (2007) identified as features of effective professional development: extended duration, teacher collaboration, focus on both content and teaching strategies, active learning, goal alignment, and support for implementation. Our professional development had a long and consistent duration, beginning the summer before teaching biotechnology and extending throughout the school year to the time of this study. It involved our collaboration as we met in person and corresponded by email. We focused on both biotechnology content to be taught and strategies for teaching that content. It also involved active learning as we co-constructed curriculum. It naturally aligned the aim of the professional development with our own goals as we, the designers and administrators of our own professional development, determined ourselves what we needed to learn and create. Finally, it provided support for the implementation of our curriculum as we shared our struggles and successes and problem solved together, as well as attended to the barriers to implementation we encountered by employing our shared expertise and tapping into other resources when we encountered problems outside of our shared expertise. Our collaboration also enacted the characteristics of teacher-led professional development that are most likely to ensure success in that kind of venture as articulated by Bullough and Smith (2016). One of the important features of this teacher-led professional development was that each of us could contribute as a capable other. As an experienced biology teacher, my deep PCK could direct our learning, and Natalie's college lab experience and knowledge of chemistry had the potential to deepen and build connections in our subject matter knowledge.

Participants. The participants in this study were my colleague, Natalie, who, at the time of this study, had just completed her first year of teaching and who served as critical friend in this study, and me. In our collaboration together, we sat side by side, Natalie as a novice teacher, and me as expert-turned-novice. In this section I describe our backgrounds and our expertise and novice-ness as teachers.

At the time of the study, I was a high school science teacher completing my eleventh year of teaching. I taught seventh-grade life science my first year of teaching, and biology, grades 9–12, the other 10 years. I taught five years, left the classroom for 10 years, and then returned to the classroom and taught for another six years before the time of this study. Therefore, while at the time of the study I had 11 years of teaching experience, I had been a licensed teacher for 21 years. During the 10 years that I was not teaching in the classroom, I worked in public education in various capacities, including serving as a science assessment workshop facilitator and science wide-scale assessment writer. Because of my years of classroom teaching experience and my additional work in the science education community in my state, I considered myself a seasoned biology teacher.

Although I was an experienced biology teacher, as I taught biotechnology, I considered myself expert-turned-novice. My first real experience with biotechnology as a discipline was during the summer of 2011 when I attended a weeklong biotechnology workshop. I was invited to participate by a colleague at my school who had begun teaching a biotechnology course at the school two years earlier. I was intrigued by the biotechnology content and decided that I would begin preparing to teach the course so that I could move into the teaching assignment when my colleague retired in the next five to 10 years. This preparation would involve fulfilling a number of requirements, including completing college coursework and attending state health science conferences, in order to receive a biotechnology teaching endorsement from the state department of education. In addition to obtaining the requisite teaching endorsement, because the biotechnology course was designated as a concurrent enrollment class in which students received both high school and university credit for the course, it also required being certified by the local university, which included completing a master's degree. I had quite a bit of work to prepare to teach biotechnology, but I had several years to accomplish these requirements and began working toward this goal. In retrospect, I recognize that the actions I took to prepare to teach this course resulted in learning about teaching, biotechnology, and teaching about it, that informed and pushed my learning, both in the teacher-led professional development and in the analysis of the retrospective study of it.

Unexpectedly, my colleague changed teaching assignments in the middle of the 2013-2014 school year. This opened the biotechnology teaching position about five years earlier than

I had anticipated. I did not want to delay taking the assignment because I did not want the school to lose the course or have another teacher move into the teaching position. Because I had already begun work on the requirements for my biotechnology teaching endorsement and had almost completed my master's degree, I was given the biotechnology teaching assignment for the 2014-2015 school year. This new assignment was both exciting and daunting. In order to prepare for the upcoming school year and the new teaching assignment, I attended another biotechnology summer workshop and a subsequent collaboration with biotechnology teachers from a neighboring school district that I met at the summer workshop. These teachers became important friends and colleagues, as well as resources for me as I prepared to teach this unfamiliar course. The roots of my ongoing professional development with Natalie began during this summer work.

Planning for the upcoming school year was daunting. The course required teaching in-depth content and specialized lab techniques involving technical lab equipment I had not used before. Teaching the course required me to know how to use and how to teach students to use equipment with which I was unfamiliar. Additionally, I had to set up my laboratory to make a space in which my students and I could work, as well as organize the curriculum. As part of this process I had to determine what labs and activities to use to teach certain skills and concepts. I worked during the summer with Natalie and the teachers from the other school district, but as the school year began I realized I needed continued support. Through my communications with Natalie, we realized we both needed this support and because we were both new biotechnology teachers, decided to meet monthly to continue building curriculum. We began to discuss our vision of what we wanted our biotechnology courses to look like. The more we talked, the more we realized we shared the desire to create a very organized curriculum, complete with activities, calendars, assessments, notes, and labs. We decided to take up this task together and this was the goal of our collaboration and the outcome we would work toward. This also provided us with an opportunity to work together to resolve questions of content and troubleshoot use of specialized biotechnology equipment. In a very real sense, we created a teacher-led professional development that exhibited features of professional development that Desimone (2009) identified. Namely, our professional development had a content focus as we concentrated on teaching biotechnology, we engaged in active learning as we planned and created curriculum, it had had a long duration with many meetings throughout our first year of teaching biotechnology continuing through the time of this study, and we had a collective participation as we collaborated in our own professional learning community.

At the outset of our collaboration, Natalie was a first-year honors chemistry and biotechnology teacher, and also coached the girl's volleyball team. She graduated from college with a Bachelor of Science degree with a double major in chemistry and biology, and did her preservice teaching experience in a high school chemistry class. Her extensive chemistry coursework, as well as work she did in a chemistry laboratory as a college student, resulted in thorough chemistry knowledge. She was a novice teacher, but had recent expertise in science SMK.

Despite the differences in our teaching experience, Natalie and I each brought with us elements of being both novice and expert. As a science teacher in my professional years (Ryan & Kokol, 1988), I brought experiential knowledge that she did not have. I had rich, connected biology SMK and PCK that she, as a recent chemistry and biology graduate and novice teacher, did not have. As a graduated chemistry major, she brought specific SMK and emerging PCK that I, as a graduated biology major, lacked. She also brought the expertise of a more recent background in biotechnology content—content that was only emerging as a field of study when I received my undergraduate degree more than 20 years ago. While there were differences in our SMK and teaching experience, we were both novice biotechnology teachers. The two of us worked side-by-side, expert-turned-novice and novice, each with our own strengths and weaknesses, and with shared expertise as we created curriculum for a new and rigorous course.

Data sources and collection. The data sources for this study emerged in four phases. Phase 1, the research conversation design phase, involved designing the meetings that would occur in the next three phases. During Phase 1, a specific purpose guided the design for each meeting. In this phase, I determined the specifications for the artifacts that would be used to guide the data generated in subsequent phases of the study. Indeed, Natalie and I brought artifacts from our practice to each meeting (see Tables 1, 2, and 3 for a description). They served as data and were carefully designed to anchor our discussions and provide insight into the development of our learning. The specifications for the artifacts were designated at the outset of the study and were not fluid, nor did the artifacts contain identifiable student data. I also created a list of prompts and probes (see Tables 1 and 2) that would push our thinking as we discussed our artifacts. The artifacts and the accompanying conversations about them focused on three different perspectives: (a) the person—who we were as science teachers before and as we took up the new course; (b) the lived experience—the ups and downs we experienced as we developed curriculum and taught a new course; and (c) knowledge—the contextualized PPK that developed through a teacher-led professional development. Specifications for the selection of each artifact, and the accompanying prompts and probes are provided later in this chapter and are detailed in Table 1, 2, and 3.

Table 1

Meeting 1 Overview: The Purpose, Artifacts, Ideas Explored, and Prompts

Purpose	Artifacts	Ideas Explored	Prompts to Guide Research Conversation across All Artifacts
To uncover who we were and who we are now as science teachers	Item from before teaching biotechnology	Beliefs about science teaching and learning How we enacted (or planned to enact) science teaching before teaching biotechnology How we viewed ourselves as science teachers before teaching biotechnology	What elements of good teaching does the artifact display? What weaknesses in our teaching does it reveal? What does the artifact and our discussion reveal about our beliefs about how students learn science? What does the artifact reveal about our beliefs about teaching science? (science content and pedagogy, science practices, inquiry, nature of science…)
	Item from early in teaching biotechnology	The types of things that unhinge us in our teaching How we respond as teachers to disequilibrium	What does the artifact reveal about our beliefs about our role as teacher in student learning? What does the artifact reveal about how we live as teachers in our classrooms, schools, and local science education community?
	Item from after teaching biotechnology	How we see ourselves now compared to who we were before the new assignment Growth and development in knowledge and teaching practice How beliefs about teaching changed or remained constant How our view of ourselves as science teachers changed or remained constant	How do we position ourselves or view ourselves (identity) as teacher in relation to students, content, school, science education community? What does the artifact reveal about barriers we encounter as science teachers, and how do we respond to such barriers? What does the artifact reveal about our confidence in our own ability to teach? What does the artifact reveal about us as competent teachers and problem solvers? About us as learners and adapters as we change assignments? What do the three artifacts reveal about our growth and development as teachers this year and as we collaborated in our professional development?

Table 2

Meeting 2 Overview: The Purpose, Artifacts, Ideas Explored, and Prompts

Purpose	Artifacts	Ideas Explored	Prompts to Guide Research Conversation across All Artifacts
To examine the lived experience of teaching a new course and developing new curriculum	Item that represented our best lesson and an item that represented our worst lesson	Strengths and weaknesses as lesson makers and implementers Elements we believed made good science lessons What we believed constituted good and poor science teaching and learning Knowledge we gained about student understanding and learning barriers	What elements of good teaching practice does the artifact display? What weaknesses in our teaching practices does it reveal? What does the artifact reveal about our beliefs about how students learn science? What does the artifact reveal about our beliefs about teaching science? (about science content and pedagogy, science practices, inquiry, nature of science…) What does the artifact reveal about our beliefs about our role as teacher in student learning? What did we learn about student learning through our lesson successes and failures? What can we learn about what we know about teaching science from these artifacts?

Table 3

Meeting 3 Overview: The Purpose, Artifacts, Ideas Explored, and Prompts

Purpose	Artifact	Ideas Explored	Prompts to Guide Research Conversation
To establish trustworthiness of the analysis of the experience of teachers in a teacher-led professional development	The findings of the study	Coding accuracy Legitimacy of the codes in the three narratives Representation as a shifting narrative Accuracy and adequacy of the representation of her experience	Are the codes appropriate and trustworthy and do the quotes and details provide sufficient evidence? Is the way I represented the codes in each narrative coherent with that narrative? Do the three narratives resonate with your experience of your development and has my account captured them appropriately?

During Phases 2, 3, and 4, we interacted to share experiences guided by the prompts, probes, and artifacts. In Phase 2 we met together in the meeting I refer to as Meeting 1, and generated data in the form of the artifacts we presented and the recording of our conversation about the artifacts. In Phase 3 we conducted Meeting 2 and, based on new artifacts and prompts, generated additional data. Also in the second meeting, as my critical friend, Natalie evaluated the trustworthiness of the codes that represented my data analysis. I recorded audio of our conversations during these meetings, transcribed the audio using dictation software, and then checked and edited the transcripts. Listening to the recordings as I transcribed and then checked the transcripts proved to be critical, as I was able to attend to verbal cues, such as the pacing of the conversations, the tones and inflections of our voices, and the shifts in the mood of the conversation. These *listenings* helped me more accurately interpret the data. As I transcribed and checked the transcripts, I made memos of my thinking. The transcripts from the meetings, the artifacts we shared, and my memos served as the primary data sources.

Finally, in Phase 4, Natalie reviewed the findings, attending particularly to the accuracy of my account of our interactions in terms of the analysis, and just as importantly, she evaluated the accuracy and adequacy of my representation of her experiences. However, the primary focus of the final meeting was to negotiate my analysis and interpretation, rather than to expand the data, and the findings section of the thesis draft anchored the conversation.

The structure for each of the first two meetings was as follows: Natalie and I both brought the artifact or artifacts specified for that meeting. During the meeting, we took turns sharing our artifacts, telling about the thing and what it revealed about us as teachers. After sharing, the other person reflected back what she thought the artifact showed about the person. The artifacts anchored the research conversations, and general prompts and probes guided our talk. An overview of the first two meetings, including the purpose, the artifacts we brought to each meeting, what the artifacts allowed us to explore, and prompts used to guide our discussion, is included in Table 1 and 2. Each table is preceded by a description of that meeting.

At the first meeting, described in Table 1, we explored our experiences from the first perspective: the person—who we were as science teachers. We examined our experiences at the individual level—who we were as science teachers before teaching biotechnology, who we were as we took up the new teaching assignment, and who we became as a result of our interactions and curriculum making. In order to accomplish this, we each brought three artifacts: (a) one that represented us at the beginning of the new teaching assignment, as we stood on solid ground, confident as teachers ready to take on this new assignment; (b) a second that represented us as we took up this change in assignment and felt unsettled by the new assignment; (c) a third artifact that represented where we each existed as a teacher of biotechnology at the time of the meeting. In our research conversation we explored ideas such as our beliefs about teaching science, our sense of identity as science teachers, our teaching practice, and our growth and development as science teachers. We used the prompts listed in Table 1 to guide our discussion and access the ideas to explore.

At the second meeting, described in Table 2, we examined the second perspective: the lived experience—the ups and downs we experienced as we developed curriculum and taught a new course. In order to do this, we each brought two artifacts: one that represented our best lesson and one that represented our biggest failure that year. Through our discussions about these artifacts, we explored our experiences as we developed and implemented curriculum in our course. Prompts for the second meeting are listed in Table 2.

The third perspective, knowledge—the contextualized PPK that developed through a teacher-led professional development—was uncovered throughout Meetings 1 and 2, as it permeated our discussions about our biotechnology teaching experiences. The perspective was particularly prevalent as we shared our curriculum plans and calendars, as well as our successes and failures with certain curricular materials and equipment.

At the third meeting, described in Table 3, we discussed the findings of the study. The findings served as the artifact to anchor the conversation. Prior to the conversation, Natalie reviewed the findings, and then during our meeting I used the prompts listed in Table 3 to guide our talk. Through the conversation, I established trustworthiness of the analysis.

Data analysis. I used constant comparative method to analyze my data and develop understandings about teacher learning in the context of a naturally-occurring, teacher-led professional development (Glaser, 1965; Strauss & Corbin, 1998). The constant comparative method allowed me to engage in a recursive data analytic process. In this process, I generated understandings grounded in the data, which allowed me to explain the phenomenon studied in this research, namely a teacher's learning and development that occurred in the context of a change in teaching assignment coupled with teacher-led professional development.

First, after the initial meeting with Natalie, I read the transcripts of the meeting while listening to the recording and identified incidents, bounding the incidents as thought units. Then I re-read the data in a process called *open coding* (Strauss & Corbin, 1998) in which I identified concepts that each thought unit demonstrated. As I coded each incident, I made memos about my ideas about the properties and dimensions of the concept. While coding incidents, it was important to be open to various interpretations of the data and explore multiple possible meanings. These ideas were recorded in memos, and memos became data for subsequent analysis. Upon completion of the open coding process, I invited an expert in teacher learning and knowledge to evaluate my open coding.

Next, I performed a process called *axial coding*. Axial coding is "the process of relating categories to their subcategories, termed 'axial' because coding occurs around the axis of a category, linking categories at the level of properties and dimensions" (Strauss & Corbin, 1998, p. 123). In axial coding, after open coding all the data from one meeting, I compared memos and open codes, looked for patterns and trends, and determined how the "categories [varied] dimensionally" (p. 143). As I found similar open codes, I linked them for the purpose of "discovering the ways that categories relate to each other" (p. 142). I also watched for negative instances, conflicting ideas, or incongruities and made memos of these. After I created the codes, I organized them in a coding sheet, defined each code, and selected excerpts from the data that served as exemplars of each code. The coding sheet with codes, definitions, and exemplars of each code are included in Table 4 in Appendix A.

After the axial coding process, I met with the expert in teacher learning and knowledge. She reviewed the data, and we discussed my open and axial codes and exemplars in relationship to each other. Our conversation helped to deepen and extend my analysis, and increased its trustworthiness as we agreed about the coding and exemplars. While my initial open coding occurred independently, when I engaged in axial coding, the process was not linear, but as Strauss and Corbin (1998) pointed out, it was fluid and occurred in a recursive pattern. Thus, I revisited my initial open coding in interaction with my axial coding, consequently shaping and strengthening both.

The analysis and my discussion with the expert informed the next round of data creation at Meeting 2. Through our conversation, I determined how I should shift the focus of the next meeting with Natalie. I engaged in the same recursive analysis process after the second meeting, open coding and axial coding data, and continued my analysis until my categories were saturated.

In my final analysis, I shifted from creating themes from my codes to representing my findings as a narrative. Before this shift, as I worked to pull my codes together to create independent themes using *selective coding* (Strauss & Corbin, 1998), I realized that my findings were more cohesive and made more sense when written as a narrative. Maxwell and Miller (2008) asserted that the most powerful way to represent the interrelationships and patterns in the codes and categories that emerge are best captured by narrative patterns. This led me to reconsider the representation of my data, and I made the determination to represent my findings narratively. In this way, I was able to more coherently represent the shifts and the complexity of the themes and codes in my teacher knowledge and experience.

Finally, I attended to the trustworthiness of the study once more by reviewing and negotiating my analysis with Natalie. In our interaction, I used the findings as the artifact to anchor our discussion. In her role as critical friend, she read the analysis. Through our discussion, Natalie verified my interpretation of the data, identifying it as an authentic representation of our experiences in our professional development. She asserted that she had been represented appropriately in my description of her thinking and action. As both the researcher and researched, one who had complete access to my own thinking, I was able to create an accurate picture of my experience in relationship to Natalie's. Natalie concurred with my analysis. In our deliberations, Natalie asserted that her biggest challenges emerged from her beginning teacher status rather than issues with subject matter knowledge. In our re-examining the findings once more, I argued that this is how I portrayed her. We reviewed the document, identifying and considering the points in the analysis and interpretation she was concerned about.

As we revisited these items, we negotiated each. I listened to her concerns, and articulated my understandings of her concerns and my explanations of what I had written in the document. In each case, I was prepared to adjust my interpretation and representation of her, but as we reconsidered the document together, she agreed with the interpretation and its representation in the document.

Self-study of teaching practice methodology. In self-study methodology, the author is both the researcher and the researched. However, the research is not limited to the self; self-study requires collaboration with others in the practice. Through such interactions, and critical, cyclical reflections about texts within the practice, this self-study allowed me as the researcher to look into my own practice to uncover knowledge about both the self and the practice. The purpose of self-study is to produce understanding that will help me, the researcher, improve and reform my own thinking and practice, and also improve the practice of others (e.g., Berry & Loughran, 2002; LaBoskey, 2004; Pinnegar & Hamilton, 2009).

LaBoskey (2004) described five characteristics of self-study methodology. She asserted that self-studies are (a) self-initiated and self-focused; (b) interactive; (c) use multiple, primarily qualitative, methods; (d) involve exemplar-based validation; and (e) are improvement aimed.

This study met LaBoskey's (2004) criteria. First, the study was self-initiated and self-focused. I researched my own practice through my collaboration with a critical friend, Natalie. Second, the study was interactive. While it was a study of me and my practice, the study would not have been possible without my interactions with Natalie during our collaborative professional development. She was an essential part of the research, a critical friend with whom I interacted to generate data and to help me understand myself. My interactions with others during the analysis process were also crucial in order to deepen understanding, establish trustworthiness, and check for accurate interpretations of the data. Third, the study used constant comparative method of analysis, a qualitative research method that provided a systematic method to recursively reflect about artifacts from the teaching practice of my critical friend and me, and our discussions of them. Fourth, the study involved exemplar-based validation. Trustworthiness was established by making clear the constant comparative method I used to analyze the data, and rich exemplars were used to document assertions about my practice. The expert, and Natalie, in her role as critical friend, also helped establish trustworthiness. These people served as mirrors that helped me turn to self. This allowed me to clarify my learning, my experiences, and my understanding of both. The expert and my critical friend worked alongside me to help in the recursive analysis that revealed my own learning and development through my interactions with Natalie. Finally, the study was improvement aimed. Because the purpose of the study was to uncover understandings about teacher learning and development that can occur in a teacher-led professional development, the knowledge I produced through this study will help me improve my own teaching practice and has the potential to help other teachers improve theirs.

Chapter 4: Findings

When I took up the work of becoming a biotechnology teacher, I began a journey. I started in a place of security based in my teaching biology, a course I had taught for years. I left that secure place and ventured into the unknown to teach biotechnology, a course I knew little about. As I worked in this unfamiliar place I found friends—people I could work and learn with. Natalie, my critical friend in this study, and I were both new to teaching biotechnology. When we decided to meet regularly to plan and build curricula, we began what turned out to be a self-initiated, teacher-led professional development (see Bullough and Smith, 2016). Through our work I began moving back toward security in my teaching again. A careful examination of two research conversations with Natalie revealed my growth and development as a teacher during my journey from security to uncertainty and then back toward security again as I gained experience of this new assignment teaching biotechnology.

Identity as Expert

Before I began my new assignment teaching biotechnology, I felt confident in my teaching abilities. My PPK was grounded in my years of experience as a teacher and my experiences as a successful student of science. Embedded and embodied within my PPK and my PCK were expectations for my knowing about my students, teaching them, the content, and my knowing of the cultural contexts in which I taught. This embodied knowledge gave direction to my wondering and opened spaces of unease as I took up this new challenge. When I began this journey, I identified as an expert biology teacher. I viewed myself as experienced, organized, and in control of my curriculum and my classes. One artifact I brought to our first research conversation was a binder I created over several years that contained curricular materials I used with students as I taught biology. I described the binder to Natalie.

> It's organized into units, and then for each unit I know what assignments kids are turning in, I know what assessments I'm using, I have note outlines for the kids to take notes on, and then I have lab sheets and any, you know, practice sheets that I want them to do. (Meeting 1)

My binder contained materials for student use, including student learning objectives, guided note graphic organizers, practice and review worksheets, and written laboratory and activity materials. It also contained materials for teacher use, such as a course scope and sequence, a detailed daily calendar for each unit of instruction, and equipment and materials lists for laboratory activities. An examination of this biology binder revealed the expertise in my PPK as a biology teacher, particularly in my SMK, GPK, and PCK. As I began to prepare to teach biotechnology, the information in the binder indicated the categories and kinds of knowledge, skills, and practices I sought out to teach that course.

Expert biology subject matter knowledge. My biology binder demonstrated my biology SMK by making explicit the essential biology concepts students needed to learn. Through the activities and notes to me as a teacher, it also represented where difficulties might arise with content. The concepts were organized into coherent units, and these units were arranged in a sequence such that ideas connected to and built upon each other. Because I had taught the course for many years, I had worked to fix subject matter errors in the binder and the subject matter was accurate, up-to-date, and appropriate for the course.

Expert general pedagogical knowledge. My attention to including various teaching methods in the binder highlighted my expert GPK. For each unit of instruction, I used various types of learning activities, such as individual and cooperative group work, the use of scientific modeling to help teach complex or abstract concepts, and laboratory activities in which students experimented, collected data, and wrote about their results. The binder included multiple learning activities for concepts in the course that were typically difficult for students to learn. The binder also included both formative assessments and reference to avalilable summative assessments of student learning, and the assessments were tied to the learning objectives. I consistently revised and updated the binder with new ideas, and the teaching methods I used as revealed in the binder reflected practices that are regarded as effective teaching strategies both in science education and in terms of general pedagogy.

Expert biology pedagogical content knowledge. The binder of materials made clear my rich PCK, the special teacher knowledge about how to teach a specific subject matter (Shulman, 1986). It showed my detailed attention to planning, and my sense of time required for various learning tasks, evidenced by the scope and sequence document and the unit calendars. It demonstrated my belief that students construct science knowledge as they participate in the practices of science. I highlighted this when I shared my biology binder with Natalie. I explained,

> [My biology binder] reveals about my belief about teaching science that students should be doing. There's a lot of, um, activities, you know, labs, for each unit that they're doing. Because I think that kids should be doing science. (Meeting 1)

My binder also reflected my understanding of typical student prior knowledge, as well as common struggles students might have with the subject matter. The note outlines and review assignments targeted specific areas that were typically difficult for students to learn. Additionally, my lists of necessary materials for laboratory activities revealed my PCK, as did the fact that activities were designed to both optimize student learning and accommodate my own physical teaching space. Certain learning activities in the binder revealed my assumptions about specific student groupings, physical room arrangements, beliefs about teaching and learning, and my knowledge of the typical behaviors and knowledge of students who took this course. It revealed my knowing of the instructional and laboratory materials I had access to, as well as my knowing of management of these materials.

In summary, my biology binder was a physical representation of my identity as a competent teacher, and the PPK, PCK, and SMK that underpinned that identity. My knowledge and identity had developed through years of experience teaching biology, and was built on the basis of my learning as a student of science and my teacher preparation. It also revealed my own learning from both teaching failures and successes. It revealed my understanding of student learning, particularly student learning of biology. This was demonstrated in the sequencing, timing, and pacing of instructional units and the inclusion of additional assignments to target difficult topics in the curriculum. It brought together my knowing of science, the students learning the science, the context in which I was teaching, and the school year in relationship to the unfolding curriculum. It embodied my PPK and symbolized that sense of security in my own knowledge and preparation as a teacher. I summed up the significance of the binder to Natalie. "This [biology binder] represents to me, I know what I'm doing. I feel very confident in the subject matter, in my methods. I got this thing" (Meeting 1).

Identity as a teacher leader. In addition to identifying as an expert biology teacher at the outset of my journey, I also identified as a leader in the local science education community. I had taken up several leadership roles and contributed in positive ways, including presenting at conferences, doing curriculum and assessment work at the state level, and mentoring pre-service teachers in my classroom, as well as a first-year biology teacher at my school. I described this role to Natalie:

> I feel like when I have something that is organized for me, what I'm doing, where I'm going, where I've been, then I can extend and help other people, you know—present at a science teacher conference, or, you know do that kind of stuff because I feel like I have a good grip on what I'm doing. (Meeting 1)

My identity as a competent biology teacher enabled me to extend outward and contribute to the larger science teaching community.

Identity as Expert-Turned-Novice

As I prepared to teach biotechnology, I experienced a shift in my identity as an expert teacher. There were substantial gaps in my personal practical knowledge pertaining to my new teaching assignment. I felt insecure and unsure, and began to identify in many ways as an expert-turned-novice in my biotechnology teacher knowledge. I knew I lacked specific knowledge of how to teach biotechnology, and I worried about my content knowledge of the biology, chemistry, technology, and lab practices involved. An artifact I shared with Natalie at our first research meeting represented my uneasiness. The artifact was a photograph of slips of paper I had taped to my office door the summer before. The pieces of paper contained standards and objectives of the state biotechnology core curriculum cut into individual strips. I moved the slips of paper around on my door in an attempt to organize the state objectives around topics or under headings in a way that made sense to me. Over time, the randomness of the slips of paper gave way to a sort of curricular map. My uncertainty as a novice biotechnology teacher was evident as I talked to Natalie about the artifact.

> And I still, I'm looking at these headings, and I don't know. I think *Safety and Lab Methods* is probably a good heading and stuff, and *Cells* would be, but *Cells* kind of goes with *Bacteria Culturing*, and then you know, nucleic acids and plasmids kind of fit

> together, so I've got to…and *Chemistry*, that's gotta be kind of before because you've gotta know all of your dilutions and stuff. So I still feel like I'm trying to organize this. But this was just a visual representation to me of how unhinged I felt. How chaotic and out of control and, "What am I gonna do?" And how long...oh! How long? How long is it going to take? (Meeting 1)

It is clear that I was overwhelmed by the task of organizing the course and no longer felt like an expert teacher in terms of exactly how to organize and structure the content to promote student learning. As I reviewed the main topics in the course and reflected on them, the influence of my SMK for biology teaching was evident in my search to find the appropriate organization and structure of the biotechnology content. I identified with Natalie when she described her distress with her first year of teaching. She brought a bottle of ibuprofen to our first research meeting as a representation of her insecurity, and explained physical effects from the stress. "It was a migraine. I literally had…I got sick…I was ill" (Meeting 1). Later, in our second conversation, she captured the level of frustration we both felt when she described her experience with a piece of equipment. "I was at school at 11:45 one night swearing at my machines at the top of my lungs. Like, if I drop this off the stairs, is anyone gonna know?" (Meeting 2). I too had experienced this kind of anger and frustration as I learned to use new equipment for the course.

Unlike Natalie, however, even though I was unsettled, I was not completely novice. I had other experiences teaching science I could draw upon to help me on my journey through novice-ness. My attempt to build a curricular map, even though it may have appeared random or disorganized, is one example of the expertise I brought to the new course and evidence of the way in which my PPK and my PCK underlay my quest to learn to teach biotechnology within this teacher-led professional development. My beginning curricular map demonstrated my understanding that the standards, concepts, processes, and laboratory activities would have an inherent structure across the year, and that as I moved the strips, clustering and ordering content, assignments, and processes, the structure would emerge.

In addition, elements of my binder also revealed my expertise within my novice-ness. Referring to my biology binder, I told Natalie, "I don't have that same thing [a complete, organized curriculum] in biotech yet. It'll come, but…" (Meeting 1). I knew from my experience teaching biology that I was capable of coming to a place of expertise, and that I would be able to achieve this in biotechnology as well. In this way, my novice-ness in teaching biotechnology was mediated by my biology teaching expertise.

In another instance, my expertise mediated my novice-ness as evident in the contrast between my ability and Natalie's to guide our students through a complex laboratory project. We both participated in a research project in conjunction with a local university that culminated in a research symposium in which our students presented their findings. At the beginning of the year, Natalie was confident in her ability to guide her students through this complex project. She explained that she believed the project would be easy because the partnering university provided everything, including a short teacher in-service, lab materials, and written lab protocol for teacher and student use. However, she quickly became overwhelmed and found the project and her responsibility to guide students through the project far more difficult than she originally anticipated. For example, the project was more extensive and involved more laboratory skills than she realized at first. There were also some instances in which laboratory procedures did not work and she had to work with the university to troubleshoot, revise, and redo those steps. As a first-year teacher, she was not prepared to deal with these challenges, and the unexpected problems upset her. On the other hand, I knew from the beginning of the project that it would be a difficult undertaking since, from the beginning, I was thinking of the project in terms of my responsibility to support students in completing it and my own beliefs about the adequacy of my SMK for supporting students. In particular, I struggled with aspects of the project, specifically troubleshooting the source of student errors. I explained,

> I still don't know what they were doing wrong. Because I would take their extracted DNA and I did PCR [polymerase chain reaction]. They broke down somewhere in the PCR process because I took, I think I took one of every one of them just to see, "okay, can I make PCR work with their stuff?" And I got results for all of them except for one. I think none of them, except for one, got results on their own.…And then the other thing I didn't know is, it could have been that they weren't loading their samples into their wells. (Meeting 2)

There were many places students might have made mistakes, and as a novice, I did not know what they were doing wrong. As an experienced science teacher, I did know it was possible to learn where the sources of the students' difficulties might lie and I worked with students throughout the project to discover this. However, despite my frustrations, the project, across my experiences with it, did not seem as catastrophic to me as it did to her. I was not taken by surprise when I encountered problems in the same way she was. My expert science teacher knowledge, particularly my science PCK, better equipped me with the skills to navigate challenges in the project, and help my students navigate those challenges, as my students and I encountered them. In our research conversations, I focused on many positive aspects of the project and worried primarily about the timing of the project and whether students learned from it. I told her, "I loved the project…but the timing was wrong. …What it did, and it did it beautifully, it integrated so many different skills. But they didn't have them yet" (Meeting 1). By contrast, Natalie seemed more frustrated with the project overall, wondering, "why did we even attempt this?" (Meeting 2) and labeled it her biggest flop that year.

Even though I viewed myself as a novice biotechnology teacher, I drew upon my identity as an experienced science teacher as I managed students and guided them through the project. My biology teacher knowledge mediated my novice biotechnology teacher knowledge through much of this project, as I was better equipped to deal with unforeseen situations in the classroom that required adjusting my instruction. So while in many respects I identified as novice teacher, in other respects I had the characteristics of an experienced teacher as I moved through this first year teaching biotechnology.

Novice biotechnology subject matter knowledge. As an experienced biology teacher, I felt confident in my knowledge of biology subject matter and had a deep, connected, and coherent understanding of the ideas I needed to help my students learn. However, as I took up the biotechnology teaching assignment, I moved into a domain with which I was much less familiar, and I felt underprepared. In fact, both Natalie and I identified areas in which we felt insecure in our SMK. I was strong in the biological subject matter that pertained to biotechnology due to my coursework in my undergraduate degree in biology, as well as the rich connections I had made within the content as I taught it. My chemistry knowledge, however, was much weaker. I had studied only basic chemistry during my undergraduate work, which was approximately 20 years before the time of the study. I had not taught many chemistry concepts in my biology classes since then. Natalie, on the other hand, had majored in chemistry and consequently had much stronger chemistry knowledge than I did, but was weaker in the discipline of biology. Her content knowledge from her formal post-secondary education was more up-to-date with current developments in science than was mine. I contrasted our college experiences when I said to Natalie, "And it was hard, like, you had biochemistry and biology and chemistry. You had current, recent content background...Honey! They didn't even have PCR at [the college I attended] when I went there!" (Meeting 1). There were major differences in the biotechnology content we learned in college because of the significant advances in the field of biotechnology since I was a college student. She also had more lab experience in college, as she had worked as a lab assistant. However, regardless of our background, both of us found areas in which we needed to strengthen our SMK in order to become better biotechnology teachers.

During our self-initiated, teacher-led professional development, Natalie and I found opportunities to improve our SMK. One such experience grew naturally out of our conversation about an activity Natalie did in her biotechnology class. She had performed a simple DNA extraction that I had done for years with my biology students. As we talked about the procedure, our conversation shifted to why, chemically, the DNA precipitates out of solution the way it does during the extraction.

> Lorien: So it's the negative backbone [of the DNA] and alcohol. But why does it come up into the alcohol? I know I've learned this before but I forget.
>
> Natalie: When you pull it into the alcohol, the DNA sticks to itself and it coagulates.
>
> Lorien: But the salt helps somehow there. Is it the…
>
> Natalie: The salt I think helps buffer it when you lyse it open. When you smash it and you open it up. DNA is sensitive so if it's exposed to the wrong conditions it falls apart and it degrades. So I think the saltwater, or we use a soap and salt and water combination…
>
> Lorien: Well the soap is going to break open the lipid membranes.

Natalie: Yeah. Oh yeah that's right. The soap breaks the cells cause you're smashing them with the soap. And then the salt I think buffers.

Lorien: Hmm. Okay. I thought it was something with the polarity, not the polarity but the, I thought it helped the DNA stick to itself.

Natalie: Yeah. Cause the NaCl would have the positives and negatives in there. Yeah. I probably should know that off the top of my head better but I don't.

Lorien: Huh. I'll have to read up on that…(Meeting 2)

My experience led me to ask in-depth questions about a basic process we had both used in our classes. We both knew and explained some of the chemistry behind the extraction process, consequently teaching each other, but through our discussion, we also found details about which we both lacked some specific understanding of the concept. Because I felt it was important to have a thorough understanding, I resolved to learn more about the process. Our self-directed learning was leading to deeper SMK.

During our second research conversation, I described another instance in which I struggled with my SMK. I had conducted a laboratory experiment with my students using a method called sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). I had only a very basic understanding of the concepts underlying SDS-PAGE, as well as how to perform the technique. I told Natalie,

> Well, I ran an SDS-PAGE on pGLO [a bacterial plasmid].…And it worked okay, but, that was right at the edge of my…ugh. I didn't have time to do that one ahead.…And figuring out those stupid boxes. They leak, and I hate them. (Meeting 1)

My emerging SMK, which was "right at the edge" of where it needed to be, coupled with my lack of proficiency with the SDS-PAGE apparatus limited my ability to effectively help students perform the lab and to learn the relevant details from it. I also had a difficult time interpreting the results of the experiment. I related this frustration about my experience.

> Yeah. That's the worst feeling, like, I don't know what's going on. I felt that in my SDS-PAGE. Kids were like, "Well, isn't this *this* band?" And then I had another really smart kid—I'm like, "Well, yeah, you see, you have this band right here,"—and this kid who said "Well, and then aren't these two right here the partially denatured thing?" or whatever it is, I don't even. And I was like, "Oh yeah, yeah, yeah. Yep, sure enough! Good job! Good job!" Yeah. So that not knowing is so rough. It's so hard. (Meeting 2)

In this situation I felt so unprepared that a high school student seemed better able to interpret the results than I, as the instructor, could. Unlike experiences I have had teaching biology in which I am able to draw out what students know and use it as an opportunity to solidify the student's knowledge and to develop the knowledge of the other students, in my unsettled state, I was unable to use one student's knowledge to develop and deepen other students' understanding. In fact, I felt so uncomfortable with this lesson that I identified it as my biggest flop.

> My biggest flop was the SDS-PAGE thing. And I think it was the biggest flop because I had the least amount of background with the lab skills. I'd only done SDS-PAGE once at the prior summer's thing. And so I just didn't know, I just, I just don't know very much about it. I didn't understand the buffer and the Laemmli buffer and all the components in it. And I'm looking through this, going, I'm going to have to go and relearn this again. It's just not in there, as something that I know about. (Meeting 2)

Through our conversation I was able to identify and explore a specific gap in my SMK. I described this deficiency to Natalie.

> And so I didn't feel prepared, both with my background knowledge in the content that was going on, as well as how do you do [SDS-PAGE]…So it just, it just didn't feel like they learned much, I didn't feel like I knew what I was talking about. (Meeting 2)

In this instance, my only prior experience with SDS-PAGE was during a summer workshop in which a university professor provided the expert knowledge about the process. While participating as a student, I did not fully recognize all the details and concepts I would need to grasp in order to effectively teach the technique to my students. As this example demonstrated, my knowledge was lacking in both specific academic content and lab skills, such that it sometimes interfered with my ability to teach concepts well and to build on and extend student knowledge. My collaboration with Natalie helped me uncover questions I needed to pursue in order to refine and deepen my SMK.

Expert-turned-novice pedagogical knowledge. Although I began my journey with only basic biotechnology SMK, I was experienced in my GPK, or general teacher knowledge of how to teach. My GPK mediated my novice-ness as a biotechnology teacher. The photograph of my office door with the state biotechnology core standards taped to it demonstrated the mediating effect my GPK had on my novice-ness. As I arranged the standards on my door, I also wrote the names of learning activities and laboratory experiences I could use to teach each concept on sticky notes, and stuck them to their corresponding standard. Then I worked to fill in any blanks where I had a standard or objective without a sticky note. I explained the artifact to Natalie. "Oh, [my door] also shows that my focus, again, on activity. I was trying to find at least one good activity...At least one, but hopefully more ways to address that concept through activity, lab, or otherwise" (Meeting 1). My attention to learning activities that were tied to content standards revealed my expert GPK. As an experienced teacher, I knew I needed active learning experiences for each standard if I was going to support my students in developing deep knowledge of biotechnology and the skills to work in this field. I knew the importance of being able to ask and answer the question, “How will I teach the different concepts in the course?” Physically moving and arranging the slips of paper and taping them to my door where I could continue to examine and reevaluate them was my way of visualizing my pedagogical decisions. As I became more familiar with the course over the next eighteen months, I no longer needed the visual and physical curricular map on my office door because I had internalized it and used it to help build a biotechnology binder to direct my teaching. The map had become part of me—part of my PPK—and I took down the slips of paper.

Novice pedagogical content knowledge. As I journeyed from biology teacher to biotechnology teacher—from expert to novice—one of the most dramatic shifts in my teacher knowledge was in my PCK. At the outset of my journey as an experienced biology teacher, I felt secure in my PCK. I had a deep understanding of the biology concepts I needed to teach, how I wanted to teach and assess understanding of those ideas, and the curricular materials I would use in my instruction. They were organized in a meaningful way in my biology binder, which I was able to use effectively with my biology students.

In my first research conversation with Natalie, my feelings of being unsettled by my new biotechnology curriculum starkly contrasted with my secure biology PCK. I described my uncertainty about the new course to Natalie.

> This chaos that I felt at the beginning of the year, not knowing, like, what are the important pieces that [the students] need to know, and how do [the content pieces] all fit together and interconnect? And what do [the students] need to do first, so that later on they have the groundwork to do this next thing? (Meeting 1)

At the outset of teaching biotechnology, I had shallow biotechnology PCK and linked content knowledge. I did not know “how these [standards and learning objectives I taped to my door] are interconnected, what is prerequisite knowledge for the next skill, and how to build on that” (Meeting 1). As a new biotechnology teacher, my linked content knowledge was only emerging and I struggled with arranging my curriculum in a meaningful way, but as an experienced science teacher, I sensed the importance of this knowledge base as I grappled with my curricular decisions. Interestingly, in their study of new chemistry teachers, Nixon et al. (in press) found that new teachers did not draw on this domain to think about the arrangement of topics within the curriculum, rather simply followed curricular materials they were given.

Even though my biotechnology PCK was only emerging during my first year teaching biotechnology, it was mediated by my biology PCK. For example, our reflections about the extensive research project and symposium described earlier revealed interesting differences between the two of us. Natalie’s experience with the project seemed to be more challenging and left her more frustrated than did mine. Initially, Natalie thought the project was going to be easy. She explained,

> I think the problem was that I was overconfident. Because [the university] provided so much of the stuff, and it was so simple. …Because I had already lab background, …when I went to using different tools I was like, oh, this is easy. (Meeting 2)

Natalie may have been experiencing the problem of apprenticeship of observation that Hammerness et al. (2005) described. She approached this project from the perspective of a recent student, remembering that things were easy for her as a student and assumed that they would therefore be easy for her own students. Additionally, when she was a student, her teachers likely made instruction appear easy, so she imagined this instruction would also be easy.

Unlike Natalie, I did not remember feeling overconfident as I began the project. I was overwhelmed by the new course in general, and knew that this project, specifically, was going to be very involved and challenging. I approached the project by attending to what I was going to need to know to help my students learn what they needed to do to complete the project. Perhaps my prior biology teaching experience prepared me to know that I was taking on a big project and that it would not be easy; I was not sure I would always know exactly what students needed to know and what I would need to know to support their performance.

As my students and I moved through the project, I struggled, but I also had some ideas about how to manage and support students in developing the final product of the project, a student presentation at a conference with the other high school and college students involved in the project. I was able to negotiate the challenges because of my experience teaching biology, engaging with students in doing similar kinds of work, and my resulting biology PCK. Natalie's novice-ness, on the other hand, left her unprepared to deal with these logistics that, while difficult, did not seem insurmountable to me. Because Natalie did not have experience in taking responsibility to support students in doing projects like this, her assessment of the project and its difficulty rested on her belief that the content was both easy and easy to learn, I explored this possibility with Natalie as we reflected on the project in our second meeting.

> [The project] might have even been a little complex, not that it was, necessarily that it was biotech, and stuff that was hard, but it was just such a big thing, maybe that was difficult for you because of your novice-ness in teaching in general. Like figuring out how to manage... (Meeting 2)

Natalie agreed with my summation. "First month of school. First month of new teacher. Boom! To the jugular! Yeah. That got me…oh my gosh. That made me an insecure, wretched mess the whole year" (Meeting 2).

Notice that this initial difficulty of Natalie's disrupted her confidence not just initially but across the year. In contrast, because I saw this project as a process and I recognized important points for student difficulty, I also had a sense that the students and I would be able to complete the project successfully even if we struggled at the outset. I saw initial difficulties as guideposts for where to work, whereas Natalie coded those difficulties as personal failures. I experienced challenges similar to Natalie's, such as having to teach skills when they fit into the project rather than the project drawing on skills the students had already learned. In fact, we agreed that the timing of the project was a problem and that it would be better positioned later in the school year. However, I left the project with an overall positive feeling about the experience, and she labeled it her biggest flop. If I were given the chance to do the project or a similar one again, I probably would, because I thought it was such a valuable learning experience for the students. I doubt she would. My deep biology PCK mediated my lack of specific biotechnology PCK in reference to this project, and I was consequently better able to navigate the associated difficulties as I learned to teach the course.

In another example, my biology PCK enhanced my ability to identify and employ effective biotechnology teaching strategies. In the second research discussion with Natalie, I described what I thought was my best biotechnology lesson. A colleague had shared this lesson plan and materials with me and I had used them in my biotechnology class. In the lesson, students used paper folding to model different levels of molecular folding found in protein structure. My description and evaluation of the lesson to Natalie revealed the application of my PCK to a new content area.

> I love this because it was really visual, it showed a model of what was going on at the molecular level, and you know sometimes, sometimes you try and model things or show them hands-on, tactile kind of stuff, and it just doesn't really do a very good job. And I felt like this one really did. I think that [my students] really understood protein structure after that they did this activity. And I didn't create it, but after I read it, it was clear to me what I needed to do. It was clear to me what it would teach them and reinforce in them. It was just, it was like, pedagogically sound...Here's their purpose, here's what they need to learn from this, here's how they do it, here's the material I need...And I thought it was a valuable use of a class period...it had a clear purpose and I thought it helped them learn what they needed to do, what they needed to learn, and therefore was a good, a good lesson. (Meeting 2)

As an expert biology teacher, I was able to recognize a good learning activity when I saw one. By transferring my PCK to a new subject matter, I recognized important elements of the lesson—the purpose, methods, effective scientific modeling, and clear learning outcomes. It is important to note that my statements about the strength of an activity captured the tension between my knowing of the content, understanding of the pedagogical practice, and the value it would have for students. Just as importantly, I was able to enact an effective learning experience with my students by shifting my PCK from other contexts to teaching biotechnology.

In contrast, there were times my biotechnology PCK was simply inadequate, and my previous teaching experience did not prepare me sufficiently for teaching biotechnology. For example, I explored earlier my challenge with the laboratory activity involving SDS-PAGE. In conducting this lab, I was caught off guard by the technique I had only done once myself in a typical professional setting where it was presented as straightforward without much attention to the intellectual and pedagogical challenges of the lab. First, I was minimally familiar with the processes and equipment used in the method, and second, I was unable to anticipate the problems students would have. I described my confusion when students produced strange and unanticipated results.

> I don't know if their electrodes just were partly broken and not working, or if…I don't, I don't even know what happened there! I don't know enough about the apparatus to know what might have gone wrong. I don't even know. (Meeting 2)

I attempted this laboratory activity with my students, but I knew very little about the lab and felt confused and uncertain about the process and results. My limited knowledge of the equipment, procedure, and content made it almost impossible to support student learning.

Unlike the paper protein model activity, which did not require technical know-how, the SDS-PAGE lab required extensive knowledge in order to do the lab well with students. I was able to draw upon my biology PCK when new tasks involved general science skills. The paper folding protein-modeling lesson required a working knowledge of how to use scientific modeling to help students illustrate and understand science concepts. My PCK was sufficient to do this. I had extensive experience using scientific modeling in my biology classes and was able to transfer this knowledge to a new science concept in my biotechnology class. The SDS-PAGE lab, on the other hand, required a different, specialized set of knowledge—one I had not yet developed—that included how to perform the specific laboratory technique, the science concepts underpinning the technique, a new science literacy of how to read and interpret the scientific data, and how to anticipate and assist with student difficulties in any of these areas. I was unprepared for this. In the summer professional development, the presenters had the lab already set up and there was no opportunity to bring my expertise to bear on that process, both in terms of my knowing and in terms of what I knew about students' challenges with labs. Consequently, when implementing the lab in my own classroom, my PCK was insufficient, and the activity felt like a "flop." While my discussions with Natalie did not solve the problems I had with this laboratory activity, they allowed me to carefully analyze the activity and identify the specific areas in which I needed to learn more before attempting it again.

Features of pedagogical content knowledge. Analysis of my conversations with Natalie revealed various aspects of my emerging biotechnology PCK. Findings included my understanding of student prior knowledge and difficulties, pacing of the new curriculum, planning and organization of the biotechnology curriculum, and my understanding of the physical teaching space, equipment, and materials.

Student prior knowledge and difficulties. A feature of PCK that makes it distinct from other types of teacher knowledge is a teacher's understanding of students' prior knowledge, particularly, in this case, students' prerequisite knowledge for learning biotechnology (Shulman, 1986). As an experienced biology teacher, I anticipated that my biotechnology students would have varying amounts of background knowledge for the course. I described this expectation, as well as surprise, to Natalie in our first meeting. "And the students…come with prior knowledge, they come with some knowledge. It's actually, I learned, not as much as I thought it was going to be" (Meeting 1). I knew the students would be knowledgeable about some parts of my course, and lack knowledge in other areas, but overall I was surprised at how much the students had failed to retain from their prior science courses, such as biology and chemistry. Because of my novice-ness teaching this course, I had not yet developed my PCK about the prerequisite knowledge my students would likely bring with them.

One interesting thing about student prior knowledge was the different responses Natalie and I had to students' knowledge gaps. In addition to attributing an activity's failure to her own novice-ness, Natalie viewed a project as a "flop" in part because students lacked foundational understandings. I checked my understanding of her assertion by summarizing her description: "it was your biggest flop because it was, the kids didn't have the background knowledge that they needed" (Meeting 2). She agreed with my summation. By contrast, rather than identifying learning activities as failures because students were unprepared for the activity, I tended to attribute inadequate student learning to my teaching. For example, I identified the SDS-PAGE laboratory as a "flop" because I lacked the understanding to teach the techniques and underlying concepts effectively. When students had gaps in their knowledge, my PCK enhanced my ability to fill in those gaps as we moved through the curriculum. As an expert-turned-novice, I was more able to scaffold student learning and focus on remediation rather than simply determining that students were unable to do something and moving on.

This contrast was further evident in our discussion of evaluation of students' lab work during our second research conversation. Natalie had created a clear, concise scoring guide that she used to evaluate student lab reports written in their student research lab notebooks and expedite the scoring process. She described how she used the scoring guide.

> Natalie: If they miss something on the conclusion, I'll just circle "future research." [an element that the scoring guide indicated should be included in students' written conclusion] I don't even have to write anything. And it's like, 29 [the score].
>
> Lorien: And you're giving them really good feedback.

Natalie: And I tell them, I say, “It's not a redo. Next time I'd be more careful. Wrong. You should be already be being careful. Give me a new experiment.” (Meeting 2)

Natalie’s talk centered on using the tool to assign a grade. During our conversation, I emphasized the formative nature of the tool, pointing out how it could help the teacher give the students specific, immediate feedback about their writing. In this example, circling “future research” on the scoring guide indicated to students that they neglected to write about possible future research that could be done as an extension to the lab, a required part of their written conclusion. The difference in our focus revealed my beliefs about a teacher’s role as a teacher in student learning.

Understanding student prior knowledge involves another nuanced set of understandings. Teachers with strong PCK are able to anticipate the typical difficulties students will have when learning certain concepts and skills (Shulman, 1986). As an experienced biology teacher, I was familiar with many of the common mistakes students made in the course and designed my curriculum to intercept these problems, often even before they arose. I was unable, however, to employ such practices in my biotechnology class the first year I taught it. Because I had never taught the course, their difficulties with certain concepts often caught me off guard. I remarked to Natalie, “They had some major gaps that I didn't anticipate, especially in lab math” (Meeting 1). I was amazed, for example, that students had a difficult time identifying initial concentrations and volumes compared to final concentrations and volumes when calculating how to dilute a solution. I did not know this would be a common problem for students, and it took some exploring with the students to uncover and pinpoint the exact place they were getting confused. I also did not anticipate their difficulty in performing mathematical conversions and dimensional analysis. These are two mathematical processes that I assumed they would have learned in mathematics and would be able to easily apply in my class. I was wrong, and I was left scrambling to figure out how to teach these concepts.

Another instance in which I was unable to anticipate student difficulties, but then focused on ways to remediate their understanding was the first time I taught students a bacterial culturing technique called *streaking*. In this technique, a bacterial sample is spread on an agar plate (a petri dish with a layer of semi-solid, gelatinous material called agar, containing nutrients for bacterial growth) in a systematic way in order to spread the bacterial cells out until the cells sit individually on the agar. The inoculated agar plate is then incubated to grow colonies of bacteria from each isolated cell. As I talked with Natalie about my experience teaching this technique, we realized that both of our classes struggled to master the skill the first time they attempted it, despite the fact that we both thought we taught the skill well. I was surprised that they performed the skill as poorly as they did. My biotechnology PCK had not developed sufficiently for me to predict that this would be a difficult technique for students. When I realized they had not understood the technique and consequently failed in their execution, I explored other ways I could teach it better. I shared this with Natalie: “I know how I'm going to do this differently because I thought, I thought kids knew how to do streak plates [after my instruction]….It is, like, impossible for them” (Meeting 1). After my students’ initial failure, I found a virtual lab online that I used to reteach the skill. I told Natalie:

> When [my students] finally started getting [the streaking technique] was when they did the virtual lab because it… because they streak it… And then [the online simulation] incubates it and they can see if they got isolated colonies or not. It gives them feedback, which is awesome. (Meeting 1)

In this example, I used an online tool to re-teach a technique my students struggled with and found much better success the next time the students created streak plates. I pointed out to Natalie that the computer simulation gave the students immediate feedback to help them know if they had performed the procedure correctly. Through the experience, I learned that streaking was more difficult for my students than I originally thought it would be, discovered a way to effectively help students learn the technique, and was able to share this new knowledge with my critical friend during our collaboration.

I learned that other lab skills were also challenging for students. Because some biotechnology laboratory processes involve many steps, it was difficult to pinpoint places that students made errors. For instance, in the example shared previously, when students had limited success with PCR, I did not know the most likely places the students would make errors, so I tried to troubleshoot the process during my second research conversation with Natalie.

> Well…I still don't know what they were doing wrong. Because I would take their…extracted DNA and I did PCR. They broke down somewhere in the PCR process because I took, I think I took one of every one of them just to see okay, can I make PCR work with their stuff? And I got results for all of them except for one. I think none of them, except for one, got results on their own…And then the other thing I didn't know is, it could have been that they weren't loading their samples into their wells….So I had no way of knowing, did they screw up their PCR? Did they screw up the electrophoresis? I had no way of knowing. But I could do it. (Meeting 2)

I was unable to identify where students made mistakes, and because I had only emerging biotechnology PCK, did not know the typical places students may have made errors. My collaboration with Natalie allowed me to improve my future classroom instruction by analyzing laboratory activities such as this and uncovering possible mistakes the students may have made.

There were several other learning activities that Natalie and I shared through the course of our study of the teacher-led professional development that effectively taught biotechnology concepts and skills that were difficult for students. We discussed biotechnology content that was relevant in relationship to how and why the teaching methods were less effective. Complex labs seemed a common problem for students, both Natalie's and mine. Interesting, however, was the fact that the particular labs that proved difficult for each of us were different, and they were difficult for different reasons. Through our teacher-led professional development, we were able to support each other in uncovering the difficulties, develop deeper knowledge of the content and the processes we were teaching and the equipment we were using. We were able to increase our knowledge and improve our practice by sharing our successes and failures.

Pacing of curriculum. Pacing, or determining the appropriate amount of time needed for effective instruction and student learning, is related to understanding student characteristics, and is another element of a teacher's PCK. It was difficult, as a novice biotechnology teacher, to know how much class time would be needed to teach and learn concepts. I realized I had limited knowledge about the time students would need to complete most laboratory activities, and described this uncertainty to Natalie.

> And how long…oh! How long? How long is it going to take? …I was such a novice teacher in that respect…going, "I don't know!" And things that I'm like, "Yeah, I can do that in a period" would take two. (Meeting 1)

Initially, I thought that because they were advanced students, they would be faster and more efficient in the laboratory. However, I learned that as novices themselves, they were actually tremendously slow. In addition, since I was not usually aware where their difficulties might lie, I was also not able to anticipate and better prepare students to understand and engage in the learning processes needed. In one laboratory exercise, I tried to have the students do two procedures in one class period. There should have been time for the students to complete both procedures. Natalie and I discussed this surprising experience.

> Lorien: The first day they were supposed to extract their DNA and get it into PCR. They're so slow!
>
> Natalie: They're so slow!
>
> Lorien: They're so slow! And I thought that I was going to be able to get them through both of them this time. I thought I would…So I thought—and I had gone through parts of the lab the time before, and they had the protocol several days in advance—and I thought that would make a difference, but it didn't. (Meeting 2)

Just as I was unable to anticipate specific student difficulties with certain concepts and skills, I was ill prepared to predict the time required for students to perform certain laboratory skills and procedures. I was surprised concerning the amount of time it took students to do procedures that do not take much time when performed by those with some experience.

Planning. Planning was a theme woven throughout most of my conversations with my critical friend. Planning was necessary at several levels: day to day work, curricular pacing, organizing labs, ordering material, and being aware of the school context and schedule. Thus, planning permeated our talk about curriculum, calendaring, the materials we needed to budget for, when to order the materials, how to organize materials and resources, and our creation and sharing of curricular materials, as well as adjusting to the ebb and flow of unplanned interruptions that are always a part of school life.

As an expert-turned-novice, I knew the importance of developing organized, meaningful curricula that included a logical flow of concepts and ideas. I had developed curricula such as these through my experience as a biology teacher, and felt this was one of my strengths coming into this new course. The biology binder I showed to Natalie demonstrated my expertise in my biology teaching, and contrasted with my novice-ness as a biotechnology teacher.

> But the organization [of my biology binder] is really important to me so that I know where I'm going, where I've been, and that there's an organized flow to the class. And that was one of the things I struggled with last year. And I'm feeling that same struggle again this year, like, uhhh! Where do I want to start, and what makes the most sense? (Meeting 1)

When I began teaching the new course, I struggled as I worked to pull together content and learning activities, and find a flow of ideas that would best help students learn. The types of things with which I grappled as I made curriculum highlighted my expert-turned-novice nature. My novice-ness was revealed in the struggle, but my expertise was also revealed. I knew that I needed to find an organized flow to the curriculum to create continuity, and the importance of learning activities that required active student engagement. This aspect of curriculum building was difficult for me the first year I taught biotechnology, but as I gained experience teaching the course, and through my discussions with Natalie, I began to find a flow in this new curriculum.

As I worked with my new curriculum as an expert-turned-novice, I also grappled with the level of detail students needed to learn. Which topics were essential, and which were trivial details not necessary for students to know? I described this tension to Natalie. "I always have to adapt stuff…Well, and some of the stuff that I found that I was using, it went into way too much detail...And why is it important? Honestly, why is that important for them to memorize that?"

(Meeting 1). While my novice-ness as a biotechnology teacher, including my emerging biotechnology content knowledge, made it difficult to determine the appropriate level of detail for the course, as an experienced biology teacher, I knew it was critical to have this clearly defined in order to have effective classroom instruction. Natalie and I discussed specific topics in our curriculum that we needed to clarify. For example, through our discussions about chemical functional groups and molality, we decided it was unnecessary to teach these topics. In thinking about whether these were critical content pieces, I considered what a person working in a lab would need to know. "They don't need, if they were working in a biotech lab, they wouldn't need to…" Natalie agreed, "They wouldn't need to know [functional groups]. They literally would never need to know that" (Meeting 1). Natalie also looked to the state end-of-level test for guidance about level of detail students should learn. Through our collaboration, we were able to increase our understanding about the level of content detail our curriculum should include.

Organizing resources, lab materials, and curriculum materials took considerable planning as I began my journey teaching biotechnology. As an experienced biology teacher, organization was important to me. In a memo I made as I read the manuscript from Meeting 1, I remarked,

> I find myself talking and thinking a lot about organization and control. I like to feel in control of my class, knowing where I am going with the course, and being able to communicate organization and structure to my students. (Meeting 1 Memo)

When I stated that I "like to feel in control of my class," I was expressing my need for a sense of order, both in the physical space of my classroom and in the instructional design of the course. Through my lived experience as a biology teacher, I had found that as I made conscious efforts to organize my space, materials, and instruction, I became a better teacher. Now, as an expert-turned-novice, I was attempting to enact these principles in my new course.

As an experienced teacher who knew the positive effect of organization in my own practice, I yearned for organization in my new course, but had to create it out of what felt like chaos. In our second meeting, I reviewed a student binder I had begun creating for biotechnology. This binder included sections for guided note outlines, readings, assignments, and laboratory activities and protocol, and served as my principal text for the course. As I shared the binder with Natalie, I focused on its organization. I sought to improve my students' understanding by removing issues of assignment management. In this specific instance I focused on a system to label laboratory activities in order to make my expectations clear.

> Well, and what I'm hoping this does, labeling these *Lab 1*, *Lab 2*, *Lab 3*, kind of thing, I'm hoping that will solve the [students'] problem of, "do I put this in my lab notebook?" Because I have them combining things or separating things out into different, you know…And so I'm hoping that I can, it's like, "*Lab 4*. Yes, you're going to write this one up in your notebook," or, "No, you're just turning a worksheet on this one." (Meeting 2)

One of my goals in creating organized student materials was to remove barriers to student learning caused by confusion about accessing the information necessary for the course. Through my initial experience teaching biotechnology, I had learned about problems students experienced regarding expectations for certain assignments, and I worked during my collaboration with Natalie to solve those problems.

Calendaring. Calendaring was another challenging feature of curriculum making for this new course. As a novice, it was difficult to schedule time-sensitive labs and activities within the context of the school calendar. The nature of many biotechnology laboratory activities involved time-sensitive procedures. For example, some procedures required growing microorganisms for a certain number of hours prior to student use. This required calculating when to start microorganism cultures, and occasionally required me to come in on weekends to start a culture. The school calendar, coupled with weekends, holidays, and other calendar-adjusting events made scheduling such laboratory activities difficult. My frustration surfaced as I discussed the problem with Natalie. "That was a huge thing don't you think? …Oh! It's a long weekend! Crap. Can't start that lab so I gotta be doing something else" (Meeting 1). The difficulty this unveiled interacted with my novice-ness in terms of my knowledge of biotechnology, because if I was going to do something else because of a long weekend, I needed to make strategic decisions that what I did could be slightly out of order but would still support student learning.

As novices teaching biotechnology, we both experienced setbacks and surprises as we navigated scheduling. I was particularly frustrated because I knew from my biology teaching experience the negative impact on student learning of adjusting the sequence of activities simply to fit them into the school calendar. Because of my limited experience with this course, I was unable to draw on my practical knowledge to plan adequately for such calendaring issues. Through our collaboration, Natalie and I began to work through some of these problems. In our first meeting, we focused on a calendar that Natalie had created. As we discussed her calendar, we noted the timing of laboratory activities in relation to the school calendar, simultaneously attending to the sequential flow of the content. I could draw on Natalie's greater content knowledge expertise in sorting this out and determining where to adjust and how. Natalie was able to draw on my knowing of the reality of the impact of the school calendar in disrupting or supporting student learning. As a result of our conversation, we both had a better idea of how to arrange the curriculum within the school calendar to achieve better continuity.

Struggling with calendaring was not new to me. Throughout my teaching career, anticipating the amount of time my students and I needed for instruction and learning activities for a given topic was challenging. I needed to rely on an expert understanding of students' prior knowledge and difficulties, as well a rich understanding of the subject matter to determine which ideas would need more time for students to explore them appropriately. In other words, which parts of the curriculum needed emphasizing and for what purpose? I found these decisions particularly difficult as I attempted to calendar this new course. In a memo I wrote while reading the transcript from our first research conversation, I reflected on this problem.

> Calendaring a full year is tricky to me. I always struggle with staying to a schedule, even in biology—especially when I am trying to tailor my instruction to the needs of the students. I have this tension of keeping to a calendar and pushing students, and giving adequate time for learning. When are kids being lazy, and when do they genuinely need more time to learn something or complete the work I give them? I still struggle with this tension in biology, a course I've taught for 10 years now. (Meeting 1 Memo)

I revisited this tension in my second meeting with Natalie when I shared a three-day laboratory activity that another biotechnology teacher had given me. I commented, "Yeah, I'm not sure if, well, I just don't know if I have time to get that in" (Meeting 2). I was considering using the activity because it would be effective in preparing students for the culminating, laboratory assessment Natalie and I were both going to administer. After our meeting, and as the year progressed, I adjusted my calendar to include the three-day laboratory activity. Natalie did not. I made the decision because I determined it was worth it instructionally. The project prepared students for their final laboratory assessment, walking them through the processes they would need to perform. It was a decision driven by my instructional design and the things I understood about high school students' learning of science, and not by considerations of time alone. I adjusted my calendar, at the expense of losing time elsewhere, in order to include a learning experience I thought would be more valuable to my students than the other activities I had to cut out. My decision was based largely on what my expert knowledge suggested would be best to prepare my students for their final laboratory assessment.

Physical teaching space and materials. The biotechnology course required expensive laboratory materials and equipment. Planning which items and how much I should order took much thought and effort. I described my frustrations with ordering, and my subsequent concern about potentially wasting some expensive materials. "I've got the stuff…and I think I wasted about 70 or 80 bucks in those…um…the gels" (Meeting 1). I spent time and money ordering materials I never used the first year of teaching the course, and I worried that they might expire before I was able to use them. I thought I would use the materials, but due to my inexperience in teaching the course, I did not realize I would run out of time and be unable to do the laboratory activity. This had an impact on my optimal use of the materials I ordered, and I was frustrated that my planning in this instance was neither efficient nor effective.

In addition to planning what to order, timing the orders was something I learned as a novice biotechnology teacher. Sometimes the ordering process went smoothly, and sometimes it did not. I learned through experience that ordering delays might be due to the company from which I ordered, or the bureaucratic process I had to work through within the school system. This was a challenge both Natalie and I identified.

> Lorien: I had ordering problems. I learned, I learned that when I order, when I have the district order it, it takes about a full week just to get the PO [purchase order]…
>
> Natalie: Because when I remember it, I needed to order it yesterday.
>
> Lorien: Yeah. I'm in the scramble already. And it took that long to get the PO…and so she gave me the purchase order, so I just got on the phone right then and ordered it. And then the lady was like, "Okay this ships second day, so this will be here blah, blah, blah." It came, I was like, woo hoo! It came on a Friday. I was, like, "Great! I'm set to go Monday." Threw it in the freezer. And Sunday night, I was sitting there, and I went, "Wait a minute. That wasn't everything. There were supposed to be some other things that came in the kit." (Meeting 2)

I was dismayed by delays getting the purchase order from the school district, and more delays when I realized the order was shipped in different packages. I eventually postponed the laboratory activity for several days, teaching other topics while I waited for the entire shipment to come. This disrupted the flow of the content as I had planned it and thus potentially impacted the learning of my students. I felt discouraged about my planning, and my students were disappointed by the delay. My difficulties with planning were not always so extreme, but in this case, I expanded my PPK in a dramatic way.

Regaining Identity as Expert

A theme that emerged from my conversations with Natalie was the development of my identity as a biotechnology teacher. This growth was evident in the leadership roles I took up as well as my sense of self as a teacher learner.

As an experienced biology teacher before I began my journey as an expert-turned-novice, I filled many leadership roles in the local and state science education community. However, as I began this journey, taking up my new teaching assignment, I did not initially identify myself as a leader among biotechnology teachers. My identity as a non-leader was revealed in my hesitance when, during my second year of teaching biotechnology, I was asked to present to a group of biotechnology teachers in the state. I was anxious about the prospect. I told Natalie,

> I don't know what I'm going to do. I got a list of the health science people who are going, and only [one person] from our [summer collaboration] group is going. And I'm looking at everybody else—like all the health science teachers—and I don't know who the biotech teachers are outside of [our area]…Am I going to have biotech people? Or am I going to have just any ol' people [attending my presentation]? (Meeting 2)

As expert-turned-novice, I was not only nervous and unsure about what to teach or how to teach it to other teachers, but also felt disconnected from others in the biotechnology teaching community in the state. I had not yet built an extensive network among biotechnology teachers, and this heightened my insecurity.

Despite my limited connection with other biotechnology teachers, however, I was able to connect with a few people. My PPK as a biology teacher reminded me of the importance of connecting with other professionals, and I was beginning to network with a few of them. I had emailed several biotechnology teachers for ideas to take with me to the conference, and two teachers responded with help. I told Natalie,

> Sean sent me some stuff that I'm excited to look through, and Jared—oh my gosh—he uses pGLO [a bacterial plasmid] and does a plasmid miniprep and then does a digest on the plasmid and runs that and has them do, kind of walks them through the process that they'll do in the plasmid project. Isn't that smart? And he sent me stuff. (Meeting 2)

I was excited about my interaction with these experienced biotechnology teachers, and that they cared enough to help me by sending ideas and resources. I doubt had I been a first- or second-year teacher that I would have reached out to as many other professionals. Even though my connection with the community of biotechnology teachers was limited, I was beginning to build a valuable network. After eighteen months of teaching biotechnology, I had begun to move into a leadership role in the local biotechnology education community. In this new role, I relied heavily on the expertise of other biotechnology educators, largely because I still viewed myself as novice to biotechnology subject matter. My identity, however, was gradually shifting to one of a confident, capable teacher leader in this new teaching assignment.

Throughout my journey learning to be a biotechnology teacher, I observed a shift in several aspects of my teacher identity. However, my role as a teacher learner remained constant. In fact, both Natalie and I viewed ourselves as teacher learners throughout our collaboration. We both believed we were capable of developing knowledge and skills in a new area, and that we were capable of determining what we needed to learn, and how we might go about learning it. She described this belief about herself as she shared her college microbiology notebook with me: “I think that this artifact [her college notebook] also shows that I have potential to convey that knowledge” (Meeting 1).

Like Natalie, I expressed a need and desire to learn more before I performed a laboratory exercise with my students the next year: “I'm going to have to study up on that before I try this one again” (Meeting 2). As teacher learners, we both recognized the need to continually learn and re-learn content and skills, and viewed ourselves as capable of doing so.

My conversations with Natalie played an important role as I journeyed from expert to novice, and then worked to return to expert. The questions and advice I asked as expert-turned-novice were detailed, deep, and probing, and revealed my PPK. For example, I asked questions about calendaring and timing, such as "How many days are you doing [the plasmid identification practical final exam]?" (Meeting 1). I asked for details about curricular materials she had created, such as her scoring rubric, a titration laboratory activity, and a relay race that served as a scientific model of an important cellular process. I asked about her experience with certain laboratory techniques, including a bacterial staining method. I probed to learn about the effectiveness of her practice activity using honey to teach bacterial streaking, and then followed up by asking details about the technique. We discussed the depth of content needed for the course, and questioned why students needed to learn certain things. I asked how she managed her physical teaching spaces, including equipment and material setup, storage, and student access to materials.

Through my collaboration with Natalie and through the course of eighteen months teaching biotechnology, I gradually returned to a place of confidence. While my identity as a competent teacher was unsettled at the outset of teaching biotechnology, my expertise and experience in teaching biology supported my understanding that I had the ability to become a competent biotechnology teacher. By the time Natalie and I had our second research conversation in the middle of my second year teaching biotechnology, I shared the beginnings of a biotechnology student binder I had created.

> Lorien: Oh my gosh. I'm going to have to show you what's been developing as I've been building this year. I'm feeling really good about it…I'm going to be so stoked for next year. It's going to be so good…Look how pretty…
>
> Natalie: Oh my gosh. It's beautiful.
>
> Lorien: So pretty. Look-it. Look at what it is. Oh this isn't done yet…pictures,

Natalie: Oh my gosh. I can't believe you did this. I mean, I can believe you did this, cause this is how you roll.

Lorien: Yeah. This is how I roll. But it takes so long to make it…Then, look at, I'm just so proud of it…I'm just super happy with it. (Meeting 2)

Within eighteen months of teaching the course, I had the beginnings of organized curricula to use with my biotechnology students. Instead of feeling overwhelmed and uncertain, I was excited and proud of my work. My journey was steadily bringing me back to a place of security in my teaching.

The questions I asked and the rich learning that occurred through the course of our self-initiated, teacher-led professional development revealed my identity as an expert teacher. As an expert, I attended to my SMK, the curriculum, pacing, and assessment of student learning. I focused on using pedagogically sound methods, and explored the important interaction between the physical environment of the classroom and laboratory and teaching and learning. My probing questions and attention to the many detailed aspects of my teaching were evidence of my expertise. These are things expert teachers think about, and I was addressing them in our professional development in an effort to deepen my PPK in the new context of teaching biotechnology. My awareness of the nature of my novice-ness and desire to return to a place of expertise revealed my identity as an expert teacher. I experienced disequilibrium when I began the journey, and yearned to return to the place I was comfortable—that place of expertise. Our self-initiated, teacher-led professional development helped me return to that place of expertise.

Chapter 5: Discussion

The purpose of this self-study of practice was to examine the learning and development that occurred in the context of a change in my teaching assignment within a self-initiated, teacher-led professional development. Three themes emerged from my analysis of the data. In exploring these themes, in my findings section I revealed my learning in each phase of my journey in this process: confidence as a biology teacher, unsettled expertise as I took up teaching and interaction in a teacher-led professional development, and a return to confidence. The first theme was the shift I observed in aspects of my identity as a teacher. The second was the mediating effect of my expert biology teacher knowledge in my developing biotechnology teacher knowledge. The third was the learning that developed within the context of our professional development.

Identity Shift

My experience illustrated the socially constructed, multi-voiced, and fluid nature of my identity (Pinnegar & Hamilton, 2015). In fact, I called forward many different selves as I travelled my journey and shared my experiences with Natalie (Bullough, 2005), and my identity shifted as I enacted new curriculum. As I took up teaching biotechnology, for example, I considered myself a novice biotechnology teacher. However, my study revealed features of my PPK were those of an expert that I brought to bear in this new teaching context. Before the carful analysis of my data, I was unaware that I exhibited many of the features of an expert teacher, even as I enacted my new role as a biotechnology teacher. Indeed, as Sanders, et al. (1993) suggested, I was a novice in some ways in this new context, particularly in relationship to technical aspects of biotechnology. My challenges with PCR, SDS-PAGE, and lab equipment demonstrated this. I was also novice in my understanding of the biotechnology curriculum and how the content might best be arranged. I was not novice, however, in my approach to addressing these issues. My expertise was revealed as I sought the optimal way to organize the content and the lab experiences. As I attended to details and connections in the curriculum, I increased my SMK, as shown by my conversation with Natalie about the chemical processes involved during a DNA extraction. I was highly focused on determining which concepts were foundational for students to develop their knowledge of biotechnology. My approach to organizing the curriculum by physically arranging strips of paper on my door to make visible continuity in the topics I needed to teach my students is evidence of an expert teacher's thinking and processes. My focus on giving feedback to students through instructional tools such as scoring guides, rather than simply using them to assign a grade, shows expertise in my PCK. Through this analysis I recognized that, contrary to what I thought at the outset of my journey, I never really abandoned my expert identity as a science educator. It was always there, underpinning my work, but I did not recognize it as I focused on what I needed to improve in my SMK and PCK targeted specifically to teaching biotechnology. My concern about my knowledge of biotechnology and understanding my students' challenges itself, rather than novice-ness, was actually evidence of my expertise. I was unsettled and worried about gaps in my knowledge and practice that my expert self knew were problematic. In short, as an expert, I knew that I did not know.

However, consistent with the research of Sanders, et al. (1993), my identity did shift to that of a novice in some ways. Because of the disequilibrium I experienced as I took up the new course, I recognized the aspects of this experience that were similar to feelings I had as a beginning teacher. I was unsettled and I yearned to return to being an expert in the new context. My novice identity was most apparent in my biotechnology SMK, and my findings show I sought to solidify my SMK, especially my science knowledge for teaching (Nixon, 2015). This finding is congruent with the work of van Driel et al. (1998) who asserted that SMK is foundational and required for PCK development. In such instances, I was particularly anxious and frustrated, in part because I knew what it was like to be expert, and was trying to get back to that place again, but was limited by my knowledge and experience.

However, despite my novice nature in certain contexts, I never abandoned my identity as an expert science teacher and more generally, a teacher leader. For example, I continued to think about student learning, even in my new assignment, as an expert does by focusing on improving her own knowledge and making her instruction comprehensible in order to improve student learning. I was guided in these efforts by the PCK that emerged from my previous science teaching. I also quickly took up the role of a leader, even though I acknowledged my inadequate biotechnology teacher knowledge. I used strategies I had success with, both in this collaboration and in my past experience, drawing on the strengths of others. These examples illustrated that I was never a true novice during this journey. My expert identity underpinned my teaching and learning, and facilitated the shift in my identity as a novice biotechnology teacher toward expert again.

Narratives can reveal our identity development as we conceptualize and reconceptualize ourselves throughout the narrative as we visit and revisit experiences (Pinnegar & Hamilton, 2015). When I began my journey, I believed myself to be one thing—a novice biotechnology teacher; but upon analysis of my telling of my experiences, and as I wove the stories together into a narrative, I discovered that I was actually something else throughout the narrative—an expert teacher. In presenting the narrative, I created narrative coherence by linking my past identities with my current self (MacIntyre, 2001). Telling the story allowed me to call forward my past selves and create a coherent picture of my identity over time and through different experiences.

Mediating Effects of Expert Teacher Knowledge

As I developed my PPK in my new role as a biotechnology teacher, my GPK and biology PCK mediated certain features of my novice-ness. Sanders et al. (1993) maintained that GPK can serve as a framework upon which to build new knowledge about teaching in a new context, and my findings reflect this. I was able to employ my knowledge about how to teach in my new teaching context. However, GPK alone was not enough. I needed sophisticated, domain-specific science teacher knowledge (Munby et al., 2001) required to teach biotechnology. The preactive tasks that Reynolds (1992) identified, or the tasks involved in planning instruction tailored to the needs of students, such as my ability to chunk curricular information in meaningful ways, were often difficult for me in the domain of biotechnology, and I behaved much as a true novice because of my shallow biotechnology SMK and lack of experience teaching the course. On the other hand, in interactive tasks, or those involving interactions with students and content, and postactive tasks, my reflections upon teaching activities and student responses (Reynolds, 1992), I was better able to employ my expert GPK, attending to and then reflecting upon important details happening in the classroom. However, in some aspects of interactive tasks, specifically tasks involving biotechnology SMK and PCK, such as interpreting and explaining technical information, and managing my physical laboratory space, the tasks were difficult, but I attended carefully to those because I knew I needed to resolve those difficulties. In these areas, my abilities were more like that of a novice, but my attention to the problems was due to my expertise.

I was able to transfer my biology PCK to my new teaching context when teaching tasks were somewhat general, and related to biology. For example, managing and directing biotechnology students in an extensive scientific experiment and subsequent presentation at a conference was not as overwhelming to me as it was to a true novice because practices such as these are within the domain of general science PCK. However, I was only able to employ my biology PCK to a point. It only mediated my novice-ness when my biotechnology SMK was sufficient. This relates to van Driel et al.'s (1998) finding that subject matter is prerequisite for developing PCK. It is also consistent with Abell (2007) and van Driel et al.'s (2014) assertion that there is a positive relationship between SMK and science teaching. When operating in specific, content-rich domains that required technical knowledge of laboratory processes and their underlying concepts, knowledge that Munby et al. (2001) described as important for effective science teaching, I had little or none of this knowledge, and I was unable to employ my more general, biology PCK. In such instances I felt like a true novice—overwhelmed, helpless, and frustrated.

My expert biology PCK was often insufficient to predict biotechnology student characteristics such as their prior knowledge and typical difficulties. I had no way of knowing what parts of my new curriculum students would find easy or challenging. This is consistent with Shulman's (1986) conceptualization of PCK. Because PCK is experiential, developing within specific teaching contexts (Lee & Luft, 2008), and I had not yet experienced this new context, I had not yet developed knowledge about students, especially the typical difficulties they would have with technical procedures and certain biotechnology science content. My biology PCK did not mediate well in these contexts. Finding a logical flow of concepts in the curriculum, calendaring the curriculum, and working within the physical space of my laboratory were also difficult at first, revealing my novice-ness. But recognizing that these were important in my teaching, and working to resolve these problems revealed expert features of my PPK.

Self-initiated, Teacher-led Professional Development as a Viable Model

My PPK developed in important and meaningful ways in our self-initiated, teacher-led professional development. I willingly and enthusiastically deepened my SMK, analyzed my pedagogy, and focused on improving specific areas of my PCK. I shared new ideas, and explored my successes and failures as a teacher as I worked with Natalie over the course of eighteen months. Our model included the five components of the core conceptual framework for effective professional development programs that Desimone (2009) proposed. It (a) focused on learning biotechnology content and how to teach that content, (b) required our active involvement in the professional development, (c) aligned our learning with the school, district, and state goals as we worked with our state biotechnology core curriculum, (d) provided sufficient duration of the professional development as we collaborated for over eighteen months, and (e) required our constant interaction. Our professional development was also consistent with Loughran's (2007) assertion that teacher learning needs to occur in authentic, social, and collaborative situations.

My growth and development as a teacher was facilitated by my collaboration with Natalie. The professional development that my critical friend and I initiated, conducted on our own time, in which we determined what we wanted to learn and create, and then found ways to do so, honored my PPK. In this way, our teacher-led professional development was influenced by personal drivers (Bullough & Smith, 2016), rather than by externally or mandated programs. Because this model of professional development honored my experience, knowledge, and professionalism as a teacher, and because I had ownership of my learning and development, I employed the practices I learned in the professional development. Through this professional development I learned more, had more buy-in, and learned things that were more applicable to my practice, than in other traditional, top-down, one-size-fits-all programs I have experienced during my career. The problems of "fragmented, intellectually superficial" professional development that does not "take into account what we know about how teachers learn" (Borko, 2004, p. 3) were not present in our professional development. Consistent with the assertions of Bullough and Smith (2016), and Hargreaves (2013) regarding the effect of different forms of professional development, my attitude toward work that honored my experience as a teacher was more positive than my attitude toward mandated in-service, and my resulting active involvement in the professional development, as well as the implementation of the things learned in the professional development, was much better. It led to the kinds of changes Penuel (2007) argued arise from successful professional development.

From my perspective, our professional development may not have been as fruitful, nor our learning as rich, if we had both been true novices. Our collaboration required sharing our expertise. As an expert, there were things I knew about teaching, anchored in my years of experience teaching biology, that she did not and could not know. Likewise, she knew things about chemistry and lab work from her extensive and recent schooling that I did not. In fact, during our negotiation of the findings, Natalie emphasized the importance of her strong chemistry SMK and acknowledged that her challenges were primarily linked to being a first-year teacher. These differences in expertise were important, so that both of us brought something to the collaboration as we worked on common problems within our practice.

Natalie and I shared the experience of teaching biotechnology for the first time. We both wanted to improve our practice, but we brought different expertise, experience, and background in order to push our development. In teacher-led professional development, differences in expertise, focus, skills, and knowledge are essential if learning is to occur in such settings.

The purpose of this study was to uncover and describe one teacher's experience in a very specific context. While the study is not generalizable, the themes I found as I studied this phenomenon may help others understand and respond to experiences similar to mine. Putnam (2004) argued for the importance of careful studies of the particular to move our understandings and actions in education forward.

The study was analyzed through my own lens. The intent was to describe and then carefully and methodically analyze my experience as I saw it. Other lenses or theoretical frames could be used to evaluate my research conversations with my critical friend, and other findings would likely emerge. In fact, Natalie, the audience with whom I shared my experiences, helped shape the data. My stories would likely have been different had I shared them with someone else, or if Natalie's experiences had been different. However, my narrative is still a true story, "belonging to a single, whole, embodied, life—stories that speak of identity not merely of one's passing personae" (Bullough, 2005, p. 241).

During this study, I shared memories of things that happened in the past, and it was therefore impossible to capture all of my thinking as the stories unfolded. I viewed my experience through my lens after the process of my shifting identity and experience had passed. While the discussions were retrospective and not in the moment as they occurred, looking back enabled me to look at the shifts in my learning across time from the enlightened perspective of experience.

Implications

The question that this self-study was designed to answer was "What does an examination of the learning that emerges from a change in teaching assignment, coupled with collaborative, teacher-led professional development, reveal about a high school science teacher's development as a teacher?" At the outset of this self-initiated, teacher-led professional development I was unsettled by my new teaching assignment, but as I worked with Natalie, I was able to begin my return to expert in my biotechnology teacher knowledge and take up leadership positions among my growing network of biotechnology educators. My professional development experience gave me much needed support as I learned to teach biotechnology and shifted from expert-turned-novice toward expert once again.

Professional development should support teachers as they develop their teacher knowledge, particularly their specific SMK and PCK. Borko (2004) emphasized the importance of professional development "that includes an explicit focus on subject matter" (p. 5) and helps teachers increase their SMK through active involvement. Although experienced teachers such as myself have experiential tools to draw upon, such as expert PCK, there are limitations to how well that knowledge can transfer if there is insufficient SMK. PCK is domain specific, so if a teacher is to develop their PCK, it must be through work within that domain. Consequently, one-size-fits-all treatment of teachers is not a productive or effective model of professional development.

Teachers need support for learning and growth when teaching contexts change, even if they are already expert teachers. Because new teaching contexts, such as new teaching assignments, throw teachers into novice roles, even experienced teachers have the potential to feel overwhelmed and discouraged. An expert teacher such as myself yearns to leave the place of novice and return to expert when unsettled by such contexts. Effective professional development has the potential to help teachers—expert and novice alike—become more secure in their teaching. These should include features that have been found by researchers to increase professional development effectiveness such as a content focus, and active, collaborative learning (Desimone, 2009; Loughran, 2007; Penuel et al, 2007). Also of importance to this study of a science teacher, the professional development should be adjusted to individual teacher's school contexts, and include support for teachers using specialized equipment (Penuel et al., 2007). Finally, personally driven learning that responds to teachers' individual needs by allowing them to determine what they need to learn and how they want to learn it, and that honors teachers' experiences has the potential to create effective professional development (Bullough & Smith, 2016; Hargreaves, 2013). Schools, districts, boards of education, and other administrative and policy-making bodies should support professional development with such features.

Because learning is situated within specific contexts, teachers need to learn within their own specific teaching context. In my case, that was within the context of teaching biotechnology. Even professional development with a focus on general science teaching would not have helped me. I needed very targeted support. Only I could determine what that support needed to be. My school administration, district, or state administrators or policy makers could not know what I needed in my individual classroom in my specific circumstances. I needed a structure that allowed me to learn what I deemed necessary for me to improve in specific ways in my teaching. I also needed a structure that allowed collaboration with a teacher teaching in a similar context. Other teachers at my school, including science teachers, were not in a position to work alongside me and learn biotechnology teaching. I needed another teacher in a similar situation (a biotechnology novice) with whom I could learn at a similar pace. It was important that we were able to co-construct knowledge, drawing on our shared expertise, and a mentor-mentee relationship would not have been as helpful because of the perceived difference of authority (see Bullough & Smith, 2016). This study reveals the need for more self-study of teaching practice. It answered Borko's (2004) call for more research to study effective professional development and increase understanding about teacher learning by studying teacher learning in a self-initiated, teacher-led professional development, but more work needs to be done. This study demonstrated the value of doing retrospective self-studies of learning from our practice. The conversations with Natalie and the analysis of those conversations helped me make explicit learning about the development of teacher knowledge and learning in teacher-led professional development. The self-study of my experience allowed me to make available to the research community the ways in which I as a teacher learned within a teacher-led professional development. It also made clear the need for differing levels of expertise in such studies.

While this is a study of one individual, it shows that teachers can initiate and lead their own collaborative professional development centered on real problems emerging in their practice. As the one who holds personal practical knowledge, the teacher is best positioned to discover what needs to be learned and determine how to go about learning it in a way best suited for the individual. This study shows that a teacher experiencing a change in teaching assignment who encountered a shift to novice was able to design professional development that facilitated her learning in this new context. More studies of this kind designed to study self-initiated, teacher-led professional development have the potential to determine effective ways to structure professional development, and how teacher learning and development proceeds in such circumstances.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105-1149). Mahwah, NJ: Lawrence Erlbaum.

American Association for the Advancement of Science. (1990). *Science for all Americans*. New York, NY: Oxford University Press.

Avalos, B. (2011). Teacher professional development in *Teaching and Teacher Education* over ten years. *Teaching and Teacher Education, 27*(1), 10-20. doi:10.1016/j.tate.2010.08.007

Berry, A., & Y Loughran, J. (2002). Developing an understanding of learning to teach in teacher education. In J. Loughran & T. Russell (Eds.), *Improving Teacher Education Practices Through Self-study,* (pp. 13-29). New York, NY: RoutledgeFalmer.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 38*(8), 3-15.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1) 32-42.

Bullough, R. V. (2005). The quest for identity in teaching and teacher education. In G. Hoban (Ed.), *The Missing Links in Teacher Education Design: Developing a Multi-linked Conceptual Framework* (pp. 237-258). Dordrecht, NE: Springer. doi:10.1007/1-4020-3346-X

Bullough, R. V., & Smith, L. K. (2016). Being a student of teaching: Practitioner research and study groups. In J.J. Loughran & M.L. Hamilton (Eds.), *International Handbook of Research on Teacher Education* (Vol. 2) (pp. 305-351). Dordrecht, NE: Springer.

Clandinin, D. J. (1985). Personal practical knowledge: A study of teachers' classroom images. *Curriculum Inquiry, 15*, 361-385.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*, 181-199. doi:10.3102/0013189X08331140

Fessler, R., & Christensen, J. C. (1992). *The teacher career cycle: Understanding and guiding the professional development of teachers*. Needham Heights, MA: Allyn and Bacon.

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social Problems, 12*, 436-445.

Gonzalez, H. B., & Kuenzi, J. J. (2012). *Science, technology, engineering, and mathematics (STEM) education: A primer*. Retrieved from https://fas.org/sgp/crs/misc/R42642.pdf

Hammerness, K., Darling-Hammond, L., Bransford, J., Berliner, D. Cochran-Smith, M., McDonald, M., & Zeichner, K. (2005). How teachers learn and develop. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing teachers for a changing world* (pp. 358-389). San Francisco, CA: Jossey-Bass.

Hargreaves, E. (2013). Assessment for learning and teacher learning communities: UK teachers' experiences. *Teaching Education, 24*, 327-344. doi:10.1080/10476210.2012.713931

Henze, I. (2006). *Science teachers' knowledge development in the context of educational innovation* (Unpublished doctoral dissertation). Universiteit Leiden, Leiden, The Netherlands.

Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe.

International Journal of Science Education, 30, 1321-1342. doi:10.1080/09500690802187017

LaBoskey, V. K. (2004). The methodology of self-study and its theoretical underpinnings. In J. J. Loughran, M. L. Hamilton, V. K. LaBoskey, & T. Russell (Eds.), *International handbook of self-study of teacher education practices* (pp. 817-869). Dordrecht: Kluwer Academic Publishers.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*, 1343-1363.

Loughran, J. J. (2007). Science teacher as learner. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1043-1065). Mahwah, NJ: Lawrence Erlbaum.

Lortie, D. (1975). *Schoolteacher: A Sociological Study.* London, UK: University of Chicago Press.

Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 889-909). New York, NY: Routledge.

MacIntyre, A. (2001). The virtues, the unity of a human life, and the concept of a tradition. In L.P. Hinchman & S. K. Hinchman (Eds.), *Memory, identity, community: The idea of narrative in the human sciences* (pp. 241-263). Albany, NY: SUNY Press.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G.

Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Dordrecht, The Netherlands: Kluwer. doi:10.1007/0-306-47217-1_4

Maxwell, J. A., & Miller, B. A. (2008). Categorizing and connecting strategies in qualitative data analysis. In P. Leavy & S. Hesse-Biber (Eds.), *Handbook of emergent methods* (pp. 461-477). New York, NY: Guilford Press.

Munby, H., Russell, T., & Martin, A. K. (2001). Teachers' knowledge and how it develops. In V. Richardson (Ed.), *Handbook of research on teaching* (pp. 877-904). Washington, DC: American Educational Research Association.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Nature Publishing Group. (2015). *Nature.com subject areas*. Retrieved from http://www.nature.com/subjects/biotechnology

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Nixon, R. S. (2015). *Knowing science like a teacher: An exploration of the content knowledge of new science teachers.* (Unpublished doctoral dissertation). University of Georgia, Athens, GA.

Nixon, R. S., Campbell, B. K., & Luft, J. A. (in press). Effects of subject-area degree and classroom experience on new chemistry teachers' subject matter knowledge. *International Journal of Science Education.* doi:10.1080/09500693.2016.1204482

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal, 44*, 921-958. doi:10.3102/0002831207308221

Pinnegar, S. E., & Hamilton, M. L. (2009). *Self-study as a genre of qualitative research: Theory, methodology, and practice.* New York, NY: Springer.

Pinnegar, S. E., & Hamilton, M. L. (2015). *Knowing, becoming, doing as teacher educators: Identity, intimate scholarship, inquiry* (Vol. 26). Bingley, UK: Emerald.

Putnam, H. (2004). *Ethics without ontology.* Cambridge, MA: Harvard University Press.

Reynolds, A. (1992). What is competent beginning teaching? A review of the literature. *Review of Educational Research, 62*(1), 1-35.

Reynolds, A. (1995). The knowledge base for beginning teachers: Education professionals' expectations versus research findings on learning to teach. *The Elementary School Journal, 95*, 199-221.

Russell, T., & Martin, A. K. (2007). Learning to teach science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1151-1178). Mahwah, NJ: Lawrence Erlbaum.

Russell, T., & Martin, A. K. (2014). Learning to teach science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 871-888). New York, NY: Routledge.

Ryan, K., & Kokol, M. (1988). The aging teacher: A developmental perspective. *Peabody Journal of Education, 65*(3), 59-73.

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 30*, 723-736.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Utah State Office of Education. (2009). *Biotechnology standards and objectives*. Retrieved from http://www.schools.utah.gov/CTE/hs/Course-Information.aspx

Utah State Office of Education. (2014). *Data reports—Enrollment and demographics*. Retrieved from http://www.schools.utah.gov/data/Reports/Enrollment-Demographics.aspx

van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*, 137-158. doi:10.1002/1098-2736(200102)38:2<137::AID-TEA1001>3.0.CO;2-U

van Driel, J. H., Berry, A., & Meirink, J. (2014). Research on science teacher knowledge. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 848-870). New York, NY: Routledge.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673-695.

APPENDIX A:

Coding Sheet

Table 4

List of Codes, Definitions, and Exemplars

Curriculum		
Code	Definition	Exemplar
Content—depth	Knowing the level of content detail included and excluded in the course	L Uh uh. I always have to adapt stuff, cause. Well, and some of the stuff that I found that I was using, it went into way too much detail... And why is it important? Honestly, why is that important for them to memorize that? (Meeting 1)
Sequencing	Determining the order in which curriculum is taught that has a flow and makes sense	L But the organization is really important to me so that I know where I'm going, where I've been, and that there's an organized flow to the class and that was one of the things I struggled with last year and I'm feeling that same struggle again this year, like, uhhh! Where do I want to start, and what makes the most sense? (Meeting 1)
Calendaring	Calendaring time-sensitive labs and activities within the context of the school calendar	L That was a huge thing don't you think?...Oh! It's a long weekend! Crap. Can't start that lab so I gotta be doing something else (Meeting 1)

Table 4 (continued)

Planning		
Code	Definition	Exemplar
Ordering and Budgeting	Knowing what supplies to budget for and order	L ...I had ordering problems. I learned, I learned that when I order, when I have the district order it, it takes about a full week just to get the PO.... N Because when I remember it, I needed to order it yesterday. L Yeah. I'm in the scramble already. And it took that long to get the PO, and then I ordered it, and so she gave me the purchase order so I just got on the phone right then and ordered it. And then the lady was like, okay this ships second day, so this will be here blah blah blah. It came, I was like woo hoo! It came on a Friday, I was like great! I'm set to go Monday, threw it in the freezer. And Sunday night, I was sitting there, and I went Wait a minute. That wasn't everything. There were supposed to be some other things that came in the kit. (Meeting 2)
Time	Making decisions about how to spend class time	L Memo: calendaring a full year is tricky to me. I always struggle with staying to a schedule, even in biology. Especially when I am trying to tailor my instruction to the needs of the students. I have this tension of keeping to a calendar and pushing students, and giving adequate time for learning. When are kids being lazy, and when do they genuinely need more time to learn something or complete the work I give them? I still struggle with this tension in biology, a course I’ve taught for 10 years now. (Meeting 1 Memo)
Organization	Managing and organizing resources, lab materials, and curriculum materials	L Well, and what I'm hoping this does, labeling these lab one, lab two, lab three, kind of thing, I'm hoping that will solve the problem of, do I put this in my lab notebook? Because I have them combining things or separating things out into different, you know, and filling these out. And so I'm hoping that I can, it’s like, Lab 4. Yes, you're going to write this one up in your notebook, or No, you're just turning a worksheet on this one. (Meeting 2)

Table 4 (continued)

Lab preparation	Spending time planning for and preparing laboratory activities	N you know, the aliquotting and separating...as much as I wanted to do that, and I started doing that and I would set up a lab to this pristine...like, first of all, that's not practical when you go to a real lab, and I don't have time, I literally don't have time. I have one prep for three classes. (Meeting 1)

Teacher Knowledge

Code	Definition	Exemplar
Subject Matter Knowledge	Teacher knowledge of science content and skills, particularly biotechnology content and skills	L And so I didn't feel prepared both with my background knowledge in, in the content that was going on, as well as how do you do this [SDS-PAGE]. (Meeting 2)
General Pedagogical Knowledge	Teacher knowledge of general teaching methods	L Oh, it [my door] also shows that my focus, again, on activity, like I was trying to find at least one good activity...At least one, but hopefully more ways to address that concept through activity, lab or otherwise. (Meeting 1)
Pedagogical Content Knowledge	Teacher knowledge of how to teach the specific content, including understanding student characteristics that influence how to teach concepts	L This chaos that I felt at the beginning of the year, not knowing, like what are the important pieces that they need to know, and how do they all fit together and interconnect? And what do they need to do first so that later on they have the groundwork to do this next thing. (Meeting 1)

Table 4 (continued)

Teaching Ideas	Teacher knowledge and use of teaching methods specific to biotechnology that facilitate student learning	L Memo: Throughout the second interview, we discussed specific activities that did a good job of teaching specific biotechnology ideas—streaking with honey, virtual labs, games, models, etc. We were finding what worked to help teach students this particular content area. This is one way our knowledge developed during this first year. We also discussed methods that were not as helpful--complex labs seemed common to both of us, although the particular labs that were difficult for us were different, and seemed to be for different reasons. The SymLC project was a headache for her because she was not equipped to manage that kind of a project. It wasn't as bad for me because of my experience as a teacher. But labs involving the pH probes were and still are intimidating to me because my content area working with pH, acids, bases, and this tool are less familiar to me. My hesitations and struggles seemed to be because of specific tools, knowledge, or skills. Hers seems to be bigger management/uncertainty/timing issues. We both had our intimidating labs, but the reasons for the intimidation and reluctance seems slightly different. (Meeting 2 Memo)
Student Prior Knowledge	Teacher knowledge of student prior knowledge, particularly typical to biotechnology students	L And the students…come with prior knowledge, they come with some knowledge, it's actually, I learned, not as much as I thought it was going to be…They had some major gaps that I didn't anticipate. Especially in lab math (Meeting 1)
Student Struggles	Teacher knowledge of typical difficulties students will have learning concepts and skills	L I know how I'm going to do this differently because I thought, I thought kids knew how to do streak plates [after my instruction]….It is like impossible for them. (Meeting 1)
Pacing	Teacher knowledge of how much instructional time is needed to teach and learn concepts, and perform laboratory skills	L And how long...oh! How long? How long is it going to take? [In reference to gram staining and other labs] (Meeting 1)

Table 4 (continued)

Physical Needs		
Code	Definition	Exemplar
Physical Teaching Space	Understanding and managing the physical classroom and laboratory space, particularly the limitations of a small laboratory space	L Memo: Through the course of the first year I figured out how to manage the small space by bringing some materials out of the space for them to collect so they didn't need to move around in there to retrieve stuff. But I still haven't figured out how to get around to watch their skills and monitor their work. (Meeting 2 Memo)
Equipment	Knowing how to use equipment and teach students to use equipment	L See, and for me, every time I got out a piece of equipment, that stressed me out! Just because I didn't know how to use it…Yeah, that was so stressful. And not only do I need to know how to, okay, crap, I gotta program in this certain protocol into the PCR machine, but then, I gotta know how to teach it to the kids, and troubleshoot when something goes wrong. Not if, when…. And, like, how to explain, okay, this is what this piece of equipment is doing, this is the concept behind what it's doing, like, I felt really, really unprepared for that. (Meeting 1)
Materials	Knowing how to order, prepare, manage, and use chemicals, reagents, and consumables	L Winging biotech, you just, you just can't because of all the preparation, all the growing bacteria a week ahead, and aliquotting things out, and…You just can't. And ordering things, and oh my gosh, I don't have this one chemical. (Meeting 1)

Identity		
Code	Definition	Exemplar
Identity: Expert	Identity as an experienced, organized teacher in control	L This [biology notebook] like, represents to me, I know what I'm doin'. I feel very confident in the subject matter, in my methods. I got this thing. I don't have that same thing in biotech [laughs] yet. It'll come, but…[it's not there yet]. (Meeting 1)

Table 4 (continued)

Identity: Leader	Identity as a leader in the science education community	L Memo: This shows that after 1.5 years, I have moved into somewhat of a leadership position in the biotech education community. In this position I draw on the community of other biotech educators, because I still view myself as novice to the biotechnology content and also to knowing who the other players are. My involvement as a leader is due to my role as an expert teacher in other teaching aspects—I have been involved at the state level in many roles and projects, so my abilities are drawn on by state leadership, even though I am still novice in my biotech abilities. This relates to general science PCK and specific biotech PCK. In contrast, Natalie's contribution among other biotech educators was occasionally discounted or ignored. "N I don't know if it was a district training or something. But it was like the weirdest thing I've ever experienced. I sat there, and for the first time I felt like they were treating me like I was completely incompetent, and anything I said they couldn't even hear it. It was bizarre. It felt like I was in a dream. Because I'd make a comment and then, it's like I didn't even speak…I have a scope and sequence, this is what I did, and then they're like, 'That's not as good as ours.' And then they proceeded to explain the exact same scope and sequence!" This was the first time in her collaboration with these teachers Natalie had experienced this. (Meeting 2 Memo)
Identity: Novice	Identity as an inexperienced, novice teacher who is unsure of what she is doing	L Memo: "N Am I even doing this right? And I'm teaching…oh my gosh. That made me an insecure, wretched mess the whole year." Natalie started the year confident in her ability to guide her students through a project, but quickly realized she was out of her depth and found the project far more difficult than she originally thought. I struggled with some aspects of the project, particularly getting machines and techniques to work, as well as troubleshooting where students might have made mistakes (why could I get results but they couldn't?), but the project didn't seem as catastrophic to me as it did to her—in the manuscript I focused on many of the positive aspects but worried about the timing. She seemed more overall frustrated with the project. Due to my experience—my general science PCK mediated my novice-ness through much of this project. I was a little better equipped to deal with situations in the classroom where everything doesn't work and you have to punt or figure something else out. (Meeting 2 Memo)
Identity: Teacher as Exemplar	Identity as a recent college student who was good at learning science and used effective learning strategies	N It's important to try and tell them tricks and stuff that I've learned as I've studied, myself. (Meeting 1)

Table 4 (continued)

Identity: Teacher	Views of the role of teacher in the classroom	N What does the artifact reveal about beliefs about our role in teaching and student learning? Um, my job as a teacher is to try and tell them everything I know in a balanced, magical, careful way. You know? You try and tell them everything you know about biochemistry, at least for this class. (Meeting 1)
Identity: Student	View of the role of the student	N I cleaned up for my kids way too much last year. I'm going to set a 5-minute timer. If you're not done, you clean up. You leave my desks and everything in pristine condition when you leave this room because I don't have time to babysit you or clean up after you. (Meeting 1)
	Advice	
Code	Definition	Exemplar
Advice Given	Type of advice I gave as an experienced science teacher	L Memo: In Meeting 2 I give advice on sub plans, curricular materials (virtual lab), how to maybe improve/develop an activity, a stain I'm going to try. (Meeting 2 Memo)
Advice Requested	Type of advice I asked for as a novice biotechnology teacher	L Memo: In Meeting 2 the questions I ask are very probing—I'm asking for important details that may reveal my understanding of or experience with PCK. I ask for advice on curricular materials she made (scoring rubric, relay race), lab methods (stain), effectiveness of activity she made/used (honey), details about activity she made/used (honey), content depth, arrangement of her physical space, including equipment and material setup, storage, and student access as I plan for a new classroom in a new building. (Meeting 2)
	Emotional	
Code	Definition	Exemplar
Stress	Emotional stress of being a novice teacher	N I was at school at 11:45 one night like swearing at my machines at the top of my lungs. Like, if I drop this off the stairs, is anyone gonna know? (Meeting 2)