HOW TEACHERS NEGOTIATED THE MEANING OF NEXT GENERATION
SCIENCE STANDARDS (NGSS) THROUGH PARTICIPATION IN A PROFESSIONAL
LEARNING COMMUNITY

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SCIENCE STANDARDS (NGSS) THROUGH PARTICIPATION IN A PROFESSIONAL
LEARNING COMMUNITY

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To the six teachers who allowed me to be a part of their journey, and to Pat, for helping me tell their story
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Many thanks to my family, my committee, and the Mizzou science education community! Without your unfailing support, I could not have completed this journey.
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ABSTRACT

NGSS provide a new vision for K-12 science education. Teachers need time and opportunities to collaborate with their peers in order to make changes to their views and practice. PLCs are a potential support structure for reform. However, there are few studies of mature, effective science teacher PLCs working without external support and few studies of teachers’ efforts to negotiate the meaning of new standards and revise their curriculum. This instrumental case study framed by communities of practice investigated how secondary biology teachers within a mature, effective PLC negotiated the meaning of NGSS as they revised their curriculum. The study was guided by the following sub-research questions: 1) how do the Biology PLC’s interactions with other communities influence how the biology teachers negotiate the meaning of NGSS as they revise their curriculum, 2) how do the biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum, and 3) how do the biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum. The PLC was comprised of six secondary biology teachers at Cross View High, one of three high schools in the district. The state had not adopted NGSS at the time of the study, but the school district had. During the 2013-2014 school year, the following data sources were collected: 1) audio-recordings and observations of the PLC’s weekly meetings, the PLC’s pre-NGSS and revised curriculum, the PLC’s professional email, one 90-minute focus group interview, and two 60-minute, semi-structured individual interviews with each teacher. Interpretative data analysis revealed the following themes: 1) the Biology PLC’s historic participation with the World Studies and Language Arts PLC, and in particular their use of a revised World Studies Skills Rubric
to assess students’ science writing, influenced the biology teachers’ prioritization of two science and engineering practices, 2) each biology teacher filled a unique, previously negotiated, clearly defined, and mutually agreed upon role within the PLC, 3) the teachers developed a road map – a year-long plan of action that reified their meaning-making and became an enduring tool that guided their curriculum reform efforts, 4) the teachers revised each unit around a similar design structure, and 5) the teachers described their experience of negotiating the meaning of NGSS and revising their curriculum as stressful and exhausting, and marked by a central tension between content details and skills. They persevered because they valued the revisions they were making to their curriculum. This study provides implications for science teacher education, professional development, and future research.
Chapter 1

Introduction

“Science—and, therefore, science education—is central to the lives of all Americans” (NGSS Lead States, 2013, p.1). Science, engineering and technology permeate every aspect of our lives (National Research Council [NRC], 2011) from our health to the preservation of our natural resources to the infinite number of technologies upon which we rely. Furthermore, science, engineering and technology are the heartbeat of innovation (NGSS Lead States, 2013); for America to be at the forefront of 21st century innovation, we must educate world-class scientists and engineers. Thus, it is of utmost importance that every American student be given the opportunity to develop a foundational knowledge of science and the practices that contribute to that knowledge.

Unfortunately, despite decades of reform efforts, many American students are not afforded such an opportunity because many American science classrooms are still dominated by traditional, teacher-centered instruction that emphasizes rote memorization and is devoid of authentic science experiences that foster deep conceptual understanding (Darling-Hammond, 2006; Roehrig, Kruse, & Kern, 2007; Tobin & McRobbie, 1996). Therefore it is not surprising that American students’ performance on international tests of science achievement are mediocre (U.S. Department of Education Institute of Education Sciences National Center for Education Statistics, 2009). The United States is in need of radical science education reform.

Two reform documents, A Framework for K-12 Science Education (NRC, 2011) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) were written in response to that need. These documents provide a new vision for K-12 science
education; they emphasize the need for students to be actively engaged in science and engineering practices that allow them to develop deep conceptual understanding. Teachers who implement NGSS must first develop an understanding of the conceptual shifts embedded within these reforms and then design high quality curriculum to help their students achieve the new standards. How will teachers come to understand NGSS as they revise their curriculum?

In order for teachers to make changes to their views and practice, they need time and opportunities to collaborate with their professional peers (Gerard, Bowyer, & Linn, 2010; Larkin, Seyforth, & Lasky, 2008). Professional Learning Communities (PLCs) are a potential support structure for providing teachers the collaboration time needed to re-envision their practice. PLCs can help teachers overcome the challenges of science education reform implementation (Richmond & Manokore, 2011), serve as a venue for science teacher learning (Goodnough, 2010; Richmond & Manokore, 2011; Roth et al., 2011), and act as agents of change (Nelson, 2008).

In mature, effective PLCs dialogue is encouraged, practice is de-privatized, and teachers work collaboratively to improve student learning (Kruse, Louis, & Bryk, 1995). However, there are few studies of mature, effective PLCs in science education. Most of our understanding of science teacher PLCs comes from nascent communities that are often more focused on establishing group dynamics and goals than working together to achieve goals focused on student learning. Thus, our understanding of PLCs as a potential venue for science teacher learning is limited. Given the recency of NGSS, our understanding of how teachers negotiate the meaning of these new standards and revise their curricula is also limited. The purpose of this research is to understand how
secondary biology teachers in a mature, effective PLC negotiated the meaning of NGSS as they revised their curriculum.

**Rationale: A Nation (Still) at Risk**

In 1983, Ronald Reagan’s National Commission on Excellence in Education wrote a letter to the American people informing them that their nation was a nation at risk – at risk because their “once unchallenged preeminence in commerce, industry, science, and technological innovation” (p. 1) was being usurped by world competitors. They provided dismal statistics: American students ranked last on seven of 19 academic tests of achievement of the 1970s; 23 million American adults were functionally illiterate; Scholastic Aptitude Tests (SAT) scores had been declining since the 1960s; 25% of university math courses were remedial; and on national assessments of science achievement, administered in 1969, 1973, and 1977, the scores of U.S. 17-year-olds had steadily declined. This landmark paper, which made numerous recommendations for improvement, (e.g., a longer school year, more rigorous standards and expectations, competitive teacher salary, and the promise of government leadership and fiscal support) captured the attention of the American people, particularly U.S. policymakers and educators. It triggered an onslaught of reforms intended to improve U.S. education.

In science education there were multiple responses to President Bush’s subsequent call for national performance goals (DeBoer, 2000). In 1985, the American Association for the Advancement of Science (AAAS) founded Project 2061 which later published *Science for All Americans* (AAAS, 1989). This landmark document “consists of a set of recommendations on what understandings and ways of thinking are essential for all citizens in a world shaped by science and technology” (AAAS, 1989, p. xiii). The
contributing authors called for a different approach to science teaching and learning to achieve the goal of a scientifically literate citizenry. They envisioned instruction that offered opportunities for learners to critically evaluate scientific information and develop a robust understanding of the nature of science. The report, *Benchmarks for Scientific Literacy*, offered guidelines for the design of curricula consistent with these literacy goals (AAAS, 1993). *Benchmarks* identifies specific learning goals for students to achieve by the end of grades 2, 5, 8 and 12. These standards, which emphasized doing (not just memorizing) science, were used in state initiatives until the publication of the *National Science Education Standards (NSES)* (NRC, 1996). While the *NSES* content standards were informed by *Benchmarks*, the *NSES* extended the vision of reform. The *NSES* promoted an inquiry approach to teaching that would afford students “minds on” experiences, not just “hands on” activities. A further intent of the *NSES* was “science standards for all students” (NRC, 1996, p. 2, emphasis added). This guiding document included science content standards as well as standards for teaching, professional development for teachers, assessments, education programs, and the science education system as a whole. The *NSES* emphasized excellence and equity.

Various curricula consistent with the reform principles were written (Beyer, Delgado, Davis, & Krajcik, 2009; Schneider & Krajcik, 2002). *Scope, Sequence and Coordination (SS & C)*, a *NSES* aligned curriculum guide for 6th through 12th grade science, was developed (National Science Teachers’ Association [NSTA], 1996). Innumerable professional development opportunities and resources for teachers have been offered over the decades (Johnson, 2013), and science teacher educators have long discussed reform research and its implications within the pages of scholarly journals.
In 2008, Strong American Schools issued a report card evaluating the country’s progress since the “A Nation at Risk”, and “stunningly few” of the Commission’s 38 recommendations had actually been enacted (Schmidt, 2008). International tests of achievement attest to poor progress. U.S. scores on the 2003, 2006, 2009, and 2012 Program for International Student Assessment (PISA), which measures 15-year-olds’ reading, mathematics and science literacy, have hovered around average and often fallen below the average scores of industrialized nations participating in the Organization for Economic Cooperation and Development (OECD) (U.S. Department of Education Institute of Education Sciences National Center for Education Statistics, 2009). In 2009, the U.S. ranked 28th among 65 countries, and “among the 33 other OECD countries, 12 had higher average scores than the United States, 9 had lower average scores, and 12 had average scores that were not measurably different” (p. 23).

The results of the Trends in International Mathematics and Science Study (TIMMS), which measures the science achievement of U.S. 4th and 8th graders compared to same age students in other countries, provides corroborating evidence of less than stellar progress. There was no significant difference between U.S. 4th graders’ science achievement scores in 1995 and 2011. In 2011, U.S. 8th graders’ science achievement scores ranked near the middle of 56 countries, with 12 countries scoring above, 33 scoring below, and 10 scoring at a level not significantly different than the U.S. In that same year, only 10% of U.S. 8th grade students performed at or above the advanced benchmark, ranking the U.S. 13th for that statistic (U.S. Department of Education Institute of Education Sciences National Center for Education Statistics, 2011).
After decades of reform efforts, the U.S. is still at risk – at risk of not producing scientists and engineers capable of reclaiming the nation’s competitive edge in a global economy, but also at risk of not producing a scientifically literate citizenry capable of making science, engineering and technology related public policy and everyday life decisions. Why? Reform implementation is challenging!

**Challenges of Reform Implementation.** Reform is impeded by multiple factors, including negative teacher attitudes and beliefs, accountability pressures, and a lack of human and material resources needed to support teachers’ attempts to change their practice. When teachers’ attitudes and beliefs about reform are not wholly supportive of or in agreement with the reform, teachers may ignore reform recommendations or attempt to implement them in ways that are inconsistent with the spirit of the reform (Cronin-Jones, 1991; Donnelly & Boone, 2007; Donnelly & Sadler, 2009; Haney, Czerniak, & Lumpe, 1996; McRobbie & Tobin, 1995; Tobin & McRobbie, 1996). When standardized testing is emphasized at the national, state and/or local level, teachers may de-emphasize reform based instructional strategies that encourage critical thinking and inquiry in favor of more traditional instructional strategies that they feel will prepare students for fact-based assessments (Aydeniz & Southerland, 2012; Johnson, 2013; Maltese & Hochbein, 2012). Teachers may be prevented from implementing reforms because they are lacking one or more of the following: resources, such as materials and technology (Harmon, Henderson, & Royster, 2002), opportunities to participate in high quality professional development (George, 2007), good curricula (Beyer et al., 2009), and time to think deeply about and redesign their practice (Badiali & Rousmaniere, 1996).
Thus, despite the United States’ multifaceted reform efforts, many science classrooms are still dominated by traditional, teacher-centered instruction that emphasizes memorization, not broad conceptual understanding and opportunities to do science (Darling-Hammond, 2006; Roehrig et al., 2007; Tobin & McRobbie, 1996). Even in classrooms that offer engaging activities, there may be a lack of cohesive storylines (Hanuscin, et al., 2016). According to the TIMSS 1999 video study, which examined videotaped 8th grade science lessons in five countries, lessons in higher-ranked Japan and Australia focused on fewer topics and encouraged students to make connections between ideas and collected evidence. In comparison, lessons in the U.S. were “characterized by a variety of activities that may engage students in doing science work, with less focus on connecting these activities to the development of science content ideas” (Roth et al., 2006, p.21). Such ‘activity mania’ is in contrast to the inquiry approach espoused in the NSES as it does not afford students the opportunity to develop conceptual understanding through “searching for patterns and relationships in the world around us” (Moscovici & Nelson, 1998, p. 14). Certainly, the reforms of the mid 1990s provided the impetus for some positive changes, but “there is much room for improvement” (NRC, 2011, p .ix).

The Current Science Education Reform Era. Since the publication of NSES (NRC, 1996), science has advanced and the science education community has learned much about science learning, teaching and reform implementation. Based on these advancements, the NRC ushered in a new era in science education reform publishing A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas (NRC, 2011). The Framework, which provides a “broad description of the content and sequence of learning expected of all students by the completion of high school” (p.8),
is grounded in research on science teaching and learning. It recommends that K-12 science education be built around three dimensions: science and engineering practices, crosscutting concepts, and core ideas in four disciplinary areas. The writers, leading scientists and science educators, emphasize the need for students to be actively engaged in science and engineering practices that allow them to develop deep conceptual understanding of the core ideas in each of the following four disciplines: 1) physical science, 2) life science, 3) earth and space science, and 4) engineering, technology and applications of science. The primary goal of this reform document is that all students would emerge from their secondary education prepared to “engage in public discussions on science-related issues, … be critical consumers of scientific information related to their everyday lives, and … continue to learn about science throughout their lives” (p. 24); the secondary goal is that students who wish to pursue careers in science and engineering will have the foundational knowledge to do so.

The associated *Next Generation Science Standards (NGSS)*, which were written by science and education experts from 26 lead states, represent a new and improved set of K-12 science education standards “designed to prepare students for college, career, and citizenship” (NGSS Lead States, 2013, Appendix A, p.5). Each standard, or performance expectation, combines the three dimensions of science learning: 1) science and engineering practices, 2) disciplinary core ideas, and 3) crosscutting concepts. The eight practices of science and engineering are: 1) asking questions (for science) and defining problems (for engineering), 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations (for science) and designing
solutions (for engineering), 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information. Appendix F details each of these practices and what students should be able to do by the end of each grade band. NGSS supports assessment of disciplinary core ideas in ways that showcase students’ ability to “investigate the natural world through the practices of science” (NGSS Lead States, 2013, Appendix F, p.1). Similarly, the seven crosscutting concepts “bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas … and develop a coherent and scientifically based view of the world” (NGSS Lead States, 2013, Appendix G, p.). The seven crosscutting concepts are: 1) patterns, 2) cause and effect, 3) scale, proportion, and quantity, 4) systems and systems models, 5) energy and matter, 6) structure and function, and 7) stability and change.

Publication of the Framework and NGSS coincided with the national movement to adopt the Common Core State Standards (CCSS) in English Language Arts and Mathematics. Because “NGSS are aligned with the CCSS … [and] the … standards overlap in meaningful and substantive ways, … there is an opportunity for science to be a part of a child’s comprehensive education” (NGSS Lead States, 2013, Appendix A, p.5). At the time of this writing, NGSS has been adopted by eighteen states and the District of Columbia (Academic Benchmarks, 2015; Brown, 2013). In 2016, Missouri adopted a closely aligned version of NGSS.

Teachers who are implementing NGSS have a challenging task. NGSS “are student performance expectations – NOT curriculum” (NGSS Lead States, 2013, p.2, emphasis in original). Therefore, teachers must develop an understanding of NGSS and
the conceptual shifts embedded within the reform and then design high quality curriculum and instruction to help their students achieve the new standards. Given the known challenges of reform, how will teachers do this?

**Professional Learning Communities as a Venue for Science Education**

**Reform.** In order for teachers to make changes to their views and practice, they need time and opportunities to collaborate with their professional peers (Badiali & Rousmaniere, 1996; Gerard et al., 2010; Larkin et al., 2008; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). Professional Learning Communities (PLCs) are a potential support structure for providing teachers the collaboration time they need to re-envision their practice.

The concept of PLCs originated in the business sector and is based on organizational learning theory (Vesico, Ross & Adams, 2008), and the term began to appear in educational literature in the mid-1990s (Kruse et al., 1995; Hord, 1997) as a context for teacher collaboration and professional development. PLCs have since been the topic of educational research (Stoll, Bolam, McMahon, Wallace, & Thomas, 2006; Vesico et al., 2008) with some authors extolling their virtues (Louis & Marks, 1998) and others offering more cautious optimism (Hargreaves, 1994; Nelson, 2008). PLCs go through stages of development. Mature, effective PLCs are spaces where open dialogue is encouraged, practice is de-privatized, and teachers work collaboratively to improve student learning (Kruse et al., 1995). Mature PLCs can support teacher learning (Grossman, Wineburg, & Woolworth, 2001; Kruse et al., 1995; Nelson, 2008), student learning (Vesico et al., 2008) and general education reform (Englert & Tarrant, 1995).
Mature, effective PLCs may also be a powerful venue for science education reform. The relatively small body of literature on K-12 science teacher PLCs suggests several potential, positive outcomes. In a case study of three middle and secondary math and science PLCs, one PLC made changes in their practice that improved students’ science writing (Nelson, 2008). In a case study of beginning physical science teachers learning to teach science to linguistically and academically diverse student populations, teachers’ reflections and interactions within multiple learning communities helped them see how some groups are marginalized in science education and consider how different teaching strategies might address the inequity (Bianchini & Cavazos, 2007). When Roth and colleagues examined the effect of video-based analysis of practice they found that those teachers who spent additional time on analysis of practice activities in small learning communities developed meaningful science content understanding and improved their ability to analyze lessons in terms of student thinking and science content (Roth et al., 2011). In a study of 17 elementary teachers participating in a professional development program with a learning community component, Akerson, Cullen and Hanson (2009) reported learning communities can positively influence teachers’ views of NOS. In Richmond & Manokore’s (2011) study of two elementary PLCs, teachers were able to achieve their goals for excellence in science education despite external pressures to emphasize math and language in their Reading First schools. Collectively, these findings corroborate Stein, Smith & Silver’s (1999) suggestion that PLCs can be agents of change that help teachers overcome the challenges of science education reform implementation.
Gaps in our knowledge of PLCs as a venue for science education reform. The majority of what is known about the work and potential of teacher learning communities comes from research on PLCs affiliated with a professional development program, university-school partnership or other outside entity. While these PLCs may have made significant progress, they did so with support from a researcher, professor, or other facilitator – resources that are frequently not available to schools situated some distance from institutions of higher education. There is little literature about PLCs in science education working without external supports.

Because the PLCs are often formed as part of the professional development program or university-school partnership, research on mature PLCs is limited. This is problematic because PLCs in the earlier stages of development tend to be more focused on the establishment of group norms than the rich collaborative work required to achieve clearly defined goals for improving student learning (Bolam et al., 2005; DuFour, Dufour, Eaker, & Many, 2006; Grossman et al., 2001; McLaughlin & Talbert, 2006). There are a few studies of mature learning communities in science education, e.g., Larkin et al.’s (2008) retrospective study of one group of high school science teachers who implemented and sustained an inquiry-oriented science curriculum for 25 years. However, because the study was retroactive, it did not capture teachers’ meaning making through time. Also, the teachers in this study, and most other studies of science teacher learning communities, were implementing existing inquiry curricula, rather than designing curricula. Teachers implementing NGSS (or any new reform) need to make sense of the reform recommendations as they revise or develop curricula.
In summary, science teacher learning community literature has typically focused on newly formed PLCs, who are implementing existing curricula or developing curricula under the direction of a facilitator affiliated with a professional development program or university-school partnership. There are few studies exploring the work of mature, effective science teacher learning communities who are independently making sense of reform documents, developing or revising curricula or implementing reform. To date, there are only a few published studies of teachers NGSS implementation efforts and no published studies of teachers’ efforts to independently make sense of NGSS and revise their curricula. This study addresses these gaps.

A PLC as a window into current science education reform efforts. The release of *A Framework for K-12 Science Education* (NRC, 2011) and the associated NGSS (NGSS Lead States, 2013) represents a new era in science education reform and a unique opportunity in science education research to ask important questions that will help the science education community understand how teachers interpret and adopt reforms. Studying the reform efforts of science teachers participating in a mature PLC provides a window into teachers’ reform efforts. Peering through this window opens up the possibility of understanding how teachers in a learning community negotiate reform initiatives and how their experiences could inform future research, professional development, policy, and practice.

This year-long case study investigates how the secondary biology teachers within a mature, effective PLC negotiate the meaning of NGSS as they revise their curriculum. This study addresses multiple gaps in the literature as it explores a mature PLC’s efforts to make sense of reform recommendations and revise their biology curriculum sans the
support of a facilitator, university-school partnership or professional development program. This study is important not only because of its clear contribution to the literature, but because of its potential to illuminate the teachers’ experience of reform in ways that may be helpful to other teachers, teacher educators, researchers, and professional development providers.

**Theoretical Framework: Communities of Practice**

This study is framed by the theory of Communities of Practice (CoP) (Wenger, 1998). CoP is a social learning theory rooted in Vygotsky’s sociocultural theory and Lave and Wenger’s situated learning theory (Lave & Wenger, 1991). It posits “learning as social participation” (Wenger, 1998, p. 4) in a way that integrates community, practice, identity and meaning as illustrated in Figure 1.

![Figure 1. Components of a social theory of learning: an initial inventory. Reprinted from Communities of Practice (p. 5), by E. Wenger, 1998, Cambridge, U.K.: Cambridge University Press. Copyright 1998 by Cambridge University Press.](image)

Wenger views this social theory of learning as being at the crossroads of the scholarly traditions shown in Figure 2. Along the vertical axis, learning is located between theories of social structure, which emphasize norms, rules and history, and theories of situated experience, which emphasize individuals’ everyday interactions with
their environment. Along the horizontal axis, learning is situated between theories of social practice and theories of identity. Theories of social practice address how individuals interact with their world, particularly how they share resources and manage activities and relationships. Theories of identity address how a person’s individuality is formed through relationships with others.


While the vertical axis is not ignored, CoP is primarily concerned with the horizontal axis and the intermediary theories of collectivity, meaning, power and subjectivity represented by the shaded area in Figure 3. Theories of collectivity address how various social groups are formed and sustained, while theories of subjectivity address individual agency within the social group. Theories of power address who has power and how that power is conferred and used, while theories of meaning address how individuals make their own meaning through social participation. The connections between community and individual and power and meaning form fundamental themes of CoP.
Though the theory is not exclusive to education, Wenger (1998) suggests that it may be a fruitful way to view and analyze learning in any community, including those that exist within schools. The following paragraphs explain how CoP informed this investigation of how one community of practice, a mature science teacher PLC, negotiated the meaning of NGSS as they revised their curriculum.

**Practice.** Following their studies of apprenticeship among midwives, tailors, Navy quartermasters, supermarket butchers, and nondrinking alcoholics, cognitive anthropologists, Jean Lave and Etienne Wenger (1991), adopted a theoretical perspective that views learning as not just situated in a practice, but as an intrinsic part of the social practice. Lave and Wenger proposed that learning occurs through an individual’s participation in the “practices of social communities (p. 4, emphasis in original) such as the apprenticeship communities they studied. They referred to these communities as

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“communities of practice,” and defined them as “a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice” (p. 98).

Wenger (1998) clarified that learning does not occur through just any involvement in an event or group, but as active engagement in the activities and relationships of these communities of practice. As illustrated in Figures 2 and 3, this kind of participation shapes participants’ identities and influences their actions and their reflections on their experiences. To understand the influence of participation in practice requires an understanding of practice.

Wenger (1998) defines practice as a meaning making process that is negotiated through participation and reification within a community characterized by learning. The following paragraphs describe the processes of participation and reification, how these processes are used to make meaning within a community of learners, what constitutes a community of learning, and how practice is associated with each of the defining characteristics. Exemplars of these processes and characteristics in the PLC in this study are included.

**Practice as meaning negotiated through participation and reification.**

According to Wenger (1998), practice is a process by which we experience everyday life and make meaning out of that engagement with our world. He argues that meaning is negotiated through participation and reification, which form a duality that underlies our experiences.

**Participation.** Participation is a complex, active process involving actions, thoughts, language and emotions. In this case, the teachers’ participation includes formal
planning meetings, informal discussions of their work throughout the day, asking questions and distributing resources via email, sharing the workload, and supporting each other through a challenging school year marked by change. This kind of participation allows individuals to affect and be affected by the social communities in which they participate; therefore, participation provides a sense of belonging and a source of identity. Because participation is a part of who an individual is, it is not something that is turned off when one is not directly engaged with other community members – teachers are still teachers when the final afternoon bell dismisses students. Teachers also have other identities; the teachers in this study are also athletic coaches, parents, spouses, etc. Each of these individual identities affects the others as the teachers participate in the PLC and other communities.

Participation does not mean only positive interaction. Relationships within social communities may be competitive, envious or otherwise fraught with tension. For example, while all of the teachers within the PLC recognized that the curriculum must be changed to reflect reform recommendations, there were sometimes differences of opinion about how to do so.

**Reification.** Reification, as defined by Wenger (1998), is the process of creating objects, e.g., procedures, tools and stories that capture experience. Reification may occur through designing, describing, interpreting, or using and reusing as well as a host of other endeavors. It is the expression of experience, the creation of exemplars, or the design of a representative symbol. It is both the process and the resultant product. Within social communities, reification may originate in another time or space, but be reified anew.
within the current community. Reification may be fleeting or enduring, physical or philosophical, elementary, or complicated.

In this study, the teachers’ experience of negotiating the meaning of NGSS is reified through the process of creating written goals and the revised curriculum. Thus, the teachers’ instructional goals and interpretations of the reform endure in these reified objects. These products, and the processes that created them, were analyzed in order to explain how the biology teachers’ participation and reification allowed them to negotiate the meaning of NGSS as they revised their curriculum.

**Negotiation of meaning.** The negotiation of meaning that occurs through participation and reification is an ongoing social process (Wenger, 1998). This duality of participation and reification is central to the CoP framework that guides this study – for it is through the interweaving of these complementary processes that meaning is conferred. In this case, teachers discussed the standards and revised curriculum through participation in their PLC. Revised curriculum materials and planning tools are reified objects that exist because the teachers wrote reminders of decisions about what and how science should be taught. As the curriculum was implemented, the teachers reflected on their experiences, discussed student learning, and modified future lessons; meaning was negotiated anew. Thus, the teachers’ experience of meaning is rooted in history and resistant, yet ever changing, as a result of their engagement with their world and others in it.

It may be tempting to think of participation and reification as opposing ends of some spectrum, e.g., unconscious vs. conscious, private vs. public, informal vs. formal, or vague vs. defined. Case in point, documents, such as curricula, may make what is tacit,
explicit; yet, participation is not always tacit, and reification is not always explicit (Wenger, 1998). Participation and reification should be viewed as neither contrasting nor interchangeable. It is the interplay between the two that affords meaning.

Teachers negotiated meaning through discussing the new standards, co-creating lessons they felt would support students’ achievement of these standards, and reflecting on their experiences after teaching the lessons they designed. Analyzing the teachers’ discussion and planning, revised curriculum, and responses to questions about their experiences afforded an opportunity to consider how both participation and reification supported the teachers’ negotiation of meaning.

**Practice as community.** The experience of meaning making occurs within a community of practice, but how is practice associated with community? Wenger (1998) asserts that it is the “source of coherence of a community” (p. 72). It is characterized by mutual engagement, a joint enterprise and a shared repertoire.

Practice is mutual engagement. Participants engage in conversation, share information, perform tasks, form relationships and celebrate successes. They may disagree with, gossip about, or be jealous of other participants. For example, through their mutual engagement in the work of the PLC, the teachers formed relationships. Some are actually good friends who spend time together outside of school; others are not. All interacted as professional colleagues who were supportive of one another as they engaged in the challenging joint enterprise of making significant changes in their curriculum.

How they participated in this joint enterprise was collectively negotiated. Though community members may have diverse backgrounds, goals and understandings, and may
be influenced by forces outside of the community, such as institutional norms, employer expectations or other communities of practice, they must find a way to live and work together. It is “their enterprise” (p. 79, emphasis in original), and it entails mutual responsibility. It is the participants who decide their actions and how they will respond to outside influences. For example, while all PLCs within the participants’ particular school were required to articulate goal(s) for the 2013-2014 school year, they were given autonomy in their decisions.

The final property of practice as community is shared repertoire. As a community engages in its joint enterprise, resources emerge. These may include “routines, words, tools, ways of doing things, stories … or concepts” (Wenger, 1998, p. 83). These resources reflect the community’s history, yet are malleable and can be used in future practice. Thus, they are resources in the sense that they may be used in the negotiation of meaning. In this case, the PLC’s weekly meetings followed a predictable routine: brief small talk, discussion of items on an agenda that was jointly created, division of tasks to be completed, and encouraging parting comments. The PLC used technological tools to accomplish their work more efficiently; they communicated regularly through email and stored resources on a shared drive. These aspects of their shared repertoire were long standing traditions, but as they adopted the new standards, new understandings and other ways of doing things emerged. Wenger (1998) lists numerous indications of the presence of a shared repertoire and the other defining characteristics of a community of practice: “sustained mutual relationships … rapid flow of information … specific tools … shared stories [and] discourse reflecting a certain perspective on the world” (p. 126). Each of these is evident in the participating PLC.
**Practice as learning.** A community’s history may be centuries old, but it is not defined by some minimum time. A community is a community of practice if learning has occurred as the result of mutual engagement in a joint enterprise. “Learning involves a close interaction of order and chaos” (p. 97). Communities of practice supply both. Participation and reification provide a source of remembering and forgetting as well as continuity and discontinuity. As individuals participate, memories are formed. These memories can be recalled and replayed, or forgotten or reinterpreted in light of new experiences. Similarly, reified objects can remind someone of the past or help them envision the future. In these moments, continuity or discontinuity ensues. Continuity is achieved when individuals identify with other members of the community, reproduce reified objects, or preserve practices. Discontinuity ensues when old ideas are abandoned.

Continuity and discontinuity exist within this PLC. The PLC is an established community that has existed for nearly 15 years. Because the teachers have experienced the community’s past, they often remembered and discussed old lessons, before either reproducing, revising, or abandoning them in light of their newly negotiated meaning of NGSS. Some of the teachers are old-timers who have participated for more than a decade, while others are relative newcomers who have joined the group within the last three years. This changing community membership is a normal part of community life, another example of the continuity and discontinuity typical of the learning that occurs within a community of practice. Lave and Wenger (1991) proposed a process called legitimate peripheral participation to explain how newcomers who are not yet full participants can participate in some partial, but meaningful, way that supports learning
the knowledge and skills required to become a full participant. Legitimate peripheral participation suggests a way for new members to become old timers as they participate in a social community of practice. In this study, one of the teachers was new to the Biology PLC. The CoP framework supports the investigation of how the PLC offered her legitimate peripheral participation.

Through stability and instability, practice is reinvented; thus, the community has a shared history of learning that includes “evolving forms of mutual engagement … understanding and tuning their enterprise … [and] developing their repertoire” (p. 95, emphasis added). Learning is not just thinking, but doing; it is not just an in the moment process, but an ongoing process marked by both order and disorder.

**Practice as boundary.** One source of disorder may be a community’s interaction with other communities that offer new ideas. Communities of practice do not exist in isolation (Wenger, 1998). While they may have clearly defined boundaries marked by employment, title, etc., they exist within and interact with the rest of the world. One means of interaction is through boundary objects (Star & Griesemer, 1989) and practices. Boundary objects allow the coordination of various groups’ perspectives and objectives. As reified objects cross boundaries, connections are made between groups (Wenger, 1998). Boundary practices, practices established to sustain engagement between two communities, support these connections. CoP provides a useful framework for examining how the Biology PLC’s connections with other communities may have influenced how they negotiated the meaning of NGSS.

Connections may also be made through brokering (Wenger, 1998). Individuals may participate in multiple communities of practice. In their varied participations, they
may transfer something of one community into another. This brokering is complex and requires those with multiple memberships to have “enough distance to bring a different perspective, but also enough legitimacy to be listened to” (p. 110). One of the Biology PLC teachers was also a member of the school’s Executive Council, a small group of elected faculty who provide professional development and support to all of the school’s PLCs. This teacher had legitimacy in both contexts.

Similarly, the peripheral participation of other interested individuals allows connections when the individuals are outside of the community enough to gain fresh ideas, but inside of the community enough to suggest change. Even when individuals are not on a trajectory to full participation, they sometimes work with or observe communities of practice, thus enabling connection and change (Wenger, 1998). Several interested others, e.g., preservice teachers, teachers, the head of the science department, the district science coordinator, and one of the assistant principals, sometimes attended the Biology PLC meetings. Though not on a path to full participation, these others sometimes asked questions, made suggestions, or offered supports or resources that contributed to the teachers’ work and development.

In summary, communities exist not in isolation, but within and among other communities. The practices of one community affect, and are affected by, others. These affections occur through the edges of communities. Boundaries are the edges of discontinuity; peripheries are the edges of continuity. However, in practice, the two are woven together. Figure 4 provides an illustration of how these boundary practices and peripheries provide connections between communities.

Practice as locality. Sometimes social groups are too widely dispersed to be viewed as one community of practice. In such instances, they may be viewed as constellations of interacting practices. These communities may be quite diverse and separated by time and distance, yet they are related in other important ways, e.g., similar enterprises, shared history, or resources. Given many social learning theorists’ assumption that local communities lead to global societies, a focus on local community may seem inappropriate for the times. However, Wenger argues that viewing related, interacting communities as constellations of practice, allows us to see that the local and the global exist together and influence one another. He points out that while the UN is involved in international affairs, it is still a local community of practice.

Similarly, while the biology teachers in this study must respond to national reform documents, state mandates, district policies, etc., they are still a local community primarily concerned with meeting the needs of the students in their classrooms. While this study attends to teachers’ constellation of practice, it is focused on their local community, their Biology PLC.

Identity in Practice
This section examines the right side of Figure 3: identity and the parallels between identity and practice. A discussion of how identity is shaped by participation and non-participation, a sense of belonging, and the dual processes of identification and negotiability are included.

Parallels between identity and practice. Identity is deeply connected to practice; just as participation and reification allow the negotiation of meaning, they also allow the negotiation of self. As individuals interact with others, they have an effect on their world. As they experience those relationships and effects, identity is constructed. This identity is not synonymous with self-image. It is produced through lived experience, not just internal reflection. So, just as practice is a process, a process of meaning making, identity is also a process, a process of becoming that develops along a path, or trajectory, marked by participation and reification.

However, the path twists and turns and does not always lead to the same destination. Wenger describes multiple trajectories along which identities may be shaped and learning may occur. A peripheral trajectory may not lead to full participation, but it may shape the identity of the peripheral participant and lead to learning if something meaningful is experienced as a part of the peripheral participation. One of the participants in this study is a newcomer to the Biology PLC. While her participation is more peripheral, she still had an opportunity to negotiate the meaning of NGSS through her participation in the PLC. The other biology teachers also had an opportunity to learn as a result of her participation and the ideas and resources she contributed. The identities of both the newcomer and the old-timers were shaped by peripheral participation.
Of course, identity is also shaped by full participation; when individuals are members of a community, their identity is shaped by their experience of competence within that community. Recall that a community of practice is characterized by mutual engagement, a joint enterprise and a shared repertoire. Community members become comfortable with their role in mutual engagement, accountable to their community’s enterprise, and able to make use of the shared repertoire of resources. Each teacher in the Biology PLC negotiated a role. These negotiated roles shaped each teacher’s participation and identity.

Adding to the complexity of identity in practice is the reality that individuals may belong to multiple communities of practice, and therefore, have multiple identities. Their identity is shaped by their participation in each community. Though a person may behave differently in each community, they do not turn off their identity as experienced in one community when they move to another community. Thus, Wenger suggests that just as interacting communities of practice be viewed as constellations of practice, identity should be viewed as a “nexus of multimembership” in which learning trajectories “become a part of each other, whether they clash or reinforce each other” (p. 159). The result is that in order to be one person, rather than a collection of fragmented identities, one must reconcile his/her different forms of membership. This reconciliatory work is challenging and requires ongoing attention as learners move from one community of practice to another. The biology teachers in this study must reconcile their identities in their Biology PLC, other school and district level communities, and in their families.

Learners must also figure out who they are not in both local and global communities. Just as practice is both a local and global endeavor, identity is shaped by
participation in both local and global communities; the practices and ideals of these communities may or may not be consistent with one another. In this case, the teachers are attempting to revise the biology curriculum in the midst of other district and state initiatives. At times, those initiatives reinforce the goals of the PLC. For example, the school’s Executive Council provided training and resources to PLCs attempting to improve pedagogy by analyzing current student performance and making data driven instructional decisions. At other times, the policies of one community may clash with the other. For example, the Biology teachers are required to administer the End of Course Assessment (EOC), a standardized test that all Missouri biology students must take. Not only was this test designed prior to the release of *A Framework for K-12 Science Education* (NRC, 2011) and *NGSS* (Achieve Inc., 2013), research suggests that standardized testing for accountability purposes may counter science education reform efforts (Aydeniz & Southerland, 2012; Johnson, 2013; Maltese & Hochbein, 2012). Teachers must reconcile their identity in these local and global communities whether the ideals of the communities are supportive of, or in conflict with, one another.

Finally, identity is also shaped by non-membership. When individuals encounter the unfamiliar practices and artifacts of other communities, they realize who they are not, and thus refine who they are. When the teachers interacted with other biology teachers in the district, they realized they were approaching *NGSS* differently than others. When the biology teachers collaborated with other PLCs in their building, the biology teachers recognized that while some of their goals for students were similar, some of their goals and practices were unique. These interactions further refined their identities as individuals and as a cohesive community.
Identity shaped by participation and non-participation. Thus far, the focus has been on participation, but non-participation also shapes identity in significant ways. It defines and reflects what we value: what we learn or avoid, who we befriend or ignore and how we spend our time and energy. Wenger (1998) divides nonparticipation into two types: peripherality and marginality. By definition, peripheral participation requires some level of not participating so that the participant has an opportunity to learn. An example would be a new teacher’s peripheral participation in a PLC. However, marginality prevents some level of participation so that trajectories leading to learning and full participation may be closed. This kind of non-participation may arise from relationships within and between communities and their members and non-members as well as outside of institutional arrangements. For example, employees may be required to clock out at a designated time; physicians may be advised not to become personally involved with their patients, and researchers may only be able to make certain observations at certain times, but not others. In this PLC, teachers cooperatively planned the biology units, but they were not required (nor did they choose) to teach in the exact same way.

Identity shaped by belonging. Participation in a community gives one a sense of belonging that shapes one’s identity, but according to Wenger there are three different modes of belonging: engagement, imagination and alignment. These modes of belonging are represented in Figure 5.
One can belong through active engagement in the mutual process of negotiating meaning. This engagement affords learners the opportunity to develop competence in an enterprise, negotiate their role in that enterprise, and shape the context in which they are learning about the enterprise. The biology teachers in this study directed their own reform efforts. As the year progressed, each teacher expressed competence in a particular redesign task, e.g., finding resources, designing investigations that emphasized scientific practices, and rewriting assessments.

Engagement is limited by time and space and may impede one’s ability to participate in other communities. The biology teachers in this study collaboratively negotiated the meaning of NGSS as they revised their curriculum. They did so without the luxury of participating in the community of scientists, science teachers and science teacher educators who wrote the standards. The focus of this study is on how the biology teachers did this through active engagement in the mutual processes of meaning making.
While the focus of this study is on the biology teachers’ engagement in meaning making, imagination and alignment are not ignored. Wenger (1998) suggests that imagination allows learners to transcend time and space and create new images of the world and themselves. Imagination allows learners to envision the past, claim a fresh perspective of the present, and plan for possibilities in the future. The CoP framework supported an examination of how the biology teachers reimagined science teaching.

The processes of alignment form connective bridges between enterprises so that participants become a part of something much bigger, e.g., employees align their actions with the expectations of their employers when they fill out particular forms or dress in a professional manner. Alignment affords participants greater power because individual efforts are coordinated. However, it can also be a disempowering process that impedes participants’ ability to act based on their own judgments. The biology teachers revised their curricula to align with the expectations of their school, district, and state. This was empowering because they were able to revise their curriculum in ways that they felt were consistent with both NGSS and their school’s goals for supporting students’ critical thinking and writing. Yet, it was also disempowering as the teachers felt that the reform ideals espoused in NGSS were not aligned with the state’s EOC assessment.

Identity shaped by the dual processes of identification and negotiability.

Finally, Wenger (1998) claims that identity forms amidst a tension between the dual processes of identification and negotiability. In identification, learners invest something of themselves (and so shape their own identity) by participating in a community through engagement, imagination, and alignment. Identification is also shaped by the positive or
negative labels others apply. Identification is both a personal and a collective endeavor, but ultimately, it is the individual that chooses which meanings matter.

“Negotiability allows us to make meanings applicable to new circumstances, to enlist the collaboration of others, to make sense of events, or to assert our membership” (Wenger, 1998, p. 197). Participants can propose new ideas that may be adopted by the community. As the biology teachers redesigned the biology curriculum, all teachers posed possible ideas for instruction and assessment. Some of the proposed ideas were adopted; some were not. If a participant’s ideas are consistently not adopted, they may feel disempowered, develop an identity as a non-participant and be unable to learn.

While participants may be able to take away personal meaning from a story to which they can relate through imagination, they may feel marginalized and identify as a non-participant if they cannot see themselves in the story. “The critical issue is negotiability, not authority” (p. 206) coupled with identification shapes the individual’s identity.

**How CoP informs this study of a PLC**

Communities of practice are a context for learning. The dualisms and tensions that exist within them, e.g. participation and reification, experience and competence, order and chaos, etc. provide a “fertile ground for learning” (p. 214). When tensions cease, learning stagnates. The PLC in this study holds these tensions and provides a context for the teachers to negotiate the meaning of NGSS as they revise their curricula. The teachers make meaning through participation and reification and have a shared history and repertoire that brings order to their work; yet they find themselves in the midst of chaotic times as they negotiate the meaning of NGSS and reimagine their curriculum and practice in light of its recommendations.
While the authors of these new standards held a vision for the future, how teachers will come to understand that vision and claim it for themselves is unknown. What is known is that when individuals have an opportunity to participate in the practices of a community, the community becomes a “privileged locus for the acquisition of knowledge” (Wenger, 1998, p. 214, emphasis in original). When that community is also a well-functioning community that encourages idea sharing, it becomes a “privileged locus for the creation of knowledge” (p. 214, emphasis in original). In this case, the biology teachers created new knowledge about the meaning of NGSS and how they could revise their curricula to meet the new standards.

It was appropriate to frame this study of how one PLC made sense of a science education reform document by a theoretical framework about learning within a community of practice. CoP influenced the research questions, methodological choices and analysis (Hatch, 2002). Evidence of this influence can be seen in the Data Collection Matrix in Appendix A. This matrix lists research questions in the left most column, key themes of the CoP framework related to those research questions in the next column, and data that was collected to answer those questions in the remaining columns.

Further evidence of the framework’s influence is seen in the data collection methods. Group and individual interviews of the participating teachers were conducted in order to better understand the teachers’ collaborative and individual experiences of negotiating the meaning of NGSS. The interview protocols in Appendix B show attention to teachers’ individual identities as well as their collaborative efforts within their community.
During data analysis, the emphasis was again on the individual, the social context and the interplay between the two. The search for themes within the data considered how the teachers negotiated the meaning of the new standards individually and collaboratively and how that meaning is reflected in the process and products of reification. Analysis attended to the nature of the teachers’ participation within their PLC and with other communities, the PLC’s reimagined practice as represented in reified objects, e.g., their revised curriculum, and the teachers’ individual and collective experiences of negotiating the meaning of NGSS as they revised their curriculum. The final product is a rich description of the teachers’ individual and collective learning experiences as a result of their participation in their PLC’s reform efforts.

**Strengths and limitations of CoP as a theoretical framework for this study.** Using CoP as a theoretical framework for this study affords several strengths, but also limits the study in important ways. On one hand, CoP affords the appropriate level of analysis, encourages the exploration of the community in context rather than isolation, and does not falsely romanticize community. On the other hand, CoP is not a prescriptive framework, and no one size fits all recommendations come from this study. The following paragraphs further describe these strengths and limitations.

**Strengths of the framework.** Community is a midlevel category (Wenger, 1998) that is broad enough to capture meaning in context, but narrow enough to capture some of the process of learning. It allows the teachers’ story to be told in a way that is sensitive to individual identity without ignoring the social context that shapes that identity. Because CoP does not presume a dichotomy between the individual and the social, the focus of analysis is on the interaction between the two, not one or the other.
Similarly, communities such as this PLC do not function in isolation, and the CoP framework does not require one to study it as though it does. Rather, communities are viewed as a part of a constellation of communities, and members’ identities are viewed as being shaped by their participation in multiple communities. This allowed the exploration of how teachers’ participation in multiple communities shaped their participation in the PLC and how the PLC was shaped by its position within the broader systems of the school, district, and larger science education community.

Finally, community is not romanticized. Wenger (1998) cautions that saying “communities of practice provide a privileged context for meaning should not be misconstrued as romanticizing them” (p. 85). Though it is the researcher’s responsibility to conduct research in a trustworthy manner (Lincoln & Guba, 1985) regardless of the framework, CoP further supported efforts to bracket bias (Hatch, 2002); CoP offers a clear reminder that communities can be places of conflict as much as they can be places of cooperation.

Limitations of the framework. While community is the appropriate level of analysis for this study, there are limitations. Although CoP does not ignore the individual, the focus is on community. In this study, the focus is on the teachers’ meaning making within the community, not on the individual teachers’ classroom practice. I did not observe the teachers’ classroom practice. This is a reasonable and legitimate boundary for the study. My window into the biology teachers’ reform efforts is not their classroom door, but their workroom door. It is through this window that I observed how teachers collectively negotiated the meaning of NGSS as they revised their curriculum.
This is valuable research, but the end result of this research is not a prescription for teacher learning in PLCs; CoP is not a prescriptive framework. It cannot be. Wenger (1998) argues that “learning cannot be designed: it can only be designed for” (p. 229, emphasis in original). While this research does offer implications for science teachers, science teacher educators, and other members of the science education community, it does not offer a specific “one size fits all” prescription.

**Research Questions**

The primary research question guiding this study was: How do the secondary biology teachers within a mature, effective PLC negotiate the meaning of NGSS as they revise their curriculum? The sub-research questions were:

1. How do the Biology PLC’s interactions with other communities influence how the biology teachers negotiate the meaning of NGSS as they revise their curriculum?

2. How do the biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum?

3. How do the biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum?

**Significance of the Study**

This study of how secondary biology teachers in a mature, effective PLC negotiated the meaning of NGSS as they revised their curriculum is significant because it addresses gaps in the science education literature. NGSS provide a new vision for K-12 science education. Teachers who implement NGSS must first make sense of the conceptual shifts embedded in the reform and then revise their curriculum to help their students achieve the new standards. In order for teachers to make changes to their views
and practice, they need time and opportunities to collaborate with their professional peers (Gerard et al., 2010; Larkin et al., 2008). PLCs are a potential support structure for providing the collaboration time needed to re-envision teachers’ practice. PLCs can help teachers overcome the challenges of science education reform implementation (Richmond & Manokore, 2011), serve as a venue for science teacher learning (Goodnough, 2010; Richmond & Manokore, 2011; Roth et al., 2011), and act as agents of change (Nelson, 2008). However, there are few studies of mature, effective PLCs in science education; most of our understanding of science teacher PLCs comes from nascent communities that are often more focused on establishing group dynamics and goals than working together to achieve goals focused on student learning. Given the recency of NGSS, we also know little about teachers’ efforts to negotiate the meaning of these new standards and revise their curriculum. This study addresses these gaps.

Summary of Chapters

This chapter provides an introduction and rationale for the study. It includes a description of the theoretical framework, the research questions, and the significance of the study. Chapter 2 provides a review of the literature regarding K-12 science education reform implementation and K-12 professional learning communities. Chapter 3 explains the study methodology. Chapter 4 is a detailed presentation of the interpretations of the data. Chapter 5 is a discussion of the interpretations within the context of existing literature. It concludes with implications for science teacher education, professional development, and future research.
Chapter 2

Literature Review

This literature review is divided into two main sections: 1) a review of the research literature on K-12 science education reform, and 2) a review of the research literature on K-12 teacher learning communities. Special attention is given to science teacher PLCs. The review concludes with the identification of gaps in the literature.

Review of the Scholarly Literature on K-12 Science Education Reform

The purpose of this section is to synthesize researchers’ knowledge of how teachers have come to understand and implement K-12 science education reforms. The focus is on barriers, success stories, and the critical supports necessary for successful reform enactment.

The empirical studies upon which this review is based were found by searching several data bases, i.e., Google Scholar, JSTOR, and EBSCO Host (including Academic Search Elite, Education Full Text and ERIC) for key terms including “science education reform [and] implementation.” I also searched reputable science education journals, i.e., Journal of Research in Science Teaching, Journal of Science Teacher Education, and Science Education, and mined the reference sections of existing reviews and oft cited articles. I included articles between 1990 (the year after the publication of Science for All Americans) and 2016. However, since the Benchmarks were not released until 1993 and research on implementation takes time, empirical studies of K-12 science education reform enactment published prior to the mid-1990s are sparse. Research related to how science teachers have interpreted or implemented NGSS is also somewhat limited as NGSS was released in 2013.
As the study context is a high school biology PLC, studies in secondary settings were preferentially selected, but studies that included middle and elementary settings, teachers, and students were not excluded. While most of the articles explore reform implementation in the United States, international articles were not excluded as science education reform is a global issue (Tao, Oliver, & Venville, 2012). Non-empirical works (i.e., editorials and position papers) were excluded. Twenty-nine peer reviewed research articles were included in this representative review of the literature.

**Barriers to enactment.** The literature is filled with many reasons why reform implementation is so challenging. Those reasons fall into three major categories: negative teacher attitudes and beliefs, accountability pressure, and a lack of necessary supports for change.

**Negative teacher attitudes and beliefs.** Teachers’ attitudes and beliefs have a profound effect on their instructional practices (Jones & Carter, 2007), including whether and how they will reform their instruction. In a survey of 800 Ohio teachers designed to determine what influenced teachers’ intentions to implement a specific state curriculum, teachers’ attitudes toward implementation was the most important factor in predicting their intent to implement it (Haney et al., 1996). Among the three variables considered (teachers’ attitude toward implementation, teachers’ beliefs about how supportive others would be in implementing the model and their beliefs about resources, and other possible problems with implementing the model), teachers’ attitude toward implementation was the only construct that significantly contributed to their intention to implement all four strands of Ohio’s Competency Based Science Model (CBSM). Interestingly, there were important differences among subgroups. Men, high school teachers, less efficacious
teachers, experienced teachers and those less familiar with the model had significantly lower attitude scores and were less likely to implement the model.

Findings were similar in Donnelly & Boone’s (2007) survey of 229 Indiana biology teachers who were asked about their attitudes and use of their state’s science standards, particularly the evolution standards. “Teacher use of the standards was highly correlated with their attitudes toward the standards in general … and their attitudes toward the evolution standards in particular” (p. 251). Teacher attitudes toward evolution standards were also correlated with the amount of time spent on evolution instruction. These survey results suggest that when teachers have a negative view of standards, they may not implement the standards at all or they may spend less time on those standards.

Teachers attitudes and beliefs are not always as sharply divided as for or against a reform, and understanding teachers’ more complex attitudes and beliefs toward reform based standards and curricula is helpful in considering how reform will be enacted. Donnelly and Sadler (2009) described six different profiles of teacher attitudes toward standards. Analysis of 22 interviews of secondary science teachers revealed the following profiles: “negative perspectives, game of testing, already doing it, part of the cycle, reality of teaching and useful tools” (p. 1050). “Negative perspective” participants felt that teachers’ voices were not considered in the writing of the standards and that the large number of resulting standards demeaned their professionalism and negatively impacted student understanding. Unsurprisingly, these teachers frequently did not implement the standards. However, even teachers who hold less overtly defiant stances may not implement reform. Teachers who consider standards as just a “part of the cycle” may not think the standards are necessary for good teaching (Donnelly & Sadler, 2009).
Teachers who are satisfied with the status quo and content with their current practice may not implement reforms either (McRobbie & Tobin, 1995). In McRobbie and Tobin’s (1995) study of how teachers’ and students’ views of teaching and learning might constrain reform efforts, Australian chemistry teacher, Kevin, and his students were generally satisfied with current teaching and learning and saw no reason to change; Kevin felt he had to transmit a great deal of information in a short amount of time even if students did not truly understand because he saw his job as preparing students for the rigors of university. In a subsequent study, Tobin & McRobbie (1996) described Kevin’s belief in the following four myths: 1) the transmission myth characterized by an objective view of knowledge, an assumption that memorization is evidence of learning, and a belief that the teacher’s position is one of power; 2) the myth of efficiency characterized by a belief that time is of the essence and content coverage is more important than student understanding; 3) the myth of rigor characterized by a belief in strict adherence to high standards to prepare students for the university; and 4) the myth of preparing students for assessments characterized by an emphasis on low level cognitive tasks and a strong desire to have students earn high scores on exams. Interviews with teacher colleagues and administrators reveal that these myths are pervasive. Even though not overtly negative towards reform, these cultural myths are incongruent with reform ideals and thus constrain enactment.

If teachers do attempt to enact reform, the intended curriculum may not be enacted if teacher beliefs are not in harmony with the philosophy of the reform (Cronin-Jones, 1991; Czerniak & Lumpe, 1996). For example, Czerniak and Lumpe (1996) used the Science Teacher Efficacy Belief Instrument (STEBI) and BCSC’s (1994) Innovations
in Science Education survey (which includes the reform ideas of the Benchmarks, NSES, and America 2000) to determine teachers’ beliefs about the necessity of reform and their own perceptions of their implementation efforts. Of the 168 teachers who responded to the survey, 80% felt reform was necessary, but 80% also felt that constructivism, the learning theory central to the reform documents, was not necessary (Savasci & Berlin, 2012). Unsurprisingly, 74% of the teachers used constructivist approaches less than once per week or never. Hands-on/minds-on activities and nature of science (NOS) instruction were also infrequently used (Czerniak & Lumpe, 1996). Teacher beliefs explained 33% of the variance in the degree of reform implementation. Similarly, in Cronin-Jones’ (1991) case study of two middle school science teachers (Marcy and Shelley), the teachers’ beliefs about how students learn, the teacher’s role in the classroom, student ability levels, and the relative importance of the content affected curriculum implementation. Marcy and Shelley believed student acquisition of factual knowledge was the most important outcome. Thus, the teachers reduced information to factual bits, offered significant teacher direction, required drill and practice, and eliminated or reduced the amount of time intended to be completed for group work. Shelley, who did not have a positive attitude toward the curriculum, eliminated entire lessons, particularly those group tasks that fostered discovery.

Two case studies illuminate a more subtle way that the intended curriculum is sometimes not what is enacted due to teachers’ beliefs. Roehrig and colleagues’ (2007) mixed methods study of 27 high school chemistry teachers’ implementation of a reform based curriculum built around the 5E model describes three profiles of how teachers implement reform: traditional teachers, inquiry teachers and mechanistic implementers.
Mechanistic implementers included all of the elements of the curriculum, but failed to use teaching strategies that engage students in the kind of learning associated with effective inquiry instruction, e.g., collaborative group work, analysis of evidence, and thought provoking questions. This group of predominately beginning teachers believed that their students were not capable of inquiry learning and higher level thinking. So, while all of the steps of the 5E cycle were included, the curriculum intent was lost in their mechanistic implementation.

Though these studies were conducted years ago, the findings are still relevant today. Teachers’ beliefs and attitudes still influence reform efforts in subtle (and not subtle) ways. In a recent study, Chowdhary, Liu, Yerrick, Smith and Grant (2014) investigated teachers’ development of interdisciplinary science pedagogy and practice; teachers were again constrained by their beliefs about student abilities. Guided by the conception that NGSS promotes interdisciplinary learning, e.g., connections to math, English, language arts, science, and engineering, Chowdhary and colleagues designed summer research experiences and professional development workshops to support teachers’ development of interdisciplinary practices. Two of the three teachers did not implement intended interdisciplinary instruction. This was, in part, due to their belief that their inner-city students, who had poor reading skills and limited content knowledge, were unable to engage in interdisciplinary science inquiry practices.

A cross-case study of two private middle school and two public high school science teachers revealed that even when teachers’ beliefs do align with those of the intended reform, those reform-based ideals are still not always observed in practice (Savasci & Berlin, 2012). All four teachers in this study espoused constructivist beliefs
consistent with those expressed in reform documents. They described themselves as emerging, progressing or expert constructivists on a constructivist teaching and learning continuum adapted from the Teacher Pedagogical Philosophy Interview (Simmons et al., 1999). However, with one exception, classroom observations were consistent with actions one step below the teachers’ perceptions. Though the teachers at the private middle school used more constructivist approaches than the two public high school teachers, all of the teachers spent most of the class time on whole class activities, and three of the four employed more teacher-centered activities than student-centered activities.

When these reports are considered collectively, it is clear that teachers’ complex beliefs about, and attitudes toward, reform significantly influence whether and how reform is implemented. If teachers’ beliefs are negative toward the reform effort, implementation is hindered. Teachers may not implement the reforms at all, or they may implement the reforms in ways that are quite different than intended. Unfortunately, this discrepancy between the intended and the enacted curriculum can also be observed when teachers’ beliefs are aligned with the reform ideals.

Accountability pressure. While this review focuses on reform enactment at the teacher level, “a focus on teachers in classrooms is insufficient for reform, because teachers are only part of a larger system” (Lynch, 1998). What teachers do in their classrooms is not just the product of their attitudes, beliefs, education, and skills. Teachers’ practice is affected by outside forces, such as federal, state, district and individual school policies. Unfortunately, those outside forces have recently focused on
accountability measures that, despite good intentions, seem to have negatively affected classroom practice.

Educational testing used for accountability purposes existed prior to the 1990s (Anderson, 2012) but in this review, only those studies related to policies that may have affected science education reform enactment since 1990 are considered. In 1988, the Elementary and Secondary Education Act (ESEA) was reauthorized, and annual testing was mandated in those schools receiving Title 1 funds, though only some states imposed sanctions on those schools that did not meet particular performance requirements. The high stakes testing associated with federally mandated standards-based testing requirements of the 2001 No Child Left Behind (NCLB) have been more “more far-reaching...[and] more diligently enforced” (p.114).

The result has not been entirely positive. A survey of 161 secondary science teachers revealed that standardized testing for accountability purposes may counter science education reform efforts (Aydeniz & Southerland, 2012). Respondents from 14 states answered questions about their attitudes toward standardized testing and any changes they had made in their instructional practice in light of these assessments. Teachers indicated that the assessments required by the NCLB Act encouraged them to employ instructional strategies that improved assessment scores on the standardized tests. However, they did not think the tests measured the reform-based science education goals. The majority of the teachers felt the tests measured students’ acquisition of facts, and 37% changed their instruction in ways that countered their beliefs about good science teaching and learning in order to help students learn those facts. Ninety-three percent of the teachers also made significant changes in their assessment practices to better prepare
students for the high stakes tests. They reported fewer authentic, project based tests and more standard multiple choice exams. The majority of teachers’ comments about assessment for accountability were negative. In general, teachers reported that it led them to water down their curriculum, teach to the test, and de-emphasize critical thinking and inquiry. Teachers also questioned the validity of the assessments; the majority of respondents felt the tests did not assess what was taught in their secondary courses, were not reflective of teacher effectiveness, and were not taken seriously by students. The finding also highlighted teachers’ frustrations with what seems like a devaluing of science. Because many school districts do not include science results in their Adequate Yearly Progress (AYP) scores, teachers may feel pressure to emphasize math and literacy skills allowing less time for development of students’ conceptual understanding of science. This is consistent with an analysis of Indiana high school students’ 10th grade state standardized assessment scores and their 12th grade ACT and SAT scores; researchers linked students’ assessment scores from three consecutive years to their high schools’ assessment and demographic data. Schools were categorized as “improving” or “declining” based on their yearly school performance in English and Math on the state’s standardized test. Hierarchical linear modeling (HLM) was used to investigate the relationships between school and student performances. In schools identified as improving in English and math, the ACT science scores were characterized by a downward trend. The authors suggest that accountability policies that emphasize math and literacy skills may be “negatively associated with gains in science achievement and therefore contradict related STEM reform initiatives” (Maltese & Hochbein, 2012, p. 824).
It should be noted that not all findings regarding the impact of accountability pressures are negative. A minority of teachers in Aydeniz and Southerland’s (2012) study reported that the assessment policies positively influenced their practice. Four percent of teachers reported increased formative assessments, and 1% placed greater assessment emphasis on critical thinking. Still, the vast majority of teachers reported the effect of standardized testing and associated accountability pressures were negative and warrant the consideration of multiple stakeholders.

In summary, teachers’ classroom practices are affected by federal, state and local policies. Accountability policies that include high stakes testing may cause teachers to teach in traditional ways that are contrary to reform based instruction. Policies that emphasize math and literacy may be associated with a lesser emphasis on science and thus declining science achievement.

**Lack of resources.** Teachers sometimes lack the necessary resources, such as materials, knowledge and professional support, to implement science education reform. For example, teachers often use curriculum materials and the accompanying teacher resources, i.e., teacher textbooks and lab kits, to guide their planning and teaching (Ball & Cohen, 1996). Research shows that these teacher resources can help teachers develop content knowledge and instructional strategies and may offer a means for teachers to learn about reform based practices (Schneider & Krajcik, 2002). However, teachers may lack good curricula that help them make and justify sound pedagogical decisions (Beyer et al., 2009; Bianchini & Kelly, 2003). Beyer et al. (2009) analyzed eight popular high school biology curricula to determine their potential to promote teacher learning. The reviewers found that while the teacher guides provided abundant support for teachers’
subject matter knowledge (SMK) and pedagogical content knowledge (PCK) for science topics, they provided little support for their PCK for scientific inquiry. As the curricula included few inquiry opportunities, it was not surprising that they offered little support for teachers in helping students design, analyze and explain investigations. When the curricula did offer support related to the key concepts of the reform documents, most addressed how to implement particular strategies, not why one might use the strategies. Bismack, Arias, Davis, and Palincsar (2014) reported that when two fourth-grade teachers attempted to enact curricula that did not explain how or why to enact scientific practices, teachers made decisions based on their own experiences and PCK, and enacted the practices in ways that were inconsistent with the intent of the curriculum. These studies indicate that when teachers lack access to high quality educative curricula that allows them to critically consider reform suggestions and their underlying assumptions, they may enact teaching that differs from the intent of the reform or reform-aligned curricula.

Teachers may lack the skills they need to implement reform based instruction in their particular classroom environment. Luft and Roehrig (2005) studied the practices of three White, English-speaking, first-year secondary science teachers in rural and urban schools with primarily Hispanic, Spanish speaking students. Despite the teachers’ participation in a support group for beginning teachers and their enthusiasm for working with a diverse student population and teaching science using inquiry, all three teachers struggled to use reform-based instruction. In an effort to deal with the language and cultural differences, two of the three teachers’ beliefs about teaching and student learning shifted toward a more teacher-centered orientation that favored direct instruction. The
teacher who did continue to try to teach in reform-based ways was an emergency certified teacher who lacked the necessary skills to design a cohesive curriculum, so his students learned concepts in a disconnected way. In all three cases, English as Second Language (ESL) Learners were marginalized because the teachers lacked the skills they needed to teach ESL learners using reform-based principles.

Teachers may also lack the professional support of their teacher colleagues, building administrators, and state and local policymakers (Lynch, Pyke, & Grafton, 2012; Roehrig et al., 2007). Lynch et al.’s (2012) retrospective study of the implementation and subsequent scale-up of three middle school science curriculum units revealed that a lack of state and local supports can be a barrier to enactment of effective curricula. Two of the three curricula: Chemistry That Applies (CTA) and Motion and Force (M&F) were found effective, but scale-up efforts were not sustained due to insufficient support. Teachers felt that CTA was geared to minority and low SES students despite data that showed improvement for all student groups. Teachers were skeptical of M&F and preferred the less demanding, district sponsored unit that had been written by former local teachers. As both curricula went to scale, state policy and frameworks changed and support dwindled further. The state began to emphasize new science assessments and teacher evaluations that did not align with CTA. It became clear that the district was focused on assessment and teacher evaluation. Also, the state framework made a more expedient curriculum seem a better choice than M&F, which required six full weeks of instruction. Successful reform requires support from administrators and teachers, as well as state and local support of reform based curricula, particularly if those curricula seem more demanding, time-consuming, and expensive.
In summary, teachers sometimes lack the physical and human resources to reform their science instruction. They may lack good curricula that allows them to critically consider reform suggestions (Beyer et al., 2009), laboratory materials and technology that support reform-based instruction (George, 2007; Harmon et al., 2002), skills they need to teach in reform-based ways (Luft & Roehrig, 2005), time to think deeply about and redesign their practice (Badiali & Rousmaniere, 1996), or the professional support of their teacher colleagues and state and local administrators (Lynch et al., 2012; Roehrig et al., 2007).

**Success Stories.** Not all empirical revelations are so dismal. In spite of the challenges, teachers can and do enact reform-based teaching. While it is likely that many success stories do not appear in the pages of scholarly journals, many do. Some stories are of small steps in the right direction; others are of radical reformation. Here are a few of those stories, purposefully selected, because each adds something unique to the picture of successful reform.

With support from the National Science Foundation (NSF), some rural schools have overcome the challenges of isolationism and tight budgets to successfully reform science education (George, 2007; Harmon et al., 2002). Rural schools often lack physical resources, such as laboratory materials and adequate technology (Harmon et al., 2002) as well as human resources, such as access to high quality professional development (George, 2007; Oliver, 2007). The Ozark Rural Systemic Initiative (ORSI) and Appalachian Rural Systemic Initiative (ARSI) used NSF funds to improve dozens of schools’ infrastructure (particularly their technology capabilities), adopt reformed curricula and provide extensive PD for teachers with little or no experience teaching
through inquiry, problem solving and reasoning. Teachers moved away from more traditional beliefs about teaching and learning toward more student-centered beliefs and practices. The authors believe that with continued administrative support and technical assistance, the changes will be sustained.

Success on a smaller scale was observed in a study of six experienced high school science teachers who, despite their competing belief sets, enacted inquiry-based instruction in their own classes after attending summer professional development workshops (Wallace & Kang, 2004). While the teachers did ascribe to some of the constraining myths identified by Tobin & McRobbie (1996), all teachers included some level of inquiry in their instruction. Analysis of participants’ journals and interview responses revealed that each teacher held a personal, core belief that inquiry promoted critical thinking, creativity, and engagement in doing science. Despite school cultures that encouraged traditional instruction, the teachers achieved their more private goals by various means, e.g., teaching one of their two courses as inquiry, incorporating a few inquiry activities, and staying within the content of the required curriculum. Obviously this is not the perfect scenario, but it is a modest success.

Modest success was also observed in a mixed methods study of 12 high school chemistry teachers implementing the NSF funded 10th-grade chemistry curriculum, Living By Chemistry (LBC) (Roehrig & Kruse, 2010). When the teachers were using the LBC curriculum, their Reformed Teaching Observation Protocol (RTOP) scores were significantly higher; however, the change was not uniform. One of the teachers was already teaching in ways that were consistent with her student-centered beliefs and the ideals of the curriculum. Four of the teachers, all of whom were traditional teachers,
made modest changes by selecting pieces of the LBC curriculum that they could add to their regular practice. The remaining seven participants made substantial changes to their instruction. These teachers held various beliefs, but all recognized the need for change and were enthusiastic about the new curriculum. All seven were teaching out of their discipline, and though they wanted to teach in reform-based ways, they lacked the content knowledge to design lessons aligned with reform recommendations. The curriculum provided the support they needed be successful in changing their practice.

Sometimes, radical change at the school level allows for reform at the classroom level. This is what happened when the principal of a failing school (who was professor on research leave) “asked teachers to help him change the school from the inside out” (p. 3). The most critical change that resulted from those discussions was an 80 minute, four period semester schedule with a common lunch time. Teachers and students were no longer “prisoners of time” (p.4) and could include in-depth problems, lengthy discussions, and more involved laboratory work in their classes. Teachers used common planning times to discuss practice, plan and evaluate lessons, and design interdisciplinary learning opportunities. Teachers successfully planned and implemented rich learning experiences that included opportunities for inquiry and problem solving in science because they were afforded the necessary time and collaboration to do so.

Longitudinal studies of how reform was initially implemented and subsequently sustained are rare, but one particular case study of how a group of high school science teachers successfully implemented and sustained a 9th grade science curriculum, Integrated Science Program (ISP), for 25 years offers valuable insight into what is required for sustained change (Larkin et al., 2008). Teachers embraced the changes.
They felt that ISP afforded students a high quality science education that aligned with state and national standards. They also felt it afforded them a shared language and experience to discuss their practice with colleagues and others while still allowing them some autonomy in instructional decisions. However, teachers were constrained by a lack of time; creating new lessons was difficult and time consuming. As new challenges developed over time, teachers learned important lessons: 1) teaching decisions should be data driven and 2) reform efforts should consider state and local policy. The participants resolved four of Anderson’s (2007) five dilemmas. The teachers resolved the dilemma of limited time by focusing less on content coverage and more on inquiry-based approaches that supported comprehension. The teachers resolved the dilemma of idealistic standards by investigating and changing their practice in ways that allowed them to make those idealistic goals a reality in their own classroom. Collaboration eliminated feelings of isolationism and allowed them to change their roles and work. Finally, they changed their view of the goal; rather than seeing the goal of their work as preparing students for the next class, they saw developing students’ understanding of inquiry as the goal and believed this understanding would allow students to be successful in future science endeavors. The teachers did not resolve the dilemma of equity. Teachers recognized that their instruction worked for many, but not all. The teachers successfully implemented and sustained a reform based curriculum but still needed to close the achievement gap.

In summary, despite the barriers to reform enactment, the literature provides several examples of successful science education reform. With the support of external funding, rural teachers overcame a lack of physical and human resources that had previously constrained reform. With professional development, teachers within
traditional school cultures found ways to teach from an inquiry stance. With whole school support, teachers had the collaboration time to plan rich interdisciplinary lessons that supported inquiry, critical thinking, and problem solving. With the support of reform-based curricula and the continued support of their professional colleagues, teachers were able to sustain change. Teachers can make meaningful, reform-oriented changes to their curricula and practice.

**Critical supports for successful science education reform enactment.** The following paragraphs further examine the lessons learned from these studies and others about what is needed to successfully implement science education reform. The literature is filled with suggestions, most of which focus on professional development for in-service teachers, high-quality teacher education for preservice teachers, and systemic support of teachers’ reform efforts.

**Professional development.** The implications section of nearly every study discussed the need for high quality professional development (PD). The literature suggests that the kind of PD needed for teachers to enact reform addresses teachers’ attitudes and beliefs, values teachers’ voices, fosters in-depth understanding of the reform documents, and provides opportunities for collaborative planning and analysis of practice (Donnelly & Sadler, 2009; Parke & Coble, 1997; Van Driel, De Jong, & Verloop, 2002). The following studies provide a few examples and suggestions for PD programs that enable and support reform enactment.

Project LIFE, a Louisiana PD program, offered upper elementary through secondary life science teachers an opportunity to experience science as scientists and develop lessons that would allow their students to do the same (Radford, 1998). Working
in small collaborative groups, participants solved problems, analyzed data, and presented interpretations of those data in an intensive 3-week summer course. Teachers conducted independent science investigations and presented their findings at a science exposition. Teachers were asked to reflect on how they might incorporate this kind of reform-based teaching and learning in their own classroom. Each teacher developed a year-long plan for integrating these new instructional practices, authentic investigations, and alternative assessments, and during the school year, teachers received ongoing support. All of the 90 teachers who participated in the three year study were observed implementing the reform-based instruction they had experienced during the summer.

In another study of the effect of PD on reform enactment, middle school math and science teachers’ self-efficacy and reformed teaching practice improved during a three-year program that combined content knowledge support with opportunities for teacher collaboration (Lakshmanan, Heath, Perlmutter, & Elder, 2011). The teachers enrolled in a content course (physical, life or earth science) each summer and met in PLCs during the school year to share best practices and resources. Analysis of teachers’ pre and post-test content scores, their responses to the Science Teacher Efficacy Beliefs Instrument, and four observations revealed that teachers’ self-efficacy and reformed teaching increased during the program. Self-efficacy and RTOP scores were positively correlated. This result is consistent with Czerniak and Lumpe’s (1996) finding that teachers’ self-efficacy is associated with their acceptance of education reform. These studies provide evidence that a standards-based PD program that fosters collaboration and supports teachers’ content knowledge needs can have a significant positive impact on teachers’ reform enactment.
Parke and Coble (1997) recommend a five-phase model of PD that they found effective in transforming middle school science teaching. In this model teachers shared their views and concerns about education, discussed reform documents and summaries of current research on teaching and learning, discussed their own beliefs about science teaching and how those beliefs did or did not align with reform documents and research literature, designed lessons, described the kind of environment that would be necessary to implement them, and rethought the purposes of assessment. The PD was provided to teachers, principals and district science coordinators. The 19 teachers who participated in the PD taught fewer topics with greater depth than the 11 teachers who did not. Students of participating teachers had more positive attitudes and reported doing more experiments and collaborative work. There was no significant difference between the two groups of students’ scores on the state’s fact-based science test. These results are promising as they suggest that, with appropriate PD, teachers can teach in reform based ways even in a system that holds them accountable for student acquisition of facts.

Donnelly and Sadler (2009) recommend “profile-specific professional development approaches” (p.1073) based on the teacher profiles [shown in italics] revealed in their previously described study of teachers’ views of standards and accountability. Teachers with Negative Views of the standards would benefit from PD that helps them reconceptualize their favorite lessons in ways that support standards and encourages them to be involved in policy decisions at the state and local level. Testing as Focus teachers fully embrace standardized testing and tend to teach to the test. PD that helps them carefully examine the standards as they make changes in curriculum and instruction, and encourages them to share the practices that have the greatest positive
influence on students’ assessment scores would be most helpful. Teachers who were *Already Doing It* were already teaching in ways that were consistent with the standards, but reported that they would modify their instruction if assessment results indicated the need to do so. Therefore, PD that addresses data-driven instructional choices would be most appropriate. Teachers who feel the standards are just a *Part of* [the] *Cycle* would benefit from PD that helps them identify how the current standards could improve their practice. Those who viewed standards as simply a *Teaching Reality* were beginning teachers who could not envision teaching in a climate other than the current one, which is focused on standards-based reform and accountability. They might benefit from PD that fosters collaboration with experienced teachers with a different view.

I have included these PD studies in this review not to tout a particular formula, but as illustrations of the kind of powerful, extended PD that is suggested in the literature and supported by empirical evidence. In a review of the PD literature in the context of science education reform, van Driel, Beijarrd, & Verloop (2001) concluded there is not one ideal model of PD; rather, multiple strategies are necessary. Suggested strategies include those that “promote changes in teachers’ knowledge and beliefs” (p.148) and provide access to materials and opportunities for collaboration and reflection. Van Driel and colleagues suggest that these strategies might be employed in the context of PLCs, peer coaching, or collaborative action research in addition to more traditional summer PD programs and workshops. The authors caution that PD is typically not effective as a “one shot intervention,” and thus might be best designed as a more long-term approach that extends through a semester or year(s). Effective PD takes time.
In summary, there is evidence that high quality PD may support science teachers’ efforts to implement reform. While there is no one perfect PD model, those that give attention to teachers’ attitudes and beliefs, address reform principles, offer authentic science learning experiences, and foster collaboration have been shown to increase teachers’ reform enactment.

**High quality teacher education.** Just as in-service teachers need high quality professional development, those entering the field need to receive high quality teacher education that equips them to enact reform-based instruction. The literature supports teacher education programs that address teachers’ attitudes and beliefs (Jones & Carter, 2007), have a strong focus on reforms (Luft & Roehrig, 2005), encourage appropriate use of standards (Donnelly & Sadler, 2009), and allow students to experience inquiry-based instruction as learners and develop as reflective practitioners (Luera & Otto, 2005).

Again, the studies included here are not meant as a suggestion of a single best approach, but as exemplars of possible approaches to teacher education that would prepare preservice teachers to teach in reform-based ways.

Teachers, especially beginning teachers, often teach as they were taught (Bryan & Abell, 1999; Loughran, 2007); so, when the University of Michigan revised their elementary science education program, one of their goals was to allow students to experience learning science through inquiry in their science content courses (Luera & Otto, 2005). The revised program used inquiry-based pedagogy in the three required content courses: physical, life, and earth and planetary science. The content of those courses was tied to the *NSES* and Michigan’s state frameworks. Data from 119 students who completed the old program, 21 students who completed the reformed program, and
145 students who completed a mixture of traditional and reformed courses were compared using ANOVA. Students who completed the reformed program (or two or more of the inquiry courses) had significantly higher self-efficacy scores on the STEBI. However, the outcome expectancy did not differ significantly between the groups indicating that teachers’ beliefs that their teaching will impact students’ understanding of science are resistant to change. Still, this study provides evidence that preservice teachers who are taught content through inquiry learning and are encouraged to reflect on their learning and teaching can increase their content knowledge and their confidence in their ability to teach science; the preservice teachers may teach in the inquiry-based way they were taught in the reformed courses.

Likewise, opportunities for teacher candidates to engage in NGSS science practices as learners may impact their future efforts to engage students in science practices. Richmond, Parker, and Kaldaras (2016) examined preservice teachers’ ability to construct explanations, an NGSS science practice. In methods courses, the preservice teachers constructed explanations based on a what (data)/how (patterns or laws)/why (explanations) framework. The authors imply that the framework could be used by the preservice teachers to guide and assess their future students’ constructed explanations.

Teacher education forums that allow preservice teachers to explore reform documents in meaningful ways may also impact future reform enactment (Lynch, 1998). Twenty-five preservice and beginning teachers in a M.Ed. program for secondary science education studied Science for All Americans, the Benchmarks and the NSES in small groups and then presented their findings to their peers during an interactive seminar. Each seminar leader then developed a set of teachers’ criteria that could be used to
determine whether a teacher was actually helping students achieve the desired outcomes. For example, one group’s criteria included this question: “Has the teacher provided students with the opportunity to use their imaginations to solve science problems and analyze the results?” (p. 11). Teachers developed teaching units and analyzed them using the criteria. Though only some teachers were able to implement the units, participants reported in post study formal evaluations that they had a deeper understanding of the reform documents, agreed with the recommendations, and were eager to implement them. The author asserted that this forum is promising since reform efforts “must be understood well and appear to be implementable” (p. 14) before they can actually be implemented.

Another compelling approach by Lynch and her colleagues was to require students to build curriculum units using a web database and Project 2061’s Curriculum Analysis (Lynch, Pyke, & Jansen, 2003). Fifteen beginning high school science teachers, who were enrolled in an advanced math and science methods course, searched for a web database that would be appropriate for secondary students and aligned with the standards. For example, one teacher used a “Duke University mathematics database on the relationship of snowshoe hares to Canada lynx populations … over a 90-year period” (p. 201). Students built a framework for a curriculum unit based on a single standard using the web database and the guidelines provided in Project 2061’s Curriculum Analysis. If time allowed, students built lessons based on their framework. Lynch analyzed the frameworks and found that students typically addressed four of the seven topics included in the curriculum analysis by providing a sense of purpose, taking into account student ideas, engaging students with phenomena, and enhancing the learning environment for
all. A follow-up study of one of the students who successfully implemented the curriculum the following fall provided evidence that graduate courses that provide “meaningful intellectual encounters with reform principles and curriculum materials” (p. 127) do impact teachers’ practice.

These collective findings suggest strong teacher education programs can equip beginning teachers to enact reform-based instruction. Programs that offer preservice teachers opportunities to experience non-traditional instruction as learners, explore reform documents, and plan reform based lessons may support their future classroom enactment.

**Systemic support.** While there is a clear need for high quality teacher education and professional development, teachers are a part of, and affected by, a larger educational system. In order for teachers to implement reform-based instruction in their classrooms, they require the support of that larger system.

Data from a three year longitudinal case study of seven principals’ efforts to support science education reform indicate what a tremendous impact school leadership can have on teachers’ efforts to teach in innovative ways (Gerard et al., 2010). During the first year of a five year NSF funded reform project in 29 schools across five states, researchers were inspired by principals’ interest in regular face-to-face collaboration regarding their schools’ efforts to enact technology-enhanced science curricula. Their teachers were attempting to implement Web-Based Inquiry Science Environment (WISE) curriculum modules that addressed challenging middle and high school science concepts through inquiry activities enhanced by interactive models and simulations. Four high school principals and two middle school principals met regularly to discuss how to best
support their science teachers. Qualitative analysis of observation notes, meeting
transcripts, interviews and a questionnaire revealed a variety of ways these principals
were able to support the science teachers’ reform efforts. The principals learned how
teachers’ pedagogical decisions and students’ thinking and learning during WISE lessons
were different than during lessons from traditional textbooks. Principals valued these
differences such that their focus shifted from WISE-specific discussions to larger issues
of reform. They began “framing challenges and generating strategies for reform” (p.
164). They wrote grants, sought support from parent committees, and allocated funds for
the purchase of necessary technology. They used state mandated PD time to support
science teachers’ professional growth, reworked schedules to allow teachers sufficient
time to implement new lessons, checked in with their science teachers and recognized
their efforts, and began to see how teachers’ willingness to implement reform might
influence their future hiring decisions. This research suggests that principals can have a
powerful impact on teachers’ efforts to enact innovative instructional strategies and that
“a professional learning community provides a space for principals to think about …
curriculum reform from a systemic perspective” (p. 173). The powerful impact of a
proactive principal is seen in other studies as well (Badiali & Rousmaniere, 1996).

District policy makers can also have a powerful impact on teachers’ reform
efforts. When these individuals have a deep functional understanding of the message of
the reform documents, they can support teachers’ efforts to make deep structural changes
in pedagogy (Spillane & Callahan, 1999). Spillane and Callahan selected nine school
districts for their case study of district policy effects on reform implementation. They
analyzed school policy documents and the transcripts of 165 interviews with district math
and science consultants, lead teachers, and other policy makers involved in science education reform. Participants were familiar with science education reform documents and perceived that they were implementing the recommendations, but substantive alignment was only found in three of the nine districts. Analysis of participants’ rhetoric about reform indicated a somewhat limited understanding of the reform. While 83% of policy makers discussed “hands-on” activities, only 45% discussed students’ conceptual understanding and just 13% mentioned constructivist learning theories. Thus, they supported surface-level changes in science education, but “learning was still chiefly about remembering, and teaching was about telling and showing. New pedagogical forms—hands-on science activities—were understood in terms of conventional pedagogical functions” (p. 415). However, policy makers in the three schools who were implementing substantive reforms had a more in-depth understanding of the intent of reform recommendations, and were thus better able to support teachers’ efforts to effect students’ conceptual understanding.

Revisiting the findings and implications of studies previously described in this review reveals other ways that school leaders and others involved in science education at the local, state and federal level can support or thwart K-12 science education reform enactment. State and local administrative emphasis on accountability measures and curricula that covered more topics more expediently contributed to the failure of efforts to scale-up reform-based middle school curricula (Lynch et al., 2012), but administrative support allowed for sustained change (George, 2007; Harmon et al., 2002). Accountability measures, such as those of the NCLB act, led some teachers to enact instructional strategies that contradicted the philosophy of reform documents and
devalued science education (Aydeniz & Southerland, 2012); however, Anderson’s (2012) review of the related literature suggests that policies and assessments could be altered to emphasize the goals of science education reform and thus better support teachers’ enactment efforts. Beyer et al.’s (2009) analysis of high school biology curricula found that many curricula lack high quality, in-depth support of teachers’ PCK for scientific inquiry, but asserted that more educative curricula that guide teachers’ critical examination and implementation of reform do exist and can be written. Following this study, Krajcik, Codere, Dahsah, Bayer, & Mun (2014) offered a 10-step guide to designing NGSS aligned lessons and NSTA has offered many practitioner resources.

In summary, the burden of science education reform does not rest entirely on teachers. Teachers’ efforts to reform must be supported by the larger educational system. They need the support of their professional peers (Lynch et al., 2012), building principal (Badiali & Rousmaniere, 1996; Gerard et al., 2010), district administrators, curriculum developers (Beyer et al., 2009), and state and national policymakers to implement and sustain change (Aydeniz & Southerland, 2012; Spillane & Callahan, 1999).

**Conclusion and implications.** In conclusion, the vision of science education, as articulated in recent reform documents, has not been achieved. The relevant scholarly literature illuminates multiple barriers to reform enactment at the K-12 classroom level. These include teacher attitudes and beliefs that are not consistent with reform ideals, accountability pressure that sometimes leads to practices that are contrary to reform recommendations, and a lack of resources that constrain teachers’ efforts. Despite these barriers, the literature includes many success stories and suggests that high quality
professional development and teacher education, as well as systemic support of teachers’ reform efforts, are critical for future successful science education reform.

The collective implications of the literature point to a need for the development of high quality professional development and teacher education programs; changes in national, state and local level behaviors and policies; and future research that supports those efforts. Though the lessons of past reform efforts are invaluable, there are few studies related to the implementation of current reforms. NGSS offers unique reform recommendations based on three dimensional learning. Future research might explore how teachers make sense of these recommendations and integrate crosscutting concepts into their instruction in the core areas, and what teachers learn about science teaching as they attempt to enact NGSS aligned instruction. One possible way to explore these and other questions is through the lens of teachers’ collaboration in contexts such as PLCs.

**Review of the Literature on K-12 Teacher Professional Learning Communities**

The purpose of this section is to synthesize researchers’ knowledge of K-12 teacher learning communities. The focus is on how these communities can support teacher and student learning, and function as a context for education reform. Particular attention is given to science education PLCs.

I searched the same databases and the same journals for this review as I did for the previous section. I used the following search terms: professional learning community (PLC), “professional community,” “teacher learning community,” “professional learning team (PLT),” “collaborative inquiry community,” and “critical friends group (CFG).” The review includes articles published between 1995 and 2016 as these concepts did not
appear in the literature until 1995. A total of 26 peer reviewed research articles and two literature reviews were included in this representative review of the literature.

I begin by discussing the scholarly literature within the broad context of K-12 education. The purpose of this part of the review is to define what constitutes a PLC and synthesize what is known about creating and sustaining effective PLCs; the purpose of the later part of the review is narrower. The later part of the review synthesizes research on PLCs within K-12 science education with special attention given to research on secondary science teachers’ learning communities and their potential to support teachers’ efforts to implement reform-oriented instruction.

**Defining an effective K-12 teacher PLC.** Various definitions of a PLC exist within the literature, but all convey the idea of a group of teachers working “collaboratively to reflect on their practice, examine evidence about the relationship between practice and student outcomes, and make changes that improve teaching and learning” (McLaughlin & Talbert, 2006, p. 4). For example, Hord (1997) defines a PLC as teachers and administrators who “continuously seek and share learning, and act on their learning…to enhance their effectiveness as professionals for the students’ benefit” (p.1). Bolam et al. (2005) define an effective PLC as one that has “the capacity to promote and sustain the learning of all professionals in the school community with the collective purpose of enhancing pupil learning” (p. 145). Clearly, there are similarities between these definitions - each emphasizes community and teacher and student learning.

While there is no single agreed upon definition of a PLC, there is broad agreement these communities have defining characteristics (Bolam et al., 2005; Stoll et
al., 2006). Through their study of 15 restructuring elementary, middle and high schools, Kruse et al. (1995) identified and described the following five essential features of PLCs.

1) Reflective dialogue. Kruse and colleagues (1995) reported teachers in a learning community talk about a variety of relevant issues including subject matter, problems of practice, student learning and larger institutional concerns. In a review of the peer reviewed research and practitioner literature, Hord (1997) reported that through these conversations participants seek and share knowledge of teaching and student learning that may be used to solve problems.

2) Deprivatization of practice. Traditionally teaching has often been a private, even isolated, endeavor (McLaughlin & Talbert, 2001; Rosenholtz, 1989; Snow-Gerano, 2005), but teachers in a PLC may observe one another and openly discuss their teaching, thus making their practice public (Kruse et al., 1995).

3) A collective focus on student learning. Teachers assume all students can learn and teachers can help them do so (Kruse et al., 1995). The teachers’ focus is not on just their teaching or their own acquisition of content, but on their students’ well-being (Grossman et al., 2001) and what their students actually learn (DuFour, 2004).

4) Collaboration. Teachers work together to develop an understanding of instructional policies, curriculum materials, and new approaches to their own professional development (Kruse et al., 1995). The teachers take collective responsibility for their students’ learning (Bolam et al., 2005) as well as their own continuing intellectual development (Grossman et al., 2001).
5) Shared norms and values. Through their interactions, teachers form common values regarding educational concerns, such as how students learn, the best use of resources, and the role of teachers and other individuals in student learning (Kruse et al., 1995). Teachers’ shared values and vision guide their actions in teaching (Hord, 1997).

Other researchers have confirmed these features of PLCs, though sometimes they have done so with slightly different terminology or with additional characteristics. After analyzing 393 survey responses and 16 case studies from English elementary, middle and secondary schools, Bolam et al., (2005) identified eight characteristics of effective PLCs, which include “shared vision and values; collective responsibility for pupils’ learning; collaboration focused on learning; individual and collective professional learning; reflective professional inquiry; openness, networks and partnerships; inclusive membership; mutual trust, respect and support” (p. i). Through her case study of nine middle and secondary math and science teacher PLCs, Nelson (2008) also identifies inquiry as an essential component of PLCs, but defines this inquiry stance as collective knowledge negotiation which allows teachers to “develop common understandings about learning, students, curriculum, subject matter, teaching practices, or contextual influences” (p.551). Although the labeling is different, the idea is similar to what Kruse et al. (1995) referred to as collaboration and a collective focus on student learning.

Terminology aside, the implication across the literature is that communities with these characteristics are effective (Bolam et al., 2005; Stoll et al., 2006), strong (Kruse et al., 1995) or exemplary (Cowan, Fleming, Thompson, & Morrisey, 2004), and it is suggested that within these effective PLCs, these features operate synergistically, not
independently (Hord, 2004). This study focuses on the work of a mature, effective PLC that also meets Wenger’s (1998) definition of a well-functioning community of practice that freely explores new insights without becoming stuck. Such effective PLCs are not established overnight. The following section highlights what is known about creating (and sustaining) effective PLCs.

**Creating and sustaining PLCs.** PLCs may be a promising venue for teacher learning (Grossman et al., 2001; Kruse et al., 1995; Nelson, 2008; Vesico et al., 2008) and change in the educational reform movement (Englert & Tarrant, 1995). However, traditional American schools are not set up for community in the work place; teachers work is private (Rosenholtz, 1989; Snow-Gerano, 2005), and there is no time for teacher learning during the school day (Grossman et al., 2001). Teacher collaboration and professional development must occur before or after school or during the summer away from their school context and colleagues (Grossman et al., 2001). Even if teachers are given time and a place to meet, simply bringing teachers together does not make a PLC (van Es, 2012); as is surely evident from the preceding definitions of a PLC, teacher learning communities are more robust than just a group of teachers who meet for casual conversations. Rather, PLCs are potentially powerful communities of teachers working collaboratively to improve practice and ultimately, student learning (Bolam et al., 2005; van Es, 2012; Hord, 1997; Kruse et al., 1995; Stoll et al., 2006). Creating and sustaining such a community is no easy feat; in fact, Grossman and her colleagues (2001) liken the formation of a teacher community to the pangs of birth!

Much of what we know of this sometimes painful process comes from case study research during professional development (PD) programs and university-school
partnerships with a learning community component. The forthcoming sections of the literature review summarize a few of these accounts of PLC formation, describe the stages of PLC development evident within these examples, explain the obstacles PLCs must overcome during development, and outline the supports necessary for sustaining a PLC.

**Case studies of PLC formation.** Grossman et al. (2001) invited secondary English and Social Studies teachers to create an interdisciplinary curriculum as part of a 2.5 year professional development program. The 22 volunteers met bi-monthly and for one week of the summer to read and discuss literature about how to teach students through critical reading of texts. The PLC had a rocky beginning - the participants were an eclectic group of teachers, many of whom probably would not have joined were it not for the stipend and departmental pressure to do so; the teachers were familiar with one another and there was already tension between the two departments and some of the teachers. Initially, a sort of pseduocommunity formed where everyone played nicely, spoke in generalities, suppressed conflict and let the facilitator attempt to lead discussion, but as teachers attempted to define their purpose and what is meant by critical reading, cracks formed in the pseudocommunity with one teacher leaving and fractions and alliances forming within those remaining. Facilitators openly discussed their concerns and established norms for future discussions. Though tensions between content and pedagogy remained, the teachers’ interactions began to be more positive, productive, and respectful of differences. The facilitators’ role decreased as teacher leaders emerged from within the group. By the end of year two, the teachers’ conversation invited new ideas, treated those ideas as public property, and respectfully pushed those ideas further.
The teachers spoke of themselves as a collective unit, and were aware of how much progress they had made as a community. However, the researchers recognized that the community was still fragile, and suggested that perhaps the formation of a community is a journey, not a destination.

Van Es (2012) also describes an arduous journey with a similarly challenging beginning as she sought to form a teachers’ video club and propose a framework for the development of a teacher learning community. As part of this university-school partnership, seven fourth and fifth-grade elementary teachers (whose students had low math proficiency) met regularly for one year to discuss students’ mathematical thinking. The transcripts of these meetings were analyzed for evidence of three features of PLCs: collegial and collaborative interactions, participation and discourse norms for productive collaboration, and focus of activity on teaching and student learning. Initially, the teachers’ conversations were one-sided, focused on general education issues and personal experiences, and devoid of collaboration. As the year progressed, the teachers began to support each other’s work, listen to others’ ideas and attend to particular teaching practices. By year’s end, they had developed strong cooperative relationships, consistently pushed each other’s thinking and were deeply committed to the pursuit of improved teaching practices and student learning. Though the author deemed the PLC high-functioning in all three of the areas considered, progress was not equal in these areas. The development of participation and discourse norms was most challenging. In agreement with Englert and Tarrant’s (1995) assertion that time is critical to the development of teacher learning communities, van Es asserted that taking time for
participants “to learn about each other’s goals and to develop norms for interaction” (p. 190) was critical to community development.

The importance of good communication is compounded when a fledgling teacher community is attempting to impact the whole school as 10 teachers in an Australian secondary school undergoing a revitalization process called Innovative Design for Enhancing Achievement in Schools (IDEAS) soon discovered (Andrews & Lewis, 2002). These teachers represented multiple disciplines, but all desired to support and further the school’s vision of teacher excellence. Despite the initial stress and messiness of reconciling different teachers’ perspectives, these volunteers learned to dialogue across departments, changed their own practice, and developed a framework that other teachers could use to “plan, assess, evaluate, guide practice, change student-teacher interaction and generate deep discussion” (p. 247). However, the young teacher community struggled to clearly communicate their work with other teachers in the school, causing some to feel excluded, unaware or uninterested.

Nelson’s (2008) in-depth case study of three middle and secondary math and science PLCs (developed in a three year PD program) was also a story of mixed success that further elucidates the challenges of establishing and sustaining an effective PLC. One of those challenges is that developing an inquiry stance towards one’s practice requires deprivatization of practice and a collective focus on student learning. Developing such a culture is no easy task as is evidenced in Nelson’s examination of the teachers’ dialogue, activities and learning, and the impact of these on their practice. Though all three of the PLCs wanted to positively impact students’ learning, two of the PLCs struggled – the ninth grade physical science teachers had little support from a
facilitator, struggled to find regular meeting times, switched their focus from inquiry to curriculum alignment, interacted more as experts than learners, and ultimately failed to significantly change their practice. The cross-grade science and math PLC did have considerable support from a project facilitator, but struggled to work across disciplines and grade levels. The teachers did not know how to analyze their students’ work and use that data to inform their teaching. Only the middle school science PLC (led by two teachers who demonstrated an inquiry stance) successfully deprivatized practice and maintained an inquiry stance throughout the year. These teachers had strong relationships and began their collaborative work by looking at anonymous state data that may have helped make the transition to looking at their own students’ work less difficult. The teachers then adopted a clear goal, critically evaluated their teaching and students’ learning, and made changes in their practice that positively impacted students’ science writing ability.

When considered collectively, these case studies suggest that beginning teacher communities need time to establish group norms and become comfortable with deprivatizing their practice. The varied success of these PLCs suggests that leadership and a focus on inquiry and strong teacher relationships that offer support for sharing and risk taking may be keys in developing PLCs, but the mixed result also raises questions about how to create and sustain effective collaborative communities.

**Stages of PLC development.** PLCs go through predictable stages of development. Grossman et al. (2001) proposed that communities progress through three stages (beginning, evolving, and mature) with respect to the following four dimensions of community formation: 1) formation of group identity and norms of interaction, 2)
navigating fault lines (those issues which are a source of discord), 3) negotiating the essential tension (between content and pedagogy), and 4) communal responsibility for individual growth. Bolam and colleagues (2002) proposed similar stages of development which they termed starter, developer and mature. DuFour et al. (2006) described five stages of a development continuum; in the final stage, sustaining, teachers have clearly established short and long term goals, created action plans, worked together to achieve their goals, and celebrate efforts and success.

Clearly, the formation of a PLC is a process; teachers’ initial interactions differ from their later discussions. Teachers in PLCs in the initial stages of development are more focused on their interactions with one another (DuFour et al., 2006); they are establishing productive group dynamics, defining their role within the group, and just beginning to articulate goals. With a better sense of how to work together, teachers in mature PLCs are free to focus on achieving their clearly defined goals for improving student learning. It is for these reasons that a mature, effective PLC was purposefully selected for this investigation of the teachers’ reform efforts. If a beginning PLC was chosen, the teachers might be more focused on the challenges of establishing community than reforming science education.

The challenges PLCs face. The challenges of community formation are significant as illuminated by the previously described case studies. During the early stages of development, teachers must establish group identity and productive norms of interaction (Grossman et al., 2001; van Es, 2012). They must learn to see individual differences, not as threats, but as valuable resources for teacher and student learning (Grossman et al., 2001). As PLCs mature, they must move away from the old traditions
of isolated practice (McLaughlin & Talbert, 2001; Rosenholtz, 1989) and establish new traditions of deprivatized practice (Kruse et al., 1995) and collective learning (Grossman et al., 2001).

Through their extensive studies of teacher learning communities in 16 public and private high schools in California and Michigan, McLaughlin and Talbert (2006) explain that moving toward this kind of learning community requires re-culturing. An essential component of this re-culturing is that teachers must learn to analyze students’ work and critically examine their teaching in ways that allow them to identify and close the gaps between teaching and learning. Herein lies another challenge – teachers often have limited experience with classroom-based data collection and analysis (Nelson, 2008) making it difficult to take an inquiry stance toward their work. It is significant that the high school in this study context provided professional development to all teachers for making data driven instructional decisions.

Another challenge PLCs may face is “contrived collegiality” (Hargreaves, 1994). Hargreaves applies this term to enforced collaboration that occurs in response to administrative directives. In contrived collegiality, teacher meetings are a matter of compulsion and are often implementation oriented, meaning that teachers are expected to implement a particular, mandated program or curricula. Unfortunately, this kind of collaboration is inflexible at best, and demeaning at worst, as it may not allow teachers to work on what they feel is important in ways that it would be most helpful to their particular students. Certain aspects of the PLC in this study are contrived. The district requires all science teachers to meet and plan with the other teachers in their school that teach the same discipline, and all science teachers are required to begin implementing
NGSS (NGSS Lead States, 2013). However, much of the teachers’ work is at their discretion. The meetings are not regulated by administration, and the teachers may choose when they meet, how they spend their time, and how they implement the new reforms.

In summary, PLCs face many challenges from the early stages of community formation to the more mature stages of collective teacher learning aimed at improved student learning. Overcoming these challenges requires re-culturing. We now consider the supports that are necessary for this re-culturing to occur.

**Critical supports for success.** Several researchers, i.e., Kruse et al (1995), Richmond and Manokore (2011), and Snow-Gerano (2005) investigated critical supports for teacher learning communities to be successful. Kruse et al. (1995) suggested these supports can be divided into two categories: structural conditions and social resources. The structural conditions include: 1) physical proximity that allows for observation and discussion, 2) interdependent teaching roles that encourage team planning and teaching, 3) communication structures such as regular meetings or an email group that supports the exchange of ideas, 4) teacher empowerment and school autonomy that affords teachers the ability to use their own judgment, and 5) time. Others have confirmed the value of these supports. Teachers need time to develop as a community (Grossman et al., 2001; McLaughlin & Talbert, 2006; van Es, 2012), think critically about and discuss their practice (Badiali & Rousmaniere, 1996; Englert & Tarrant, 1995; Stoll et al., 2006) and understand and implement reform (Akerson et al., 2009; Osborne et al., 2013). When teachers do not have sufficient collaboration time, they may be unable to effectively implement reform, as was evidenced by the null findings of Osborne et al.’s (2013) study.
In this investigation of four UK school science departments attempting to develop the use of argumentation as an instructional strategy, no significant differences in students’ reasoning ability, science content knowledge, or beliefs of and attitudes toward science were found. Comparisons were between an experimental group (students whose teachers were attempting to implement argumentation) and a control group. The authors suggest this was because teachers in the experimental group, who were participating in a minimalist professional development program, did not have sufficient time to make changes in their beliefs and practices.

Despite the importance of these structural conditions, Kruse and colleagues (1995) suggest that social and human resources are even more important. First, they suggest that PLCs must feel an openness to improvement. The inservice and preservice elementary teachers in Snow-Gerano’s (2005) investigation echoed this finding; they valued the openness to dialogue, uncertainty, and change that existed within their university school partnership PLC. Richmond and Manokore’s (2011) investigation of two elementary, grade level, cross-school PLCs participating in a professional development program also revealed a similar finding; support for taking instructional risks was seen as key to community sustainment. Second, Kruse et al. (1995) identified trust and respect as a necessary social resource. Again, the teachers in Snow-Gerano’s (2005) study echoed this sentiment, stating that they valued the PLC as a safe space to question their practice and take risks. Third, Kruse et al. (1995) and Richmond and Manokore (2011) found that PLCs must include teachers who have content knowledge and pedagogical knowledge. Fourth, all researchers identified the need for supportive leadership; that supportive leader is sometimes a school principal who offers time for
collaboration, seeks to understand teachers’ needs, and provides resources (Badiali & Rousmaniere, 1996; Gerard et al., 2010; Snow-Gerano, 2005). A facilitator can also play an important leadership role. In the vast majority of the case studies included in this review, the communities were supported by a facilitator(s) who helped the teachers establish norms, frame discussions, assist with data analysis, etc. For example, in the 2012 study by van Es, the facilitator (a university researcher) showed video segments of the participants’ teaching and prompted them to identify and analyze evidence of students’ understanding. Grossman et al. (2001) reported the facilitators/researchers initially chose the PLC readings, helped the teachers define critical reading, and mediated difficult group dynamics. Richmond and Manokore (2011) reported the facilitator (the district science coordinator) raised issues for discussion and helped the teachers assess students’ work in ways that could help them understand students’ thinking. The support of these facilitators and professional development programs or university-school partnerships were seen as critical to the teachers’ success. Finally, Kruse asserts that PLCs must allow for socialization, some means of passing on the communities’ vision to newcomers. Wenger (1998) would describe this process of socializing newcomers as legitimate peripheral participation. Richmond and Manokore (2011) describe these processes of socialization as key to sustainability.

In conclusion, there is broad agreement that structural and social supports such as time, openness to risk, and supportive leadership are critical to a PLC’s success. In the presence of such significant support, there is potential for significant success. PLCs can exist as a venue for teacher learning, student learning, and educational reform. In the forthcoming sections, I synthesize what is known about PLCs as a context for teacher
learning, student learning, and educational reform, with special attention given to science education contexts.

**PLCs as a venue for teacher learning.** Englert and Tarrant (1995) reported on the formation of a teacher/researcher community that devised a new curricula for literacy instruction for students with mild disabilities. The researchers provided some ideas for assessing and addressing students’ literacy needs, but “because teachers had different settings, goals, activities and ways of teaching” (p. 328), they also learned from one another. “The accumulated wisdom of the members of the community was far greater than that offered by researchers alone or by individual teachers alone” (p.328). The collective wisdom of a community is what makes learning in communities possible.

While it is valuable to consider teacher learning in PLCs of various disciplines, it is a mistake to assume that PLCs are generic; issues of context, e.g., grade level and discipline, matter (Bolam et al., 2005; Grossman et al., 2001; McLaughlin & Talbert, 2001). With that in mind, we now turn our attention to *science* teacher learning with PLCs.

PLCs can help teachers develop meaningful science content understanding (Goodnough, 2010; Melville & Wallace, 2007; Nelson, 2008; Richmond & Manokore, 2011; Roth et al., 2011). For example, Roth and colleagues (2011) examined the effect of a video-based analysis of practice professional development program on elementary teachers’ science content knowledge, teaching practice, and student learning. In this quasi-experimental design, all 48 teachers received content instruction at a summer institute. In the experimental group, the 32 teachers spent additional time on analysis of practice activities in small facilitator-led learning communities that continued to meet
throughout the year (this group was referred to as Science Teachers Learning from Lesson Analysis [STeLLA]). The 16 teachers in the control group did not participate in the STeLLA program, and received only “as-needed” support. The STeLLA group experienced significantly greater gains in science content knowledge that did not wane throughout the year, and only the STeLLA group improved in their ability to analyze lessons in terms of student thinking and science content. The authors attributed the differences to the program’s sharp focus and learning community component. In another study, a two-year investigation of 10 secondary Australian science teachers’ learning within a PLC, teachers shared content knowledge and pedagogical content knowledge (PCK) for teaching geology and ideas about science and society (Melville & Wallace, 2007). Importantly, the constructed narratives illustrated transfer, movement of the knowledge between persons, and transposition, evidence of teachers using the knowledge in practice in new contexts.

PLCs can also influence teachers’ views of the nature of science (NOS) (Akerson et al., 2009). Seventeen elementary teachers participating in a professional development program formed a community of practice that met regularly with a facilitator to discuss their developing views of NOS. Through their analysis of participant interviews and pre-post V-NOS responses, Akerson and colleagues found that all teachers improved their views of NOS, and some were able to change their practice, in part, due to the influence of their community of practice. The authors suggested the open, trusting environment supported change when paired with NOS modeling and reflection.

PLCs may help teachers teach science in more equitable ways. For example, Bianchini & Cavazos (2007) asked how two beginning teachers were influenced by their
participation in a teacher learning community as they learned to teach diverse students in equitable ways. Though the two teachers did not have equally positive experiences, both were influenced by their interaction with their peers; their reflections and interactions helped them see how some groups are marginalized in science education and consider how different teaching practices might address the inequity. Findings were similar in a study of eight middle school science teachers participating in a three-year transformative professional development program designed to support teachers’ efforts to implement culturally relevant science instruction in their classrooms (Johnson, 2011). As part of the professional development program, the teachers (all from diverse, urban, high-poverty, low-performing schools) met regularly to share experiences and learn together. Teachers improved their beliefs and practice in all areas of culturally relevant pedagogy (CRP).

PLCs can be places where teachers learn new pedagogy. In Osborne et al.’s (2013) study, teachers learned to use argumentation in their science classrooms. As a part of a minimalist professional development program, lead teachers from four UK science departments received professional development regarding argumentation that they shared with their respective learning communities. In Richmond and Manokore’s study (2011), teachers learned not only science content, but general pedagogical content knowledge (PK) and pedagogical content knowledge (PCK). Similarly, in a three-year professional development program that combined content knowledge courses with PLCs for middle school math and science teachers, classroom observations using the Reformed Teaching Observation Protocol revealed significant improvement in teaching practices (Lakshmanan et al., 2011).
PLC’s may positively influence teachers’ self-efficacy and outcome expectancy (Mintzes, Marcum, Messerschmidt-Yates, & Mark, 2013). In Mintz et al.’s (2013) investigation of changes in elementary science teachers’ self-efficacy and outcome expectancy, there were significant differences favoring teachers’ participating in PLC supported by university professional development. Interview data revealed that PLC participants who had previously minimized science in their curricula and practice felt empowered by their PLC and appreciated the opportunity to work together on creating and revising lessons. They shared successes and felt more confident in their ability to include science in their practice. Their students’ enthusiasm for the new lessons provided further encouragement to continue to “take that type of teaching back to the classroom” (p. 1214).

In summary, PLCs can be a venue for teacher learning. Research shows that within science teacher learning communities, teachers can improve their NOS views and learn science content, reform-based pedagogy, and equitable ways of teaching science to all learners. Thus, as van Driel et al. (2001) suggested, science teacher learning communities can be a context for professional development that changes teachers’ knowledge and beliefs and supports reform.

**PLCs as a venue for supporting students’ learning.** While teacher learning is important, the ultimate goal of a teacher’s work is student learning. Vesico et al. (2008) reviewed the literature on “how teaching practices or student achievement change due to teachers’ participation in a learning community” (p. 82). At the time, there were only 11 empirical studies that linked teachers’ participation in an effective learning community to teachers’ practice in their classroom; 8 of the 11 studies linked teachers’ participation to
student achievement via reporting students’ standardized test scores or teachers’ responses to interview questions about student achievement. “All eight studies … that examined the relationship between teachers’ participation in PLCs and student achievement found that student learning improved” (p. 86). Moreover, “student achievement gains varied with the strength of the PLC” (p. 87) - the stronger the PLC, the greater students’ achievement.

However, none of the studies were science specific. Since the publication of the Vesico et al. (2008) review, a few studies link science teachers’ participation in teacher learning communities to gains in students’ science achievement. For example, the teachers in the eighth-grade science PLC in Nelson’s (2008) investigation worked collaboratively to improve students’ science writing, particularly their use of evidence in writing conclusions. When the science writing scores of students of PLC teachers were compared to the science writing scores of students of non-PLC teachers, the PLC teachers noted substantial positive differences.

In Roth et al.’s (2011) examination of a video-based, analysis of practice PD program with a learning community component, not only did teachers’ science content knowledge improve, students’ science content knowledge also improved. Students completed a written science content exam before and after instruction during the year prior to teachers’ participation in the program; a new group of students completed the same pre-post exam the year after the teachers participated in the program. Students’ science learning gains were compared before and after their teachers’ participation. Students’ science learning gains nearly doubled after teachers’ participation in the learning community based program.
Two studies suggest that students’ science learning may improve when their teachers participate in a PLC because when teachers experience for themselves the power of collaborative learning within a community, they may implement powerful cooperative learning in their own classrooms. Two of the teachers in Johnson’s (2011) study found the PLC component of the PD program so valuable that they developed student collaborative learning communities. This cooperative classroom learning structure lent itself to more reform oriented teaching practices where students were regularly engaged in inquiry and co-construction of meaning. The teachers in Akerson et al.’s (2009) study of a PD program with a learning community component also fostered collaborative student learning. The purpose of the PD program was to improve teachers’ views of nature of science (NOS), but the teachers reported that because of their work in their community of peers, they were able to establish a similar climate of trust in their own classrooms that allowed them to better teach their students about NOS. The teachers saw subsequent gains in students’ science understanding.

In summary, while a focus on student learning is a defining characteristic of effective PLCs (DuFour, 2004; Kruse et al., 1995), there are only a few empirical studies that have examined the relationship between science teachers’ participation in a teacher learning community and students’ science learning. However, those that have investigated this, have found that students’ science achievement is greater when students’ science teachers are involved in a PLC. There is evidence that the stronger the PLC, the greater students’ achievement is. There is also evidence that when teachers experience the benefits of collaborative learning, they are more likely to offer collaborative learning experiences to their students.
PLCs as a potential venue for science education reform. PLCs may be a potential venue for science education reform because they may help teachers overcome the very things that impede reform implementation. For example, accountability pressures may negatively impact science teachers’ reform efforts (Aydeniz & Southerland, 2012; Johnson, 2013; Maltese & Hochbein, 2012). However, there is evidence that when teachers are working within a PLC, they may find ways to achieve their goals for science education reform despite accountability pressure (Richmond & Manokore, 2011). In Richmond & Manokore’s (2011) study of two elementary PLCs, science was not a priority in the participating Reading First schools. Math and language, not science and social studies, were assessed on the state and district assessments; therefore, many of the PLC participants’ peers were ignoring or deemphasizing science. Though the participants were not oblivious to the external pressures, they were committed to science teaching and found ways to achieve the PLC’s science teaching goals while still meeting district demands.

Moreover, when science teachers experience success, they can become agents of change (Stein et al., 1999). Case in point, in Nelson’s (2008) study, the eighth grade science PLC that experienced success in helping students improve their science writing ability presented their work at faculty meetings, a district showcase event, and a national conference causing a ripple effect among their professional peers - one principal in attendance implemented PLCs for each department at his school. Thus, Nelson offered cautious optimism of the transformative potential of PLCs. She is optimistic because her research and the research of others provides evidence that teachers’ collaboration within PLCs can make a difference. She is cautious because, like others, she is aware of the
many challenges PLCs must overcome in order to reform science teaching in ways that positively impact students’ science learning.

**Conclusion and implications.** PLCs are potentially powerful communities of teachers working collaboratively to improve practice and ultimately, student learning. These communities do not develop overnight, but develop slowly over time in the presence of various structural and social supports. Mature, effective PLCs can be a context for teacher learning that positively impacts student learning.

Teachers within science PLCs have improved their content knowledge and views of NOS, learned reform-based pedagogy, and learned to teach science in equitable ways. Thus, PLCs may be a venue for science education reform. However, much of our understanding of science teacher PLCs is from investigations of newly formed PLCs affiliated with professional development programs. Future research regarding mature, effective science teacher PLCs is needed

**Gaps within the Literature**

When the literature on K-12 science education reform and K-12 science teacher PLCs is considered collectively, it is apparent that there are gaps in our understanding. Those gaps, and how this study addresses those gaps, are stated explicitly in the bulleted list below.

- **There are few empirical studies of NGSS implementation.** Decades of science education reform efforts and research have yielded multiple insights regarding reform implementation, but we know little about how teachers will come to understand and implement the most recent reforms. Through the
window of a mature, effective PLC, this study investigates how secondary biology teachers negotiate the meaning of and implement NGSS.

- **There are few studies of mature, effective PLCs in science education.**
  While research suggests that mature, effective PLCs may be a powerful venue for education reform, most of our understanding of science teacher PLCs comes from nascent teacher learning communities that may be more focused on establishing group dynamics and goals than working collaboratively to achieve goals focused on student learning. This study investigates the collaborative efforts of a *mature, effective* PLC that has articulated clear goals for implementing NGSS and improving students’ science learning.

- **There are few studies of science PLCs working without external support.**
  The vast majority of studies of science teacher PLCs are affiliated with a professional development program, university-school partnership or other external support. Thus, we know little about the work and potential of science teacher PLCs attempting to reform their practice without the help of a professional development program, science education professor or other facilitation. This is a significant gap given that these resources are often unavailable to PLCs situated some distance from institutions of higher education. This study addresses this gap by investigating the work of an *independent*, mature, effective science teacher PLC.

- **There are few, if any, studies of science teachers working within a PLC to negotiate the meaning of reform and develop their own curricula aligned to that reform.** Most studies of PLCs reform implementation efforts are of
PLCs who are implementing developed curricula or who are developing curricula within a professional development program and/or with a university researcher(s). The PLC in this study is collaboratively negotiated the meaning of *NGSS* and *developed their own curriculum* to help their students achieve the standards.
Chapter 3

Methodology

Paradigm

In 1970, physicist turned philosopher, Thomas Kuhn, suggested that “the history of science is a history of revolutions wherein scientific paradigms have emerged, suffered crises, and been replaced by competing paradigms” (Hatch, 2002, p. 11). Paradigm is one of those overused words that has lost some of its original meaning in recent years, but when used as Kuhn intended, the term refers to a set of assumptions about “how the world is ordered, what we may know about it, and how we may now it” (Hatch, 2002). It describes a way of looking at the world (Patton, 2002). For example, a positivist paradigm assumes that objective reality exists and can be known through experiments. The postpositivist paradigm also assumes that an objective reality exists, but it asserts that because of human limitations that reality can only be approximated through quantitative and qualitative methods.

The paradigm to which I subscribe is constructivism. As a constructivist, I believe that absolute truth cannot be known and that multiple realities are constructed by individuals (Hatch, 2002). I believe that knowledge is a human construction based on individual experiences that are best understood through naturalistic qualitative research (Denzin & Lincoln, 2005). In the following paragraphs, I further describe my underlying ontological, epistemological, and methodological assumptions and how they have guided this research.

Ontological Assumptions
Ontology is the study of reality; it answers the question, “What is the nature of reality?” (Patton, 2002, p.10). The constructivist paradigm assumes a world devoid of objective, absolute reality; constructivists believe that multiple realities exist because each individual constructs his or her own reality based on unique experiences in the world (Hatch, 2002). Individual realities are experientially based, local, and specific (Lincoln & Guba, 2000).

I believe each teacher in the Biology PLC constructed his or her own reality regarding reform implementation based on experiences of meaning-making within the PLC. As a constructivist researcher, I sought to understand these “multiple social constructions of meaning and knowledge” (Patton, 2002, p. 18), not because the results would represent a “definitive capture of a reality that can be generalized to a larger population” (Patton, 2002 p. 18), but because they may be adapted by others in ways that may be meaningful to them.

**Epistemological Assumptions**

Epistemology addresses the limits of human knowledge; it answers the questions, “What is the nature of knowledge and the relationship between the knower and the would-be known?” (Patton, 2002, p. 10). Constructivists view knowledge as a human construct and believe that the knower (researcher) and the known (participants) influence one another (Hatch, 2002; Patton, 2002). Constructivist researchers believe that they co-construct understanding with their participants and that truth is what they and their participants agree it is (Hatch, 2002). They do not claim to be distant or objective. Rather, the validity of claims is supported by multiple data sources (Patton, 2002).
In this study, I viewed myself as a “human instrument” (Denzin & Lincoln, 2005). I personally attended the PLC meetings and became familiar with the teachers and their work within the PLC. I collected multiple sources of data, and used that data to co-construct meaning with the participants. Thus, the product of this research is a rich narrative of the constructed interpretations (Hatch, 2002).

**Methodological Assumptions**

Methodology addresses how knowledge is gained (Hatch, 2002); it answers the question, “How can the knower go about obtaining the desired knowledge and understandings?” (Patton, 2002, p. 10). The methodological assumptions of the constructivist paradigm are underpinned by hermeneutic-dialecticism (Hatch, 2002; Patton, 2002; Thomson & Butson, 2008). “Hermeneutic-dialecticism pays particular attention to context, takes account of different constructions of the phenomenon under study and allows for these constructions to be understood, discussed and subjected to critique. Hermeneutics views …interpretation as central. A priority [of hermeneutics] is to capture or reveal the perspectives, and elucidate the context, of research participants, including the researchers” (Thomson & Butson, 2008 p. 2). The purpose of this kind of research is to tell the participants’ story through the researcher’s interpretations of data (Patton, 2002).

The methodological implications of multiple realities are many. Participants are not randomly chosen to represent a larger population, but purposefully selected because of unique qualities and contexts of interest to the researcher (Patton, 2002) and his or her academic community. Constructivist researchers favor prolonged observation of the purposefully selected participants in their natural setting and collect data from multiple
Research and interview questions evolve over time as the study progresses and more is understood about the participants and their construction of reality (Patton, 2002). Ultimately, reality is actually co-constructed as the researcher shares data analysis and interpretations with participants in a process that Hatch (2002) refers to as member checking. To clarify, in this study, I co-constructed a description of how the teachers collaboratively negotiated the meaning of NGSS. I did not co-construct the meaning of NGSS with them.

In light of these methodological assumptions, I chose to do naturalistic qualitative research, which is typical of constructivist work (Lincoln & Guba, 1985). For this particular investigation, I purposefully selected a mature, effective PLC that adopted NGSS in the fall of 2013. I believe that in telling their story others may recognize pieces of their own reality and be able to apply what these teachers learned to their own unique contexts. In order to tell their story, I observed them for an extended period of time – one complete calendar year, and collected data from multiple sources including PLC meetings, curriculum created by the teachers, and extensive interviews of the teachers. As I analyzed and interpreted the data, I shared my tentative interpretations with the teachers and asked them to confirm or disconfirm whether the interpretations accurately portrayed their experience of negotiating the meaning of and implementing NGSS.

**Research Tradition**

Case study, a unique tradition within qualitative research, is a typical constructivist approach (Hatch, 2002) that affords the researcher the opportunity to study
“the particularity and complexity of a single case, coming to understand its activity within important circumstances” (Stake, 1995, p. xi). Thus, I chose this research tradition for this investigation of one case, a mature, effective PLC negotiating the meaning of the most recent U.S. science education reform. The following paragraphs further describe the case study research tradition and how its principles were applied in this investigation.

According to Stake (1995), there are three types of case studies: intrinsic, instrumental and multiple. Intrinsic case studies allow the researcher and reader to develop a better understanding of a particular case for the sake of understanding that unique case, not a generic phenomenon. Instrumental case studies examine a particular case in order develop an understanding of a more general issue, and multiple case study research refers to the examination of more than one case in order to understand an even greater collection of similar cases. This is an instrumental case study. The purpose of studying this particular case is to better understand how science teachers might collaboratively negotiate the meaning of science education reform as they revise their curriculum.

Merriam (1988) defines case study as “an intensive, holistic description and analysis of a single instance, phenomenon, or social unit” (p. 27). That single instance, phenomenon or social unit (Merriam, 1988) is the case or bounded system (Smith, 1979; Stake, 1995). Yin (1984) defines the case as “a contemporary phenomenon within its real-life context” (p.13). Merriam (1988) offers some clarity to Yin’s rather broad definition, explaining that the case may be “a program, an event, a person, a process, an
institution or a social group” (p. 13). In this study, the case is a social group, the Biology PLC.

**Case study boundaries.** The boundaries of the case or system must be defined by the researcher (Smith, 1979). This case is bounded by time and the participants’ practice. Data collection centered on the meaning making which occurred within and along the edges of the Biology PLC during the 2013-2014 school year. The majority of the teachers’ practice, and thus the majority of the data, came from the teachers’ face-to-face interactions during PLC meetings, email communication, jointly created curriculum documents, and interviews about their experiences of collaboratively negotiating the meaning of NGSS.

The biology teachers negotiated the meaning of NGSS within their own unique context. Communities do not exist in isolation (Wenger, 1998). The practices of their community intersected, overlapped, and interacted with other communities. For example, as part of their reform efforts, the Biology PLC interacted with other PLCs at their school (particularly the World Studies PLC), other Biology PLCs in the district, and representatives of their school and district administration. I provide a “thick description” (Denzin & Lincoln, 2005) of the context and explore how the PLC’s interactions with other communities at the edges of their own community influenced their reform efforts. Yet, the focus is not on the other communities. It is on the practices of the biology teachers within and along the edges of their community. I did not collect data beyond the community interaction that occurred along those edges. I did not attend other discipline’s PLC meetings or other district biology PLC meetings. However, I did ask the biology
teachers about the influence of these other communities and collect data during jointly held meetings.

Even though the final narrative describes how the teachers planned to implement NGSS and their reflections on their efforts to reform their teaching, this is not a study of classroom implementation or reformed teaching practice. I did not observe any of the teacher’s classroom practice because this is a study of the PLC’s negotiated meaning of NGSS. Finally, this case is bound by time. Data was collected during the 2013-2014 school year and the following summer and early fall as teachers reflected on their experiences and made plans to extend and improve their reform efforts in the 2014-2015 school year.

Context

The School. I purposefully selected a mature, effective PLC: a group of six high school biology teachers teaching general biology at Cross View High School (pseudonym). This Midwestern high school had a total enrollment of approximately 2,000 students in grades 9-12 during the 2013-2014 school year. The student population was somewhat diverse; seventy-five percent of the students were European American, and the remaining 25% were African American, Asian, Latino and Indian. Twenty percent of the students received free or reduced lunch.

Cross View High School is an innovative, student-centered community with a commitment to providing a high quality educational experience to every student and a strong history of academic achievement. Although the state had not adopted NGSS at the time of the study, the school district decided to do so at the recommendation of the district science coordinator. All science teachers in the district were working within their
local and district level communities of practice to negotiate the meaning of NGSS and revise their curricula during the 2013-2014 school year.

Cross View High operates on an alternating day, eight-period block schedule. The science department offers a variety of courses including zoology, entomology, oceanography, astronomy, and exercise science courses in addition to general, honors and Advanced Placement (AP) physics, chemistry, biology, and human anatomy and physiology courses.

The school district. Cross View High School is one of three public, secondary schools within a larger school district that serves more than 18,000 students. Within each high school, the teachers who teach the same discipline plan in teams that they refer to as Professional Learning Teams or PLTs. For the sake of simplicity and consistency, the term PLC is used throughout the dissertation when referring to all same-discipline communities of teachers within the district. However, anecdotal evidence obtained prior to data collection suggests that the degree of collaboration within each community varies widely, and only some teams would be considered mature, effective PLCs as defined by Kruse et al. (1995). Figure 6 provides a graphic representation of the Cross View Biology PLC’s interactions with the two other biology PLCs in their school district.
The Cross View High School Biology PLC is depicted in red. The two other high schools in the district, Mountain View High School and Valley View High School (pseudonyms), are shown in white. In Figure 6, the overlapping lines represent the PLCs’ overlapping practice. The PLCs primarily plan independently. However, in June 2013, all three PLCs met to discuss how they would approach revising and aligning their curricula in response to the district science coordinator’s request that the teachers adopt NGSS and give a common semester assessment.

**The PLC.** I purposefully selected the Cross View High School Biology PLC (henceforth referred to as the Biology PLC), because it was an established, mature PLC. The original PLC was formed during the 2000-2001 school year to allow and encourage teachers to collaboratively plan for their science course(s), examine student work and reflect on their teaching and students’ learning. None of the original members of the PLC still teach at Cross View, but the current science department chair joined the PLC just one year after its inception, and one of the participants in this study, Nancy (pseudonym) joined in 2002. During its 14 years of existence there have been many changes in
membership. Old-timers and newcomers (Lave and Wenger, 1991) have worked through the difficult early stages of development described by Grossman et al. (2001), Bolam et al. (2002) and DuFour et al. (2006), making this a PLC a mature PLC.

A shared vision that is focused on student learning is one of the characteristics of mature, effective PLCs (Bolam et al., 2005; Hord, 1997; Kruse et al., 1995). This trait is evident in this PLC’s articulation of long and short terms goals. In 2013, their long term goals were to: 1) “develop students who can think critically and communicate effectively about scientific concepts and issues, and 2) make science more relevant by focusing on skills and by connecting knowledge with cross-curricular applications.” Their short term goal was to “revamp each unit this year.” As they redesigned each unit, they wanted to 1) “build in instruction and practice that allows for the development of critical thinking and communication, 2) include common assessments that truly assess/evaluate these skills, 3) align language and rubrics with other departments (beginning with [World] Studies), 4) grade assessments together to build understanding among the PLC and to reflect on what is and is not working, and 5) use this information to highlight ideas for best practices” (email communication, 11-4-2013).

Another indication of the PLC’s maturity is that they established time, space and group norms for their collaborative work. The teachers met once each week before school for 45 minutes in the science department’s workroom to collaboratively plan their curriculum, instruction, and assessment. They discussed their practice and student learning. Because they were making significant changes in light of NGSS during the 2013-2014 school year, they regularly met at other times for a longer period of time. The PLC also scheduled additional longer meetings to develop a unit outline or discuss and
grade student work. The teachers set aside this kind of extended collaboration time after school or during professional development or teacher work days. During the week, the teachers communicated via email. As the teachers worked on their PLC homework (individual tasks they assigned themselves in order to meet group goals), they emailed drafts of curricular documents and solicited feedback. They also shared how students responded to a new activity and offered helpful tips to those who would be teaching the same lesson later. Prior to each PLC meeting, teachers emailed items for the upcoming meeting agenda.

These established practices of setting goals and collaborating to achieve them provide clear evidence that this Biology PLC had worked through the difficult early stages of development (Bolam et al., 2002; DuFour et al., 2006; Grossman et al., 2001) that can impede less mature communities’ efforts. I recognize that such longstanding, mature, effective PLCs are the exception, not just in the literature, but in the real-life context of schools. I recognize that in purposefully selecting this PLC, I have selected the exception, and am writing about the potential of the ideal.

**PLC history.** Shortly after the Biology PLC’s grass-roots inception in 2000, the Biology teachers tried to co-teach with their school’s Language Arts teachers and World Studies teachers. While that was too challenging at the time, the World Studies teachers and Language Arts teachers continued to co-teach. The Biology teachers continued planning together within their discipline, and all of the teachers of the three disciplines have continued collaborating over the years (Member checking, 2015).

The Biology PLC’s historic participation with their school’s World Studies and Language Arts PLC had a significant influence on their practice leading up to the release
of NGSS in 2013. Circa 2007, the World Studies and Language Arts teachers created a rubric to assess students’ writing, particularly their ability to write a thesis statement and support it with evidence. They called it a skills rubric. Prior to the release of Common Core in 2010, the World Studies and Language Arts teachers shared the rubric with the Honors Biology teachers. Over the years, the rubric was revised, particularly in light of Common Core. The Biology and World Studies attempted an interdisciplinary writing task prior to the release of NGSS. The teachers did not deem the attempt successful, but they still valued the idea of interdisciplinary teaching and assessment. The Biology PLC adopted the World Studies Skills Rubric to assess students’ science writing when NGSS was released in 2013, just prior to data collection. Figure 7 presents a timeline of these events.

History of Cross View Biology PLC

![Timeline of Events](image)

*Figure 7. History of Cross View Biology PLC*

The PLC’s interactions with other communities at the building level. Figure 8 provides a graphic representation of the PLC’s interactions with other communities at the building level. The figure illustrates the communities’ overlapping practices.
Figure 8. The Biology PLC’s interaction with multiple communities at the building level

All disciplines at Cross View High School plan in teams, but for the sake of clarity, Figure 8 only depicts two disciplines: the Biology PLC and the World Studies PLC. The overlap shown in Figure 8 between the Biology and the World Studies PLC represents collaboration between these two communities.

Figure 8 also includes the Executive Council. The Executive Council consists of the Cross View High School principal and six teachers from various disciplines who are elected by teachers to a two-year term of service (Member checking, 2015). The Council provides professional development and support to all PLCs, not just the two shown in Figure 8. Each teacher elected to the Executive Council serves as a liaison between the Council and a small group of PLCs. One of the participants, Nancy (pseudonym) was an Executive Council liaison to the Biology PLC during data collection. She explained the Council’s role as follows: “The Executive Council … overlooks PLTs as a whole” (Nancy, Individual Interview, 6-3-14). For example, during the 2013-2014 school year, the Executive Council encouraged teachers to use real-time data to make informed instructional decisions about students’ needs. The Council viewed a Decision Making for Results (DMR) PowerPoint, discussed how DMR might be used at Cross View, and
shared the PowerPoint with Cross View teachers during shared planning time. (Field notes, 1-8-14). Shared planning represents another layer of community interaction and collaboration that exists at Cross View High School. All PLCs at Cross View meet as small, interdisciplinary groups of PLCs every other week.

During 2013, the Executive Council asked all PLCs to write short- and long-term goals. The Biology PLC’s desire to continue collaboration with World Studies is evident within their goals, which are presented in entirety in the preceding section. This reification of their ideals and intentions focused their reform efforts.

Participants

After receiving approval from the University’s Institutional Review Board (IRB) and the school district, I formally invited each teacher in the Cross View Biology PLC to participate in a study regarding their collaborative work within their PLC. The IRB approved recruitment script is available as Appendix C. Each of the six Biology PLC members agreed to participate and signed the IRB approved informed consent form (Appendix D).

With the exception of Nancy, who taught Honors and AP Biology, all participants taught General Biology and one or two other courses. All were actively involved in the Biology PLC. Each participant, given a pseudonym, is briefly described below.

Amanda earned a B.S.Ed. in secondary science education with a biology certification. She completed her student teaching at Cross View High School. During the 2013-2014 school year, her third year of teaching at Cross View, she taught General and Honors Biology.
Art earned a B.S. in biology and an M.S.Ed through an alternative certification program. He completed his student teaching and his first year of full-time teaching at a smaller high school in a nearby community before coming to Cross View High. The 2013-2014 school year was his third year at Cross View. Art is certified to teach biology and chemistry. During the 2013-2014 school year he taught a ninth grade physics course in addition to general biology.

Kate earned a bachelor’s degree in biology/pre-medicine, but after substitute teaching for a year, decided to pursue a master’s degree in secondary science education through an alternative certification program. She completed her student teaching at Cross View High School. During the 2013-2014 school year, her seventh year of teaching at Cross View, she taught General and Honors Biology and coached soccer.

Nancy holds a B.A. in secondary theatre education with a minor in biology education and a master’s in secondary school administration. During the 2013-2014 school year (her 12th year of teaching at Cross View), she taught Honors Biology and AP Biology. She attended and fully participated in the Biology PLC for a variety of reasons. There are many similarities between General and Honors Biology; it made sense for her, and the other two Honors Biology teachers who also taught General Biology (Amanda and Kate), to attend this PLC. Nancy served as a liaison between the Biology PLC and the school’s executive council. It was important for her to participate in and support the PLC during this reform year.

Paula was a newcomer to the Cross View Biology PLC. She earned a B.S.Ed. and an M.S. Ed in science education plus more than thirty hours of additional college credit in science and education. This veteran teacher had 24 years of national and
international teaching experience at the time of data collection. The 2013-2014 school year was her fifth year of teaching at Cross View, but her first year teaching General Biology at this school, and her first year teaching biology in many years. She also taught chemistry and oceanography.

Reese earned a B.S. in exercise science and an M.S.Ed. in secondary science education through the same alternative certification program as Art and Kate. She did her student teaching at Cross View High School and was teaching her sixth year at the school at the time of data collection. She is certified to teach biology and taught General Biology, Exercise Science, and Anatomy and Physiology during the 2013-2014 school year.

Beyond the primary participants, other teachers and administrators sometimes attended and participated at the periphery of the Biology PLC. For example, while the PLC did not formally report to building administrators, it was supported by them. One of the six assistant principals regularly attended the Biology PLC’s early fall semester meetings. He listened to the teachers’ collaboration and offered occasional support in the form of encouragement or options for additional collaboration time during school. He was also copied on most of the PLCs’ emails. The district science coordinator occasionally attended the Biology PLC meetings to discuss progress toward district initiatives, such as NGSS implementation and to inform teachers of opportunities for funding STEM projects, professional development, etc. The head of the science department also joined the Biology PLC from time to time to share district directives, answer questions, or offer suggestions if she had ideas about the task the teachers were currently discussing. The Biology PLC frequently collaborated with the teachers in the
World Studies PLC. The World Studies teachers sometimes attended the Biology PLC meetings and vice versa. Twice, both communities met together in what they termed a Mega Professional Learning Team.

I considered all of these individuals as peripheral participants in that they were, at times, participating in the Biology PLC in meaningful ways. All signed consent forms as their voices were sometimes captured during data collection. However, they (and their respective communities) were not the focus of this study. I did not interview any administrators, the district science coordinator, or the World Studies teachers. I did not collect data during any Executive Council meetings or World Studies PLC meetings that were not held in concert with the Biology PLC meetings. I did attend and collect data during both Mega PLT meetings. I also asked the biology teachers how their reform efforts were influenced by these individuals and communities as well as their own individual memberships in other communities.

Data Collection and Sources

Case study research makes use of multiple sources of evidence. Yin (2003) recommends six data sources: archival records, interviews, direct observations, participant-observations and physical artifacts. This study makes use of each these data sources as described in the forthcoming sections regarding data collection and sources.

I attended and audio-recorded each of the regularly scheduled PLC meetings and as many of the impromptu meetings as possible during the 2013-2014 school year. During these meetings I wrote observation notes and collected the agenda and other documents discussed during the meeting. I photographed any work the teachers did on the whiteboard, and collected curriculum documents saved on their school’s shared drive.
I was privy to the teachers’ professional email communication throughout each week as I was copied on PLC emails. During the spring of 2014, I conducted one focus group interview (Creswell, 2007) with all of the teachers. During the summer and fall of 2014, I conducted two, semi-structured individual interviews (Patton, 2002) with each of the teachers in an effort to better understand their experiences of meaning making within the PLC.

The Data Collection Matrix (Appendix A) provides a graphic representation of what data was collected to answer each research question and when that data was collected. In the following paragraphs I further describe the multiple sources of data used in this investigation, how I collected data from each of the sources, and the purpose of each type of data.

**Transcripts of PLC meetings.** I attended and audio-recorded each of the 45-minute weekly before school meetings and as many of the additional meetings as my teaching and supervision schedule allowed. I attended and audio-recorded a total of 40 PLC meetings and two Mega PLT meetings. Each of the audio-recordings was transcribed using Express Scribe Pro. The purpose of these transcripts was to describe the social practices that the teachers engaged in as they negotiated the meaning NGSS and revised their curriculum.

**Observation notes.** During the PLC meetings, I wrote observation notes. The purpose of these notes was twofold: 1) to describe the social context not captured in the teachers’ talk, e.g., teachers’ actions, administrative observations, etc., and 2) to record research notes about emerging ideas, future data exploration or questions I might want to ask the teachers during interviews. The latter were bracketed, meaning that these ideas
were held up “for inspection while suspending presuppositions and avoiding interpretations” (Hatch, 2002, p. 86).

**PLC meeting documents.** Each PLC meeting followed an agenda that was cooperatively written via email prior to the meeting and then printed and distributed at the meeting. I collected these agendas as they represent how the teachers chose to use their time, what kinds of tasks teachers sought peer support for and what issues received priority. Teachers occasionally distributed documents that were works in progress, e.g., an assessment they were writing and revising. I collected these documents as they represented an important, in-between, thinking stage in the teachers’ planning.

**Photographs.** A large whiteboard is attached to one wall of the meeting room. Teachers sometimes wrote on this board during the PLC meetings. For instance, over the summer the teachers met with other biology teachers in the district to study NGSS. Teachers wrote the units they wanted to teach in the order they wanted to teach them, the big ideas they wanted to emphasize, etc. on the whiteboard. At other times, the teachers used the whiteboard to explain content, design an activity or write down their schedules to identify a convenient meeting time for all. I photographed these whiteboard texts and drawings. The purpose of these images was to further describe teachers’ participation and reification.

**Transcripts of interviews.** I invited each teacher to participate in two, one-hour, semi-structured individual interviews (Patton, 2002) and one 90-minute focus group interview (Creswell, 2007). The purpose of these interviews was to further explore how the teachers participated in their PLC as they negotiated the meaning of NGSS, how the PLC’s interactions with other communities influenced their reform efforts, and how the
teachers described their experience of negotiating the meaning of NGSS and revising curriculum within the PLC. Creswell (2007) recommends focus group interviews when the participants are cooperative and interaction among participants is likely to yield the best data, as was the case in this investigation. However, the individual interviews were more appropriate for the exploration of issues of identity in practice, such as each teacher’s view of his or her role within the PLC. The guiding questions, which are available as interview protocols in Appendix B, are based on the CoP framework and the six kinds of questions (experience/behavior, opinion/value, feeling, knowledge, sensory, and background/demographic) identified by Patton (1980). Other questions emerged (Lincoln & Guba, 1985) after listening to the participants’ planning sessions and responses to the initial interview questions. The interviews were transcribed using Express Scribe Pro.

**Curriculum materials.** I collected all curriculum materials, e.g., unit outlines, lesson plans, Power Point presentations, student worksheets, lab sheets, study guides, and tests. These reified objects represent the teachers’ collective understanding of the spirit of the reform, their teaching intentions, and their goals for student learning. The teachers saved these documents on a shared drive so that they could all access them. I downloaded and saved all of these documents on an external storage drive.

**Emails.** The teachers in this PLC communicated with one another throughout each week via email. They asked questions about their homework, shared internet resources, provided helpful tips on new lessons, and asked that items of concern be placed on the next meeting’s agenda. I received all of these emails. This data source allowed me to describe another facet of the teachers’ participation and reification. It
provided a window into individual teacher’s thinking and questions about NGSS and the PLC’s efforts to revise the biology curriculum. A total of 40 email threads were collected and analyzed.

**Role of the Researcher**

My role during this study was that of participant observer (Patton, 2002), but my participation as a researcher was characterized by distant peripherality. I connected with the PLC only through peripheral experiences, not as a full participant. During my initial visit, I explained that I was not there to evaluate or provide input, but to simply observe how they work together. My participation was generally limited to brief pleasantries before or after PLC meetings. During the meeting I was quiet, only asking the occasional clarification question or request to see a document. When I was asked a direct question, I did not refuse to answer, but the teachers asked questions infrequently.

**Data Analysis**

Data analysis was interpretive. “Interpretation is a defining element of all qualitative research” (Hatch, 2002, p. 179). Qualitative researchers interpret or make meaning of data. This is not to say that researchers may construct any meaning, lest it appear a mere opinion; all interpretations must be supported by data (Wolcott, 1994).

Data analysis was ongoing throughout the study, and data sources were triangulated (Hatch, 2002) to corroborate findings. I began by identifying instances relevant to the research questions, e.g., moments and documents that represented the teachers’ participation within the Biology PLC, the influence of other communities, and the teachers’ descriptions of their experiences. I also used the Data Collection Matrix (Appendix A) to guide the identification of data relevant to the research questions. I then
used open coding (Strauss & Corbin, 1998) to briefly describe the essence of each of these instances. I then applied axial coding methods (Strauss & Corbin, 1998) to reassemble these fractured pieces of data into groups of similarly coded data that could be described by some category or subcategory (Saldaña, 2009). Ultimately, these categories were combined to form emergent themes that captured the essence of the PLC’s collaborative efforts to negotiate the meaning of NGSS and revise their curriculum in ways they felt were consistent with these new standards. I employed Computer Assisted Qualitative Data Analysis Software (CAQDAS) – NVivo10. The following paragraphs further explain how data was analyzed for each research question.

**RQ1: The influence of other communities.** The focus group interview transcript and the revised curriculum were the primary data sources considered in answering the first research question. Data from the focus group interview and curriculum were triangulated with PLC meeting transcripts, and photographs and observation notes taken during PLC meetings.

In the focus group interview, teachers were asked to describe the influence of others in achieving the Biology PLC’s goal of revising the biology curriculum. The teachers identified their interaction with other Biology PLCs in their district and their collaboration with their building’s World Studies PLC as influences. I searched individual interview and meeting transcripts for all references to these and other communities; next I identified and briefly described teachers’ talk about their participation with these communities. There was consistency across all three data sources.
The PLC’s revised curriculum is a reification of the teachers’ meaning making that provided further evidence of the influence of the World Studies PLC. Within each of the eight revised curriculum units, I identified and briefly described the teachers’ plans to engage students in each of the eight science practices. I used Appendix F of the NGSS, which details the practices and what students should be able to do by the end of each grade band (NGSS Lead States, 2013), to guide identification of the curriculum plans as particular practices. This curriculum analysis consistently revealed links to a boundary object borrowed from the World Studies PLC – a revised version of the World Studies Skills Rubric. Within each unit, I coded whether and how the rubric was used. Two themes were evident and were confirmed through member checking. These two themes are presented in the interpretations section. The themes describe how the Biology PLC’s interactions with other communities, particularly the other Biology PLCs in the district and their school’s World Studies PLC, influenced how the biology teachers negotiated the meaning of NGSS as they revised their curriculum.

**RQ2: Teachers’ participation in the PLC.** The individual interview transcripts and the revised curriculum were the primary data sources considered in answering the second research question. Data from the individual interviews and curriculum were triangulated with the focus group and PLC meeting transcripts, email communications and observation notes taken during PLC meetings. In the first individual interview, each teacher was asked to describe their role and the role(s) of others in achieving the Biology PLC’s goal of revising the biology curriculum. I used open and axial coding to describe each teachers’ response to these questions (Strauss & Corbin, 1998). Next, I analyzed the teachers’ participation within the PLC by analyzing a secondary data source, the
transcripts of the weekly PLC meetings. I analyzed four weekly meetings during the first quarter of the school year. Though role(s) were largely negotiated and established prior to data collection, those roles were reestablished/confirmed during the beginning of the year. I did not identify any new codes regarding teachers’ participation beyond the first few weeks, therefore, when the data was saturated, I did not analyze additional weekly meetings. Data from the interviews and weekly meeting transcripts were triangulated with observation notes and the teachers’ email communications. The purpose of this secondary analysis was to determine whether and how the teachers enacted the role(s) they ascribed to themselves and others and to conduct negative case analysis (Marshall & Rossman, 2011) that might reveal other ways the teachers were participating in their community. The teachers’ descriptions of their roles were consistent with descriptions of the nature of teachers’ participation via email and researcher descriptions of their face-to-face participation. For example, the participant who identified as the PLC organizer was the same individual who solicited teachers’ help in building the PLC meeting agendas via email, and distributed agendas, and helped keep the PLC on track during PLC meetings. Interpretations of the teachers’ participation were confirmed through member-checking. Unaware of their pseudonyms, participants easily identified themselves and others in the descriptions of teachers’ participation.

Interview data and observation notes revealed frequent reference to a PLC created tool that guided the teachers’ reform efforts. The teachers described this tool as a road map that guided their curriculum revision. I used interview data to describe how the teachers participated in their PLC to create and use the map. I analyzed the map by comparing it to NGSS and the PLC’s revised curriculum. I identified how the map was
aligned to NGSS disciplinary core ideas and performance expectations, and how the teachers’ planned to engage students in science practices to meet those standards as indicated in their revised curriculum. Interpretations regarding the value and use of the road map were confirmed during member checking.

Without comparing the revised curriculum to the previous curriculum, it could be argued that the teachers merely claimed to revise their curriculum but made no substantive changes. I completed a side-by-side description and comparison of one unit of the PLC’s revised and previous curriculum in order to explain how the teachers negotiated the meaning of NGSS and revised their curriculum in ways that they felt were consistent with the new standards. Curriculum unit was the appropriate unit of analysis because the PLC organized their curriculum in units. I purposefully chose to analyze the Biology PLC’s 2013-2014 Unit 2: Structure and Function and their 2012-2013 Unit 2: Cell Parts and Classification, which addressed similar content. Though all of the teachers agreed that their sense-making and ideas for revision improved as the year progressed (Focus Group Interview (FGI), 4-24-14), several of the teachers were less satisfied with their revisions to the units taught in the Spring of 2014 when they were tired and pressed for time (Art, Individual Interview, 6-12-14; Kate, Individual Interview, 5-16-14; Reese, Individual Interview, 6-3-14;). A side-by-side comparative analysis of the two units focused on differences, similarities, and patterns. The teachers’ use of a planning framework in the revised unit was confirmed in the remaining curriculum units.

**RQ3: Teachers’ experiences of meaning making within the Biology PLC.**

The individual interview transcripts were the primary data source considered in answering the third research question. Data from the individual interviews and
curriculum were triangulated with the focus group interview, revised curriculum, and photographs. In the individual interviews teachers were asked questions related to their experiences of negotiating the meaning of NGSS as they revised their curriculum. I used NVivo 10 to apply open and axial codes (Strauss & Corbin, 1998) to teachers’ responses. Open coding revealed teachers’ tendency to describe their experiences in terms of tensions. According to Wenger (1998), the dualisms and tensions that exist within communities of practice, e.g., order and chaos, remembering and forgetting, identification and negotiability, etc., provide a context, or fertile ground, for learning; meaning is negotiated through the dual process that underlie community members’ experiences. I applied axial codes to describe the tensions the teachers experienced. One tension was pervasive throughout the interviews, the revised curriculum, the road map, and observations. The resultant theme explains how teachers describe their experiences of negotiating the meaning of NGSS as they revised their curriculum as marked by this central tension.

Open coding of the individual interview transcripts also revealed teachers’ tendency to describe their experiences of negotiating the meaning of NGSS and revising their curriculum in terms of strong emotions. Axial coding revealed two emotions that were consistently experienced by all teachers. Descriptions of these emotions were confirmed in the focus group interview and were consistent with researcher observations. Interpretations were confirmed through member checking.

**Trustworthiness**

Just as quantitative researchers must use validated instruments and report reliability measures, qualitative researchers must also provide evidence that their research
is trustworthy (Lincoln & Guba, 1985). Lincoln & Guba (1985) identify four aspects of trustworthiness: credibility, transferability, dependability and confirmability. The acceptance of the interpretations as truth is ultimately the decision of the reader, but I made every effort to address the threats to these aspects of trustworthiness as described below and in Table 1.

**Credibility.** This study is tenable. During my prolonged observation of this PLC, I obtained multiple sources of data and triangulated those data sources during data analysis. As analysis progressed, I debriefed (Marshall & Rossman, 2011) with peers and experts involved in qualitative research. These knowledgeable others helped me further recognize and bracket my own bias. As I identified themes, I checked with the participants to confirm that I was telling their story, even if it was through my own eyes. As a final member check (Hatch, 2002), I invited the participants to review the dissertation prior to submission.

**Transferability.** Qualitative research is not generalizable to the population in the same way that quantitative research may be. However, the interpretations and implications may be transferrable to other contexts. To help the reader to decide whether the results are transferrable, I used the data collected during my prolonged observation of this PLC to provide “thick descriptions” (Denzin & Lincoln, 2005) of this particular context.

**Dependability.** The prolonged period of data collection allowed me to establish redundancy making the work more dependable. I collected multiple sources of overlapping data, e.g., observing the PLC meetings, transcribing the audio-recordings of the PLC meetings, photographing the teachers’ whiteboarding during the PLC meetings,
collecting agendas and other documents used during the PLC meetings, as well as the
PLC’s pre-NGSS and revised curriculum, and interviewing teachers about their
participation in the PLC meetings. The Hawthorne effect (whereby participants modify
their behavior in response to being studied) and the Pygmalion effect (whereby
participants improve their performance in response to some expectation) are threats to
dependability; however, the research design addresses these threats via prolonged
observation and my careful consideration of how much of the research question(s) I
shared with the teachers.

**Confirmability.** The final criterion of trustworthiness is confirmability. All
conclusions must be grounded in data with each theme is supported by data so that the
findings could be confirmed by another researcher (Lincoln & Guba, 1985). Thus, I
collected, labeled and stored all data in a clear, logical manner, triangulated data sources
and retained all data analysis records. As I analyzed data, I continued peer and expert
debriefing (Marshall & Rossman, 2011) in order to reduce researcher bias and ensure that
I made logical inferences based on data.
### Table 1

*Criteria for Evaluating the Trustworthiness of Qualitative Research*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Concerns</th>
<th>Methods</th>
</tr>
</thead>
</table>
| **Credibility** | a. Learn the culture  
    b. Test for misinformation  
    c. Build trust  
    d. Identify salient elements  
    e. Identify crucial atypical events  
    f. Researcher bias  
    g. Human instrument frailty | a. Prolonged observation  
    b. Triangulation  
    c. Provide anonymity; be transparent  
    d. Peer and expert debriefing  
    e. Negative case analysis  
    f. Member checking  
    g. Constant Comparative Method and estimations of data collection obtrusiveness; (bracketed bias) |
| **Transferability** | a. Provide reader with contextual reference | a. Thick descriptions |
| **Dependability** | a. Methodological shifts  
    b. Establish redundancy  
    c. Pygmalion effect  
    d. Hawthorne effect  
    e. Inquirer sophistication | a. Documentation of systematic observation and data collection  
    b. Overlap of data collection methods; prolonged observation  
    c. Careful consideration of what (of the research question) is shared with participants during data collection  
    d. Extended observation and estimations of data collection obtrusiveness  
    e. Analysis of researcher’s role and expert debriefing |
| **Confirmability** | a. Theory grounded in data  
    b. Logical inferences and clear reasoning for category identification  
    c. Accommodate negative evidence | a. Triangulation; audit trail – each theme supported by data  
    b. Peer debriefing and documented systematic observations, data collection and data analysis  
    c. Negative case analysis; member check |

Adapted from Baker (1995)

### Limitations

This study is limited in three important ways. First, it is limited in scope. Reform implementation is a complex issue influenced by teachers’ beliefs (Donnelly & Sadler, 2009; Jones & Carter, 2007; McRobbie & Tobin, 1995), education (Donnelly & Sadler, 2009; Loughran, 2007; Luft & Roehrig, 2005), available resources (Beyer et al., 2009;
Bianchini & Kelly, 2003; Harmon et al., 2002), and the lack or presence of systemic support (Gerard et al., 2010; Spillane & Callahan; Lynch et al., 2012; Anderson, 2012). The purpose of this study is to investigate just one aspect of this through an investigation of one community of teachers’ use of one resource – their PLC, as they attempt to reform their own curriculum. Even if the scope of the study was much broader, it is not meant to be prescriptive. The end result is not a one-size-fits-all recommendation. Still, the interpretations are informative, and may be helpful to other science teachers or those interested in science education research.

Second, this study is limited by time. While one year of data collection is a prolonged observation period that allowed me to collect sufficient data to answer the research questions, there is considerable evidence that it takes at least two years for teachers to develop an understanding of the rationale for new practice and to implement the new practice(s) effectively (Osborne, 2013).

Finally, the ultimate goal of science education reform is student learning, but this investigation does not explore student learning or teachers’ classroom level implementation. However, this study does explore an important aspect of implementation: how teachers collaboratively negotiated the meaning of reform standards and revised their curriculum based on their shared understanding of the reform.
Chapter 4

Interpretations

The overarching research question is: How do the secondary biology teachers within a mature, effective PLC negotiate the meaning of NGSS as they revise their curriculum? My interpretations of the data are written as themes organized around the sub-research questions. These themes explain the following: 1) how the PLC’s interactions with other communities influenced how the teachers negotiated the meaning of NGSS as they revised their curriculum, 2) how the teachers participated in the PLC as they negotiated the meaning of NGSS and revised their curriculum, and 3) how the teachers described their experience of negotiating the meaning of NGSS and revising their curriculum. Each theme is presented as a claim supported by evidence – the analysis of triangulated data from at least three data sources.

Research Question 1

How do the Biology PLC’s interactions with other communities influence how the biology teachers negotiate the meaning of NGSS as they revise their curriculum?

Claim 1.1. The Cross View Biology PLC minimized the potential influence of other Biology PLCs in the district by providing leadership in negotiating only the sequence of NGSS topics, but not specific standards. This allowed the PLC to meet district requirements for NGSS alignment and common semester assessments while revising their own curriculum in ways that were consistent with their local community and building-level goals.

Evidence for claim 1.1. On June 25, 2013, the secondary biology teachers from across the district held a joint professional development day to discuss NGSS and develop
an initial plan of action for revising and aligning their curriculum. Since NGSS progress toward end of high school achievement standards, the disciplinary core ideas and the individual performance expectations within grade bands need not be taught in a particular order (NGSS Lead States, 2013). However, in this case, it was important that all biology teachers within the district teach the same units in the same order because they were required to administer a common district assessment at the end of each semester. Thus, one of the teachers’ first tasks was to decide, as a district, the order of the biology units. During the focus group interview, Kate explained that the Cross View Biology PLC led the other PLCs in the district to a broad agreement to teach the same topics in the same semester despite disagreement amongst the PLCs about sequencing.

Reese: The overall order of units kind of was district wide …

Amanda: We created that during a PD day last year.

Kate: No, let's be honest here. It was Amanda and Reese sitting in the back while everybody (other district biology teachers) [was] arguing how to do it (others laughing), and Reese hands it over to me and says, 'Will you just tell them this is what we're gonna do?' … So, then I stood up and, I said, 'Here!', and they said 'Great!'…

All: Hmmm ... mmm ... correct (agreeing). (Focus Group Interview (FGI), 4-24-24)

The Cross View Biology teachers recalled that there was initial disagreement among the district biology teachers regarding the most appropriate way to order the units, but they negotiated this disagreement by advocating for a broad agreement to teach the
same NGSS topics in the same semester. When Kate said, “This is what we’re gonna do” (FGI, 4-24-24), the other district biology teachers followed Cross View’s lead.

What Kate proposed was teaching the curriculum units in the order listed: 1) Nature of Science and Characteristics of Life, 2) Structure and Function, 3) Inheritance and Variation of Traits, 4) Natural Selection and Evolution, 5) Matter and Energy, and 6) Interdependent Relationships (Photograph, 8-29-13). A matrix of eight foundational Nature of Science understandings and their relationship to the practices are presented in Appendix H of the NGSS; each of the other units (units 2 - 6) is one of the NGSS High School, Life Sciences topics. (NGSS Lead States, 2013). The teachers agreed to teach the first three units in the fall, and the second three units in the spring. It was important that they teach the same units in the same semester in order to give the required common semester assessment. Reese and Amanda explained that while the only requirement was that they teach the same units in the same semester, most teachers in the district taught the units in the same order (Member Check, Email 11-16-2015).

This broad, district-level agreement on NGSS topics did not require that all teachers within the district teach the units in the same way. At the district meeting, the teachers did not negotiate specific NGSS Performance Expectations, or even emphasis on specific NGSS science and engineering practices or crosscutting concepts. Negotiating at the level of individual learning objectives and major assignments would have been problematic as the Cross View Biology teachers felt they were in a different place than the other Biology PLCs in the district. While the Cross View Biology PLC was an established PLC, Mountain View High School was a new high school in its first year of existence at the time of data collection. The Mountain View Biology teachers were still
learning to work together as a team; they were focused on getting their PLT “on the same page” (Reese, 8-29-13, PLC Meeting (Mtg)) and “philosophically on the right track” (Nancy, 8-29-13, PLC Mtg).

Though the Valley View High School was more established, the Cross View Biology teachers felt they were taking a different approach to reforming their curriculum. The Valley View Biology teachers were “attacking things just from the complete opposite direction” (Reese, 11-7-13, PLC Mtg); “they’re doing more experimental design and we’re doing more…reading and writing” (Kate, 11-7-13, PLC Mtg). Reese’s and Kate’s comments allude to very different building-level approaches to reform. Such disparate approaches might have presented barriers to the Cross View Biology teachers if they had been obligated to enact a more specific, district-wide curriculum.

In summary, how the Cross View Biology PLC negotiated the meaning of NGSS and revised their curriculum was influenced by their interactions with other Biology PLCs at the district level. However, the Cross View PLC minimized this influence (and potential barrier) through negotiation at the broad level of sequencing NGSS topics. When the PLC met with other Biology PLCs in the district to discuss revising and aligning their curriculum, they provided leadership in negotiating only the sequence of NGSS topics, not specific standards. By advocating for such a broad agreement, the PLC was able to meet district requirements for NGSS alignment and common semester assessments while removing any potential barriers that might have been presented by an obligation to teach a more specific, district-wide curriculum. Thus, the Cross View Biology teachers were able to negotiate the meaning of NGSS and revise their curriculum in ways that were consistent with their local community and building-level goals. In the
next section, I examine the PLC’s interactions with other communities at the local building-level and how those interactions had a greater influence on how the biology teachers negotiated meaning of NGSS.

**Claim 1.2.** The Cross View Biology PLC’s historic participation with their school’s World Studies and Language Arts PLC (and in particular their use of the World Studies Skills Rubric to assess students’ science writing) influenced the biology teachers’ prioritization of the following science and engineering practices: obtaining, evaluating, and communicating information and engaging in argument from evidence. The teachers placed a secondary emphasis on analyzing and interpreting data and constructing explanations.

**Evidence for claim 1.2.** The influence of the Biology PLC’s participation with the World Studies PLC is evident in the PLC’s revised curriculum. Analysis of all eight revised curriculum units reveal the teachers’ intentions to engage students in NGSS science practices, particularly obtaining, evaluating, and communicating information and engaging in argument from evidence. A secondary emphasis on analyzing and interpreting data and constructing explanations is also evident. Where the biology teachers indicated intentions to emphasize these practices, they also frequently planned to assess students’ written work, e.g., their arguments and explanations, using a revised version of the World Studies Skills Rubric (Table 2).

Tables 3, 4, and 5 detail the Biology PLC’s curriculum plans to engage students in each of the NGSS science practices and to assess students’ written products using a revised version of the World Studies Skills Rubric. Table 3 details the PLC’s curriculum plans to engage students in the NGSS practice of obtaining, evaluating and
communicating information and to assess students’ written communication products using the rubric. Of the eight listed curriculum plans, six were linked to the rubric. Table 4 details the PLC’s curriculum plans to engage students in the NGSS practice of engaging in argument from evidence and to assess students’ written arguments using the rubric. Of the eight listed curriculum plans, six were linked to the rubric.
Table 2 Revised World Studies Skills Rubric used by the Biology PLC to assess students’ written products

<table>
<thead>
<tr>
<th>Category</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis Statement</td>
<td>Thesis statement fully addresses the prompt by making a claim and provides controlling, thoughtful reasoning for the claim.</td>
<td>Thesis statement addresses the prompt by making a claim and provides logical reasoning for the claim.</td>
<td>Thesis statement attempts to address the prompt by making a claim and provides reasoning that may be too narrow, superficial, and/or vague.</td>
<td>Thesis statement does not fully address the prompt by lacking a claim or reasoning.</td>
</tr>
<tr>
<td>Description</td>
<td>Uses specific, relevant, and accurate evidence, creating a strong foundation for the argument.</td>
<td>Uses specific, relevant, and accurate evidence, creating a foundation for the argument.</td>
<td>Uses limited and/or general evidence; may lack relevance and/or accuracy, creating a weak foundation for the argument.</td>
<td>Attempts to use evidence, but is insufficient in creating a foundation for the argument.</td>
</tr>
<tr>
<td>Analysis</td>
<td>Clearly and efficiently breaks down and elaborates on meaning and significance of each piece of evidence.</td>
<td>Breaks down and elaborates on meaning and significance of each piece of evidence.</td>
<td>Breaks down evidence but provides limited meaning and significance.</td>
<td>Breaks down evidence in a confusing or incomplete manner.</td>
</tr>
<tr>
<td>Communication</td>
<td>My command of language skill is superior. I am professional, fluent, and engaging to the audience.</td>
<td>My command of language skill is above average. I demonstrate above average professionalism and fluency, and I am engaging to the audience.</td>
<td>My command of language skill is inconsistent. I attempt to be professional and fluent, but I may not consistently engage the audience.</td>
<td>My command of language skill is lacking. I demonstrate a deficiency in being professional and fluent, and I am largely disengaging to the audience.</td>
</tr>
</tbody>
</table>

*Four categories are shown in this representative rubric. The Biology PLC assessed students’ science writing in three of these four categories: description, analysis, and thesis statement or communication.
Table 3 Biology PLC’s curriculum plans to engage students in the NGSS practice of obtaining, evaluating and communicating information and to assess students’ written communication products using a revised version of the World Studies Skills Rubric

<table>
<thead>
<tr>
<th>NGSS Science and Engineering Practice</th>
<th>How the Biology PLC Teachers Engaged Students in the Practice</th>
<th>Assessed via Skills Rubric</th>
</tr>
</thead>
</table>
| Obtaining, Evaluating, and Communicating Information | **Unit 1**  
  • **NOS:** Students asked to respond to the prompt: “What is science?” following NOS card sort activity and discussion  
  • **NOS:** Students read article about Harvey’s discovery of circulatory system; asked to compare discovery to what they know about science  
  • **Characteristics of Life:** Students asked to respond to the prompt: “Is fire alive?” following reading and discussion about bacteria, viruses, and the characteristics of living organisms | Yes | No |
| | **Unit 2**  
  • **Organic Molecules:** Students read information about each macromolecule, analyzed a food label, read a study, and answered questions about the importance of breakfast  
  • **Homeostasis:** Students asked to create a homeostasis billboard with visual and written explanation of how some functions, e.g., hunger response, temperature regulation, etc. demonstrate homeostasis | Yes | X |
| | **Unit 3**  
  • **Stem Cells:** Students completed a stem cell WebQuest to describe types and uses of stem cells, the goal of regenerative medicine, and the pros and cons of cloning. Students asked to describe and analyze three social and or ethical concerns surrounding medical stem cell use | X | Yes |
<table>
<thead>
<tr>
<th>Unit 4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cancer:</strong> Students completed a WebQuest to describe how cancer develops, current state of cancer research, and to describe and analyze three social and/or ethical concerns surrounding cancer research and treatments</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit 5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DNA/Chromosomes:</strong> Students asked to read articles and view video before writing thesis statements in response to the following question: “Do genetic mutations always have a negative affect?”</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 4 Biology PLC’s curriculum plans to engage students in the NGSS practice of engaging in argument from evidence and to assess students’ arguments using a revised version of the World Studies Skills Rubric

<table>
<thead>
<tr>
<th>NGSS Science and Engineering Practice</th>
<th>How the Biology PLC Teachers Engaged Students in the Practice</th>
<th>Assessed via Skills Rubric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engaging in Argument From Evidence</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Unit 3</strong></td>
<td><strong>Stem Cells</strong>: Students asked to take a stand for or against adult embryonic stem cell use and argue from evidence in Socratic seminar</td>
<td>X</td>
</tr>
<tr>
<td><strong>Unit 4</strong></td>
<td><strong>Cancer/Mutations</strong>: Students made claims regarding the impact of behaviors, e.g., diet, tobacco use, tanning, etc. on cancer risk</td>
<td>X</td>
</tr>
<tr>
<td><strong>Unit 5</strong></td>
<td><strong>Mutations</strong>: Students made claims in response to the following question: “Do genetic mutations always have a negative effect?”</td>
<td>X</td>
</tr>
<tr>
<td><strong>Unit 6</strong></td>
<td><strong>Genetics</strong>: Students asked to respond in writing to the prompt: Should genetic screening be regulated?</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><strong>Genetics</strong>: Students read human variation article, recorded variation within their class regarding certain traits and then used evidence to support given claim in response to following prompt: Are genes completely responsible for determining traits?</td>
<td>X</td>
</tr>
<tr>
<td><strong>Unit 7</strong></td>
<td><strong>Evidence for Evolution</strong>: Students created graphic organizer describing lines of evidence, e.g., fossils, comparative anatomy, etc., and how that evidence supports evolution</td>
<td>X</td>
</tr>
<tr>
<td>Unit 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• <strong>Human Impact</strong>: Students asked to respond in writing to prompt: What should be done to slow down the impact of human population growth?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• <strong>Human impact</strong>: Students read an article regarding Easter Island and defended or refuted the claim that what happened on Easter Island may happen to Earth as a whole.</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 5 details the Biology PLC’s curriculum plans to engage students in the remaining six NGSS practices of 1) analyzing and interpreting data, 2) constructing explanations, 3) developing and using models, 4) planning and carrying out investigations, 5) using mathematical and computational thinking, and 6) asking questions. The table also indicates whether teachers planned to assess students’ written products using a revised version of the World Studies Skills Rubric.

The teachers planned multiple opportunities for students to analyze and interpret data. While students’ data analysis was not directly assessed using the rubric, students were asked to use their data analysis and interpretations in writing evidence-based arguments that were assessed using the rubric. Students were asked to construct explanations less frequently than they were asked to obtain, evaluate, and communicate information or engage in argument from evidence, but each time students constructed written explanations, their explanations were assessed using a revised version of the World Studies Skills Rubric.

The teachers initially planned to emphasize modeling (FGI, 4-24-14; Field notes, 8-23-14). Table 5 reveals that while the teachers planned five modeling opportunities, the models were typically literal illustrations of a single phenomenon with limited power to explain and predict (Schwarz et al., 2009). For example, students were asked to make playdough chromosomes and move the chromosomes through the phases of mitosis. According to Schwarz et al. (2009), this type of modeling would be considered the first (lowest) level of understanding models. At this level, models are viewed as “a means of showing others what the phenomenon looks like” not as flexible, “generative tools for predicting and explaining” (Schwarz et al., 2009, p.640).
Table 5 Biology PLC’s curriculum plans to engage students in the NGSS practices of 1) analyzing and interpreting data, 2) constructing explanations, 3) developing and using models, 4) planning and carrying out investigations, 5) using mathematical and computational thinking, and 6) asking questions and to assess students’ written communication products using a revised version of the World Studies Skills Rubric

<table>
<thead>
<tr>
<th>NGSS Science and Engineering Practice</th>
<th>How the Biology PLC Teachers Engaged Students in the Practice</th>
<th>Assessed via Skills Rubric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzing and Interpreting Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Unit 2</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- <strong>Homeostasis</strong>: Students asked to represent and analyze their data using appropriate mathematical technique</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>- <strong>Cell Structure</strong>: Students used microscopes to view various cell types, e.g., bone and nerve cells and describe how cells’ structure/shape informs functions</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>- <strong>Cell Size Investigation</strong>: Students asked to interpret data from their investigation of why cells are so small</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><strong>Unit 4</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- <strong>Cancer Stations</strong>: Students asked to analyze and interpret data, e.g., incidence and survival trends and environmental influences, regarding various cancers</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><strong>Unit 7</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- <strong>Natural Selection/Antibiotic Resistance</strong>: Students asked to analyze and interpret data from their investigation of the impact of antibiotics on bacterial populations over time</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>- <strong>Natural Selection/Bird Beak Size</strong>: Students asked to analyze data on finch beak size and rainfall in the Galapagos Islands and describe the relationship between beak size and rainfall</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>- <strong>Natural Selection/Peppered Moth Color vs. Bark color</strong>: Students asked to analyze data on peppered moth and tree bark color pre-/post-industrial</td>
<td>X</td>
</tr>
</tbody>
</table>
Constructing Explanations (for Science) and Designing Solutions (for Engineering)

| Unit 2 | • Levels (of Organization): Organ project: Students researched an organ, its function, its cells’ structure and specialized functions, created organ poster, did a gallery walk, explained how their cells, tissues, organs were similar/different and how organ systems worked together |
| | • Homeostasis/Organ Systems’ Structure and Function: After organ project, homeostasis investigation, and reading article, students asked to explain how three body systems work together to allow a rowing competitor to maintain homeostasis during competition |

| Unit 4 | • Cancer: Students asked to explain why the development of cancer is different among individuals |

| Unit 7 | • Natural Selection: Students asked to explain changes in bacterial populations in response to antibiotics over time |
| • Speciation: Students asked to explain how a poisonous snail might have evolved from an nonpoisonous ancestral species |

Developing and Using Models

| Unit 3 | • Cell Division (Mitosis)/Embryogenesis model: Students modeled cell division and differentiation by building a playdough model of embryogenesis |

<p>| Unit 6 | • Cell Division (Meiosis): Students modeled meiosis using playdough and chalk |</p>
<table>
<thead>
<tr>
<th>Planning and Carrying out Investigations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 7</strong></td>
<td><strong>Unit 8</strong></td>
<td></td>
</tr>
<tr>
<td>• <strong>Natural Selection:</strong> Students did traditional moth and bird beak labs as models of natural selection</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>• <strong>Food Webs:</strong> Students built a yarn food web as an interactive model of the complexity and interrelatedness of organisms in an ecosystem</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>• <strong>Carbon Cycle:</strong> Students modeled carbon’s movement through the carbon cycle in a card-based activity;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Using Mathematics and Computational Thinking</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 2</strong></td>
<td><strong>Unit 6</strong></td>
<td><strong>Unit 8</strong></td>
</tr>
<tr>
<td>• <strong>Homeostasis:</strong> Students conducted a heart rate in response to exercise investigation</td>
<td>• <strong>Genetics:</strong> Students asked to calculate the probability of traits appearing in offspring after participating in a simulation where they flipped coins, passed genetics to offspring, and created Punnett squares</td>
<td>• <strong>Energy Pyramid Analysis:</strong> Students asked to calculate the amount of energy transferred from one organism to another and respond to the suggestion that exponential human growth cannot be supported by a diet that includes daily meat</td>
</tr>
<tr>
<td>• <strong>Cell Size Investigation:</strong> Students asked to design an investigation to explain why cells are so small.</td>
<td></td>
<td>• <strong>Carrying Capacity/Population Ecology:</strong> Students graphed results of a Grizzly Bear population growth</td>
</tr>
</tbody>
</table>
simulation and described meaning of resultant S-curve

- **Carbon Cycle:** Students tried to balance carbon’s movement through the carbon cycle in a card-based activity; students used the numerical information to determine human impact on the carbon cycle

| Asking questions (for Science) and Defining Problems (for Engineering) | • **Homeostasis***: Students asked various questions regarding heart rate response to exercise; *only those questions generated by students were considered in this analysis | X |

When considered collectively, Tables 4, 5, and 6 reveal that while other NGSS science practices were not ignored, the biology teachers’ prioritized obtaining, evaluating, and communicating information, and engaging in argument from evidence, and placed a secondary emphasis on analyzing and interpreting data and constructing explanations.

Figure 9 provides a graphic representation of this prioritization and the influence of the World Studies Skills Rubric.
Figure 9. Frequency of NGSS science practices and use of revised World Studies Skills Rubric within the Biology PLC’s revised curriculum

Figure X. This figure shows the frequency of NGSS practices and use of a revised World Studies Skills Rubric within the Biology PLC’s revised curriculum. The NGSS practices are listed in the following order: 1) Asking questions, 2) Developing and Using Models, 3) Planning and Carrying Out Investigations, 4) Analyzing and Interpreting Data, 5) Using Mathematics and Computational Thinking, 6) Constructing Explanations, 7) Engaging in Argument from Evidence, and 8) Obtaining, Evaluating, and Communicating Information.

Interview data and member-checking confirm these interpretations. In the focus group interview, teachers were given a list of the eight NGSS science practices presented in the same order as they appear left to right in Figure 9. (Teachers were not given Figure 9, only a numbered list of the eight science practices.) The teachers were asked to
identify which practices they felt their PLC focused on during the 2013-2014 school year. Their response is consistent with the preceding interpretations of the data.

Nancy: So, then 7, and 8

Interviewer: So, 7 and 8?

Art: I was going to say, speaking for myself

Others: Yeah

Nancy: And 6, too

Art: Certainly

Nancy: 6, but 7 and 8 hugely (Others agree) and

Kate: 4

Nancy: and the 4 because we've done argumentation through using data

Interviewer: 6, 7, 8 and 4 because of argumentation?

Nancy: Yeah, like, we've, like with evolution you guys analyzed and interpreted data and that easily transfers to argumentation. (FGI, 4-24-14)

Teachers also confirmed and further explained how the World Studies Skills Rubric played a role in the Biology PLC’s efforts to implement NGSS in ways that were consistent with both the new standards and their local, building-level goals. The teachers viewed the skills assessed by the World Studies rubric, e.g., describing and analyzing evidence and making claims supported by that evidence, as similar to some of the NGSS science practices. The teachers adopted NGSS and included science practices in their revised curriculum, but they did not adopt NGSS language; they continued to use the familiar term skills, rather than the NGSS term, practices. Their use of the World Studies Skills Rubric provided a bridge between the familiar – their historic collaboration with
the World Studies PLC and the skills assessed by the World Studies Skills Rubric, and the unfamiliar – the NGSS and the recommended science practices. Amanda explained:

When we realized we were going to be doing these skills things, we were like, well, we need to reach out and look at what World Studies already has as far as what is their description and analysis strands on their scoring guides. Like, how do they define good description versus okay description versus bad description, and same thing with the other skills, too … Then it was just like, okay, now that we're implementing this, those conversations are being had throughout the building and with different people, and you know, Dan (pseudonym, World Studies PLC leader) has been a big help with that, like merging the gap. He's a great resource to have with that. (Amanda, FGI, 4 -24-14)

The influence of the World Studies PLC on the Biology PLC’s meaning making around NGSS goes beyond merely borrowing a rubric. As articulated in the PLC’s goals, the biology teachers wanted to align their use of language, teaching and assessment practices with the World Studies PLC. The following quotes explain why the teachers valued this alignment.

Reese: My kids basically had a mutiny, telling me that I'm teaching them about analysis – totally different than all their World Studies teachers. But as I'm having these conversations, it seems to be not totally across the board. Like, there were patterns that I started seeing, and so I did a very informal survey of like, ‘In World Studies, what is analysis? In biology, what is analysis?’ on scraps of paper … Mitch (pseudonym, World Studies PLC leader) and I kind of started talking about that.
Kate: In Honors Biology for years, we've been writing and doing description, analysis, [and] evaluation, and so we've had those rubric strands, but it wasn't until recently that we really actually made sure that the wording … was all the same. (Kate, FGI, 4-24-14)

One of the ways the communities pursued consistent language was to give a more formal survey to World Studies and Biology students regarding their perceptions of consistency across the two disciplines. The results of this survey were shared as descriptive statistics via email (PLC email 1-24-14.) In January and April, the two communities met as a Mega PLC. The purpose of these meetings was to discuss how the teachers taught and assessed the skills and to brainstorm ideas for future increased consistency and cross-curricular collaboration (Researcher observation notes, Mega PLC meetings, 1-23-14 and 4-17-14). During the April meeting, World Studies, Language Arts, and Biology teachers met in small groups with each discipline represented in each group. The teachers graded sample World Studies and Biology papers, compared assessment scores and reasoning, and then wrote jointly negotiated definitions of the skills that were assessed using the rubric on giant Post-it notes. Analysis of research observation notes and the teachers’ jointly created Post-its further illuminate how the Biology PLC’s reform efforts were influenced by their collaboration with the World Studies PLC. Figure 10 is a photograph of one group’s Post-it note. The red circles highlight language indicative of the biology teachers making sense of NGSS within the context of the language used in the World Studies Skills Rubric. Where the World Studies rubric assessed students’ ability to write a thesis statement, the biology teachers discussed engaging in argument (circled) from evidence – an NGSS science practice. The
biology teachers wanted students to support science claims with description and analysis of evidence.

*Figure 10. Biology and World Studies teachers jointly negotiated views of rubric language. (Photograph, 4-17-14)*

The biology teachers unanimously and repeatedly expressed that their reform implementation would not have been possible without their collaboration with the World Studies PLC (Focus Group Interview, 4-24-14). Kate told her students, “We don't want you to think that biology or science is kind of their own isolated little box…you should see the connection when you're going from Biology to World Studies…It just makes sense if we're all doing it the same, sort of the same way, teaching it the same way” (Focus Group Interview, 4-24-14).
In summary, the teachers negotiated the meaning of NGSS within their local context, and that meaning making was significantly influenced by their historic and continued collaboration with another local community, their school’s World Studies and Language Arts PLC. In particular, the Biology PLC’s meaning making was affected by their use of a boundary object (Star & Griesemer, 1989) – a revised version of the World Studies and Language Arts PLC’s Skills Rubric. “Boundary objects go beyond mere trading across unjoined world boundaries. [They] act as anchors or bridges [and make] possible new kinds of joint endeavor” (Star & Griesemer, 1989, p. 413-414). In this case, the Biology PLC used a boundary object, the rubric, to assess students’ ability to engage in NGSS science practices. Curriculum analysis revealed the biology teachers’ plans to engage students in science and engineering practices, particularly obtaining, evaluating, and communicating information and engaging in argument from evidence and to assess students written products using a revised version of the World Studies Skills Rubric. The teachers placed a secondary emphasis on analyzing and interpreting data and constructing explanations. Though students’ data analysis was not directly assessed using the rubric, students were asked to use their analysis and interpretations in writing evidence-based arguments and explanations that were assessed using the rubric. The Biology PLC engaged students in other science and engineering practices, but their historic collaboration with World Studies PLC, and their use of a revised version of the World Studies Skills Rubric to assess students’ writing, influenced their prioritization of these NGSS science practices. The rubric served as a bridge that allowed teachers to form connections between the familiar – their historic collaboration with the World Studies
PLC and the skills assessed by the World Studies Skills Rubric, with the unfamiliar – the NGSS and the recommended science practices.

Research Question 2

How do the biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum?

Claim 2.1. Each teacher filled a unique, previously negotiated, clearly defined, and mutually agreed upon role within the PLC as they negotiated the meaning of NGSS and revised their curriculum.

Evidence for claim 2.1. During the first individual interview, the biology teachers were asked to explain their role and the roles of others within the PLC. Each teacher was able to clearly describe their role as well as the roles of others. Table 6 summarizes the teachers’ description of these roles. The leftmost column contains a description of the role each teacher self-identifies. The column to the right contains a description of the role the teachers ascribe to their fellow PLC members. The teachers’ descriptions of their roles and the roles of others are strikingly consistent. The paragraphs following Table 6 further illuminate this consistency.
Table 6. Participants’ role(s) within the PLC

<table>
<thead>
<tr>
<th>Participant &amp; Role</th>
<th>Role(s) teacher self identifies</th>
<th>Roles others ascribe</th>
<th>Participation consistent with described roles</th>
<th>Participation that suggests other role(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amanda:</strong> Curriculum designer</td>
<td>Turns the PLT’s ideas into doable tasks, organizes daily plans</td>
<td>Unit planner; Makes lessons, assessments &amp; copies</td>
<td>Asked PLC to clarify vision before writing tasks &amp; unit plans</td>
<td>Shared ideas; offered encouragement</td>
</tr>
<tr>
<td><strong>Art:</strong> Lateral thinker</td>
<td>Offers ‘new twists’ on existing ideas; technology “go-to”</td>
<td>“Flexible thinker”; “idea guy”; tech “go-to”</td>
<td>Shared ideas for logistics, lessons, technology</td>
<td>Helped design assessment and a research project</td>
</tr>
<tr>
<td><strong>Kate:</strong> Curriculum Aligner</td>
<td>Writes curriculum based on NGSS &amp; PLC vision</td>
<td>“Nitty-gritty curriculum stuff”; “forward planner”</td>
<td>Drafted guiding questions; planned units with others</td>
<td>Helped PLC newcomer; shared ideas</td>
</tr>
<tr>
<td><strong>Nancy:</strong> Visionary</td>
<td>Encourager; helped PLC feel they could adopt NGSS</td>
<td>Encouraged different thinking; “well-read”</td>
<td>Encouraged idea sharing; discussed reading</td>
<td>Helped rewrite some lessons</td>
</tr>
<tr>
<td><strong>Paula:</strong> Learner</td>
<td>Learner; newcomer; “question-asker”; “resource finder”</td>
<td>“Learner”; asks questions; finds resources</td>
<td>Asked questions about logistics; found resources</td>
<td>None</td>
</tr>
<tr>
<td><strong>Reese:</strong> Organizer</td>
<td>Makes agendas; thinks ahead and writes PLC ‘to-dos’</td>
<td>Organizer; keeps PLC on track; makes agendas</td>
<td>Wrote agendas; tracked progress; kept PLC focused</td>
<td>Coordinated purchases; helped plan</td>
</tr>
</tbody>
</table>
Each teacher contributed uniquely to the PLC’s joint enterprise of negotiating the meaning of NGSS and revising their curriculum. Art described himself as a lateral thinker who offered new twists on existing ideas and curriculum (Art, Individual Interview, 6-12-14); Amanda helped turn those new ideas into doable tasks (Amanda, Individual Interview, 6-2-14); Paula found resources needed to carry out those plans (Paula, Individual Interview, 6-4-14); Kate helped make sure the curriculum they were writing was consistent with NGSS and the PLC’s vision (Kate, Individual Interview, 5-16-15); Reese helped keep the PLC on track by writing meeting agendas and keeping track of what needed to be done (Reese, Individual Interview, 6-3-14), and Nancy was as a visionary and an encourager who helped the PLC feel they were capable of reform. (Nancy, Individual Interview, 6-3-14)

The roles teachers self-identify are consistent with the roles others ascribe to them. For example, Nancy identified herself as an encourager who helped the PLC feel they were capable of reform. “I tried to take a bit of, not a lead, but of helping people kind of get to this idea of, we could do this! We could use NGSS ... do all these things … and really kind of think pie in the sky (Nancy, Individual Interview, 6-3-14). Her peers saw her in the same light explaining that she supported them, shared ideas from the literature and helped them think differently about their curriculum.

Nancy … is really great at helping our PLT to kind of like, to move forward, and to kind of help be brave to move in new directions … helping us think about our curriculum looking really different than it has in the past … embracing more … [of] all things that I think all of us believe in and think are important, but she really kind of gives us that push to really dive in … she also is just more well read
on kind of what's current in terms of the educational reform, and things like that, and so she kind of keeps us abreast of those type of things. (Reese, Individual Interview, 6-3-14)

As summarized in Table 6, similar consistency is seen in all of the teachers’ descriptions of their roles and the roles of others. This consistency is explained by Reese who shared that a few years ago when the PLC was not working as well together, they had an explicit conversation about how each person felt they could contribute (Field notes, 06-03-2013).

The teachers’ participation, summarized in Table 6, is also consistent with the roles they ascribe to themselves and others. PLC meeting transcripts, field notes, and email communication are replete with evidence of Nancy’s encouragement, Art’s suggestions for new lesson plans, Reese’s organization of PLC meeting agendas, etc. For example, when the teachers realized that NGSS did not require students to memorize cell organelles and functions (but to explain how structure informs function), Art suggested a new project in lieu of students building or drawing and labeling traditional 2- or 3-D cell models (PLC Mtg, 9-5-13). He led the design of the organ project in which students researched an organ, described how the structure of that organ’s cells informed its function, and explained how various organ systems worked together to maintain homeostasis. Art’s participation, his suggestion of a new way of teaching about cell structure and function, was consistent with role he and others ascribed to him. Art and his peers saw him as an idea guy (Nancy, Individual Interview, 6 -3-14) who offered a fresh perspective. (Reese, Individual Interview, 6-3-14)
According to Wenger (1998) community members become comfortable with their role in mutual engagement over time and their identity is shaped by their experience of competence within the community. In this mature PLC, the teachers’ identities were shaped by their participation and their experience of competence within their community. They confidently and consistently described their roles and the roles of others, and they pursued their joint enterprise in ways that were consistent with these identities. However, the teachers’ roles were flexible; their participation was not restricted to a single, predetermined role. The rightmost column of Table 6 describes teachers’ participation that suggests other roles. While Art did frequently bring new ideas or a fresh perspective, he also sometimes helped with assessment design work. Similarly, while Kate described her primary contribution as designing curriculum based on others’ ideas, she also sometimes contributed new ideas. For example, she suggested a Socratic seminar as a way for students to engage in argument about the use of adult and embryonic stem cells (PLC Mtg, 10-10-13). This negative case analysis revealed one exception – Paula’s participation. Paula, a newcomer, identified and consistently participated as a learner and as a resource finder. She listened, asked questions, and found resources, e.g., supplementary readings, or WebQuests. She did not participate in other ways.

In summary, each of the biology teachers participated in the PLC by making a unique contribution to the PLC’s pursuit of a joint enterprise. The teachers had previously negotiated and agreed upon these roles. They were able to clearly describe their role and the roles of others, and their participation was consistent with the role(s) they identified. However, the teachers’ roles were flexible and not restricted to a single,
defined role. Through each teacher’s participation, the PLC pursued their joint enterprise of negotiating the meaning of NGSS and revising the curriculum.

**Claim 2.2.** The biology teachers developed a road map – a year-long plan of action that reified their meaning-making and became an enduring tool guiding their curriculum reform efforts.

**Evidence for claim 2.2.** Figure 11 is a photograph of a large whiteboard in the biology teachers’ workroom. On the whiteboard, the teachers wrote the NGSS topics they planned to teach in the order they planned to teach them. Beneath each topic, they wrote subtopics based on related disciplinary core ideas and performance expectations. Finally, they wrote their ideas for how to help students achieve those standards. This year-long plan of action, dubbed the road map, guided the teachers’ reform efforts throughout the 2013-2014 school year (FGI, 4-24-14). A typed version of the road map is presented in Table 7. The following paragraphs provide an explanation of 1) how the biology teachers participated in their PLC to create this road map, 2) how this participation in meaning-making is reified within the map itself, and 3) how the teachers used this map as a tool in revising their curriculum.

During the focus group interview, the teachers explained how their initial attempts to make sense of NGSS following the summer meeting with other Biology PLCs in the district led to the creation of the road map.

Art: How we came to understand the NGSS was we got them, read them individually, and then we … hammered it out by saying, ‘Here's what I thought. Is that what you thought?’ And that went around and around and around, and then
up here on the wall, we go what we thought would be our sequencing for the year that met the NGSS. (FGI, 4-24-14)

The end result of the teachers’ discussions was the road map depicted in Figure 12. Table 7 identifies how each component of the road map is aligned to NGSS topics, disciplinary core ideas, and performance expectations. The leftmost column is what the teachers wrote on the whiteboard. For each NGSS topic, the teachers wrote the subtopics they planned to teach. For example, within the NGSS topic, Structure and Function, the teachers planned to teach the following subtopics: levels of organization, molecules, cell division (mitosis), and homeostasis as well as relevant, real-world topics, e.g., stem cells, cloning, and cancer. The columns to the right represent my analysis. Analysis reveals the subtopics were based on disciplinary core ideas and performance expectations. The corresponding NGSS disciplinary core idea and performance expectation is listed next to each subtopic. All disciplinary core ideas and performance expectations are for high school. There is clear NGSS alignment (Photograph, 8-23-13).

Nancy explained that the teachers then discussed how students would achieve those standards. “Then we really went in with the skills on our own, on that summer day to go where's the reading and writing? Where's the modeling? By looking at the actual objectives, etc. in the NGSS and then adding more” (FGI, 4-24-14). These skills are written in parenthesis next to each subtopic in Table 7. For example, they planned to teach levels of organization through modeling, homeostasis through a lab, and stem cells through reading and writing, abbreviated R/W (Photograph, 8-22-13). As mentioned previously, the teachers used the term skills, rather than practices, but curriculum analysis reveals teachers’ plans to engage students in NGSS science practices to achieve
performance expectations. The rightmost column of Table 7 shows the NGSS science practice(s) evident in the teachers’ revised curriculum for each performance expectation.

The following describes one complete example from the road map and the associated revised curriculum. Within the NGSS topic, Inheritance and Variation of Traits, the teachers planned to teach the subtopic of mutations. This is aligned to Disciplinary Core Idea LS3.B which states: “Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited” (NGSS Lead States, 2013, p.89). The corresponding Performance Expectation (LS3-2) asks that students “Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) caused by environmental factors” (NGSS Lead States, 2013, p.89). The road map indicates the teachers plan to support students’ achievement of this performance expectation via engagement in reading and writing. Lesson plan analysis indicates the teachers’ plans to support students’ achievement of this performance expectation via engagement in four NGSS science practices – 1) analyzing and interpreting data, 2) constructing explanations, 3) obtaining, evaluating, and communicating information, and 4) engaging in argument from evidence. Students were given multiple opportunities to explore the content via engagement in these practices. For example, students were asked to analyze and interpret data and answer questions related to the incidence of various cancers (Appendix E) and obtain information by completing a WebQuest that explored known mutagens and carcinogens, e.g., tobacco and UV radiation (Appendix F). After
engaging in this and other supported and independent study, students were asked to: 1) describe the process by which cancer develops and the current state of cancer research regarding a specific cancer, 2) describe and analyze three social and/or ethical concerns surrounding cancer research and treatments, 3) make claims regarding the impact of behaviors, e.g., diet, tobacco use, tanning, etc. on cancer risk, and 4) write a thesis statement in response to why the development of cancer is different among individuals (Curriculum Units 4 and 5, 2014). Students’ written responses were assessed using a revised version of the World Studies Skills Rubric (Table 2).

Throughout the year, the teachers referred to the road map in revising their curriculum. The following is an excerpt from the teachers’ discussion of its importance in holding them to the previously negotiated reform ideals.

Amanda was talking about in writing it down and making it concrete was really important. And something that dawned on me as we were talking was this also made us accountable to trying the new things and pushing through because we decided ahead of time this was what it's gonna be. So in doing a road map … it also kept us from saying, to hell with it in January – let's do [our pre-NGSS] unit 6, 7, 8. We were invested! (Art, FGI, 4-24-14)

In summary, the road map and the teachers’ talk about its development and use describes an important aspect of the teachers’ participation in their PLC as they negotiated the meaning of NGSS and revised their curriculum. The biology teachers developed an NGSS aligned road map. This map reified their decisions about what NGSS topics and subtopics they would teach, the order in which they would teach them, and the practices students would engage in to achieve performance expectations. This map
became a part of the teachers’ shared repertoire. The teachers used the map as a tool that guided their curriculum reform efforts throughout the 2013-2014 school year.
Figure 11. Cross View Biology PLC 2013-2014 road map. (Photograph, 8-29-13)
<table>
<thead>
<tr>
<th>Topic (and Skill) Listed on Road Map</th>
<th>DCI</th>
<th>PE</th>
<th>Science Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td><em><em>NOS</em> &amp; Characteristics of Life</em>*</td>
<td>NA</td>
<td>NA</td>
<td>Obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td><strong>Structure/Function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NGSS Topic: Structure and Function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels (Model)</td>
<td>LS1.A</td>
<td>LS1-2</td>
<td>Constructing explanations</td>
</tr>
<tr>
<td>Molecules**</td>
<td></td>
<td></td>
<td>Obtaining, evaluating and communicating information</td>
</tr>
<tr>
<td>Cell Division (mitosis) (Model)</td>
<td>LS1.B</td>
<td>LS1-4</td>
<td>Developing and using models</td>
</tr>
<tr>
<td>Homeostasis (Lab)</td>
<td>LS1.A</td>
<td>LS1-3</td>
<td>Planning and carrying out investigations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Analyzing and interpreting data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Constructing explanations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td>Stem Cells, cloning, cancer, embryology <strong>(R/W)</strong></td>
<td>NA</td>
<td>NA</td>
<td>Constructing explanations</td>
</tr>
<tr>
<td>Inheritance &amp; Variation of Traits</td>
<td></td>
<td></td>
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<tr>
<td>----------------------------------</td>
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<td></td>
</tr>
<tr>
<td><strong>NGSS Topic: Inheritance and Variation of Traits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell Division (meiosis) (Model)</td>
<td>LS3.B</td>
<td>LS3-2</td>
<td>Developing and using models</td>
</tr>
<tr>
<td>DNA/chromosomes (Quest)</td>
<td>LS3.A</td>
<td>LS3-1</td>
<td>Obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td>Genetics (Math)</td>
<td>LS3.B</td>
<td>LS3-3</td>
<td>Using mathematics and computational thinking</td>
</tr>
<tr>
<td>Protein synthesis</td>
<td>LS1.A</td>
<td>LS1-1</td>
<td>Not taught through a practice</td>
</tr>
<tr>
<td>Mutations (R/W)</td>
<td>LS3.B</td>
<td>LS3-2</td>
<td>Engaging in argument from evidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Obtaining, evaluating, and communicating information</td>
</tr>
<tr>
<td>Differentiation (genes on/off)</td>
<td>LS1.B</td>
<td>LS1-4</td>
<td>Developing and using models</td>
</tr>
<tr>
<td>Genetic screening/testing/therapy <strong>(R/W)</strong></td>
<td>NA</td>
<td>NA</td>
<td>Engaging in argument from evidence</td>
</tr>
</tbody>
</table>
### Natural Selection & Evolution

**NGSS Topic: Natural Selection & Evolution**

Nature of Science* [listed again here]

<table>
<thead>
<tr>
<th>Lines of evidence (R/W)</th>
<th>LS4.A</th>
<th>LS4-1</th>
<th>Engaging in argument from evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural selection (Math/Lab) (Model)</td>
<td>LS4.B</td>
<td>LS4-2</td>
<td>LS4-3</td>
</tr>
<tr>
<td>Speciation (R/W)</td>
<td>LS4.C</td>
<td>LS4-5</td>
<td>Constructing explanations</td>
</tr>
<tr>
<td>Selective breeding**</td>
<td>NA</td>
<td>NA</td>
<td>Not taught</td>
</tr>
</tbody>
</table>

### Matter & Energy

**NGSS Topic: Matter and Energy in Organisms and Ecosystems**

<p>| Photosynthesis (R/W) (Model) | LS1.C | LS1-5 | Developing and using models |</p>
<table>
<thead>
<tr>
<th>Topic</th>
<th>Model/Category</th>
<th>Level</th>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Respiration (aerobic vs anaerobic) (Model)</td>
<td>LS1.C, LS1-7</td>
<td></td>
<td></td>
<td>Developing and using models</td>
</tr>
<tr>
<td>Cycles (R/W) (Math)</td>
<td>LS2.B, LS2-4</td>
<td></td>
<td></td>
<td>Constructing explanations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Using mathematics and computational thinking</td>
</tr>
<tr>
<td>Carbon + (Model)</td>
<td>LS2.B, LS2-5</td>
<td></td>
<td></td>
<td>Developing and using models</td>
</tr>
<tr>
<td>Food webs &amp; pyramids (Math) (Model)</td>
<td>LS2.B, LS2-4</td>
<td></td>
<td></td>
<td>Developing and using models</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Using mathematics and computational thinking</td>
</tr>
<tr>
<td>Interdependent Relationships</td>
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</tr>
<tr>
<td><strong>NGSS Topic: Interdependent Relationships in Ecosystems</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Human impact (R/W) (Lab)</td>
<td>LS2.C, LS2-7</td>
<td></td>
<td></td>
<td>Constructing explanations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Engaging in argument from evidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Obtaining, evaluating and communicating information</td>
</tr>
<tr>
<td>Topic</td>
<td>LS2 Level</td>
<td>LS2-8 Level</td>
<td>Description</td>
<td></td>
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<tr>
<td>-------------------------------------------</td>
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<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Group behavior vs individual behavior</td>
<td>LS2.D</td>
<td>LS2-8</td>
<td>Not taught</td>
<td></td>
</tr>
<tr>
<td>Complexity of interactions (W) (Competition, predation, etc.)</td>
<td>LS2.C</td>
<td>LS2-6</td>
<td>Engaging in argument from evidence</td>
<td></td>
</tr>
<tr>
<td>Genetically Modified Organisms**</td>
<td>NA</td>
<td>NA</td>
<td>Not taught</td>
<td></td>
</tr>
</tbody>
</table>

*NOS is addressed in NGSS Appendix H

** Denotes topic not explicitly addressed by NGSS, but included by the Biology PLC
Claim 2.3. The teachers pursued their joint enterprise of revising the biology curriculum by building each unit around a similar design structure: guiding question(s), opportunities for exploration and sense-making via engagement in science practices, content assessment(s), and written skills assessment(s) scored using a revised version of the World Studies Skills Rubric.

Evidence for claim 2.3. One way to understand how the biology teachers participated in their PLC is to analyze a reification of that participation – their reimagined practice as represented in their revised curriculum. The following paragraphs provide a detailed comparison of one revised curriculum unit (the PLC’s 2013-2014 Unit 2: Structure and Function) and the previous year’s unit that addresses similar content (the PLC’s 2012-2013 Unit 2: Cell Parts and Classification). This comparison is followed by a description of the pattern evident in this and subsequent revised units.

Table 8 is a side-by-side comparison of the old and revised units. The teachers allocated nearly twice the amount of time for this unit as they had in past. This extended time per unit is typical of the PLC’s revised curriculum. During the 2013-2014 school year, the biology teachers taught eight total units, four fewer units than the previous year.
<table>
<thead>
<tr>
<th><strong>Old (2012-2013) Cell Unit</strong></th>
<th><strong>New (2013-2014) Structure &amp; Function Unit</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length:</strong> 6.5 days</td>
<td><strong>Length:</strong> 13 days</td>
</tr>
<tr>
<td><strong>Unit Organized around five objectives:</strong></td>
<td><strong>Unit organized around a guiding question:</strong></td>
</tr>
<tr>
<td>1. Demonstrate ability to focus a microscope</td>
<td>1. How does structure relate to function?</td>
</tr>
<tr>
<td>2. Explain the cell theory</td>
<td></td>
</tr>
<tr>
<td>3. Identify and describe the function of the nucleus, cell membrane, cell wall, chloroplast, mitochondria, ribosome, vacuoles, cytoplasm</td>
<td></td>
</tr>
<tr>
<td>4. Distinguish between animal and plant cells</td>
<td></td>
</tr>
<tr>
<td>5. Distinguish between prokaryotic and eukaryotic cells</td>
<td></td>
</tr>
<tr>
<td><strong>Instructional strategies</strong></td>
<td><strong>Opportunities for exploration and sense-making via engagement in science practices</strong></td>
</tr>
<tr>
<td>Students:</td>
<td>1. Microscope introduction lab: Obtained a prepared cell slide and wrote their own procedure for focusing from low to high power. (Science practice: Planning and carrying out investigations)</td>
</tr>
<tr>
<td>1. Microscope introduction lab: Followed directions for focusing a microscope on newspaper letter</td>
<td></td>
</tr>
<tr>
<td>2. Cell structure lab: Read given background information on various cells e.g., Elodea, human cheek,</td>
<td></td>
</tr>
</tbody>
</table>
etc.; followed instructions for viewing, drawing, and labeling cells and their visible structures

3. **Presentation of information**: Read textbook, listened to PowerPoint lecture, and took notes on cell discovery, cell theory, characteristics of prokaryotic and eukaryotic cells, and cell organelle location

4. **Identification and coloring activity**: Colored and labeled plant and animal cell organelles

5. Completed a chart by writing in the function of each listed cell organelle and whether it was present in prokaryotic or plant or animal cells

6. **Review stations**: Answered questions focused on identification of cell parts on drawings and 3-D models

2. **Cell size investigation**: Planned and carry out an investigation to answer the given question: Why are cells so small? (Science practice: Analyzing and interpreting data)

3. **Cell structure lab**: Observed a variety of cells, e.g., bone, nerve etc.; Teachers asked students to notice certain cell structures and to interpret how those structures might help the cells carry out their function. (Science practice: Analyzing and interpreting data)

4. **Organ project**: Researched an organ, its function, its cells’ structure and specialized functions, compared the organ to others, and explained how the cells, tissues, organ, and organ systems worked together (Science practice: Constructing explanations)

5. **Homeostasis scenarios**: Students were given scenarios describing humans in extreme situations, e.g., mountain hiking in the Andes, and asked to explain how the body systems are affected by the conditions and work together to maintain homeostasis. (Science practice: Constructing explanations)
Assessment:
1. **Traditional quiz:** Focused a microscope on high power, identified a cell as prokaryotic or eukaryotic and plant or animal, labeled cell organelles on a diagram, and listed three parts of the cell theory.

Assessment:
1. **Content assessment:** Two quizzes: 1) Asked to describe and analyze evidence (from investigation) to explain why cells are so small, and 2) Asked to order the listed components of the cardiovascular system from smallest to largest in terms of levels of organization, compare and contrast the uni- and multicellular organism, and describe the structure and function of cell walls based on their observations and a given description and photographs.

2. **Skills assessment:** Asked to read a case study of Jim, a competitive rower; the article described physiological changes in his body before, during, and after competition. Students were asked to explain how body systems work together to allow a racer to maintain homeostasis. Students’ written explanations were assessed using a revised version of the World Studies Skills Rubric.
Both units engaged students in activity, but the kinds of activities students engaged in were quite different. The old unit was based on traditional, teacher-centered instructional strategies. Students engaged in activities that allowed them to confirm and memorize the information presented to them. Students practiced using microscopes by focusing on newspaper print letters. They viewed and read about various cell types, e.g., Elodea, human check cells, etc., and then confirmed these characteristics by viewing these cells using microscopes. Students read textbook passages and listened to a PowerPoint lecture about discovery of cells, cell theory, and the differences between prokaryotic and eukaryotic cells, and plant and animal cells. As a whole class, students colored and labeled plant and animal cell drawings, completed a Venn Diagram that showed the differences and similarities between plant and animal cells, and completed a cell organelle function chart. Prior to assessment, students visited eight review stations where they practiced focusing a microscope and identified cells and cell parts. Likewise, the assessment asked students to do the same. In summary, analysis of the old Unit 2 revealed plans for traditional, teacher-centered lessons that emphasized identification, confirmation, and memorization.

The new unit was a more student-centered unit that provided students opportunities to engage in science practices and deepen their conceptual understanding of cell’s structure and function. Students were given the opportunity to learn to use a microscope, but they were given less direction and learned to use the tool in context. The teachers decided to forgo the use of newspaper print letters, give students prepared cell slides, and ask them to write their own procedure for focusing a microscope from low to high power (PLC Mtg., 9-26-13). After giving students this opportunity to view cells, the
teachers asked students to plan and carry out an investigation of why cells so small. In the revised cell structure lab (Appendix G), students observed a variety of cells, e.g., Elodea, human cheek cells, bone, nerve etc. Teachers asked students to notice certain cell structures and to interpret how those structures might help them carry out their function. In a newly imagined activity to teach students about the levels of organization as well as how structure informs function, teachers asked students to research an organ, its function, its cell structure and specialized function, and to create an organ poster. Students did a gallery walk where they compared their organ of choice to others and then explained how the cells, tissues, and organs were similar/different and how organ systems worked together. Students were given scenarios describing humans in extreme situations (e.g., mountain hiking in the Andes) and asked to explain how the body systems are affected by the conditions and work together to maintain homeostasis. Students’ understandings of structure and function were assessed in two ways: 1) content quizzes, and 2) skills assessments. The teachers planned two content quizzes: 1) a cell size lab quiz in which students were asked to describe and analyze evidence from their investigation of why cells are so small, and 2) a comprehensive unit quiz in which students were asked to order the listed components of the cardiovascular system based on levels of organization, compare and contrast the cells of uni- and multicellular organisms, and describe the structure and function of cell walls based on their observations, a written description, and photographs. The teachers planned one skills assessment. Students were asked to read a case study of Jim, a competitive rower, regarding physiological changes in his body before, during, and after competition. Students were asked to explain how body systems work together to allow a racer to maintain homeostasis. Students written
explanations were to include descriptions and analysis of evidence and were assessed using a revised version of the World Studies Skills Rubric. In summary, Unit 2 reveals plans for a NGGS-aligned unit that provides students with opportunities to engage in science practices that deepen their conceptual understanding of cell structure and function.

This side-by-side comparison of one revised and one previous curriculum unit reveals a pattern in how the teachers pursued their joint enterprise of negotiating the meaning of NGSS and revising their curriculum. The teachers wrote guiding question(s), planned opportunities for exploration and sense-making via engagement in science practices, and assessed students’ learning through content assessment(s) and written skills assessment(s) scored using a revised version of the World Studies Skills Rubric. This pattern is confirmed in the remaining six revised curriculum units (Curriculum Units 3, 4, 5, 6, 7 and 8, 2014).

As the biology teachers refined their meaning making, they became more explicit in defining the content and skills assessed by the content and skills assessments. Beginning in Unit 2, the teachers defined the content and skills assessed in a separate guiding document. They defined the reading and writing skills as the ability to: “1) use analysis and synthesis to better understand scientific texts and other informational sources, 2) apply the skills of analysis and synthesis to write conclusions for experimental investigations and scientific studies, [and] 3) communicate … analysis, synthesis and evaluation of scientific texts, informational sources, and experimental investigations both in oral and written form;” they defined research skills as the ability to: “1) gather relevant and reliable information from multiple authoritative sources, [and] 2) demonstrate
appropriate in-text citations, and create a list of references” (Curriculum Units 2, 3, 4, 5, 6, 7 and 8, 2014). The teachers defined the skill of modeling as the ability to “create a model (physical, visual, analogies, verbal, demonstrations, etc.) to illustrate … understanding of specific scientific concepts” in Unit 2, but the revised curriculum did not include modeling until Unit 3 (Curriculum Units 2 and 3, 2014). The teachers defined the skill of scientific investigation as the ability to: “1) ask questions to further learning … 2) design and conduct investigations to provide evidence for scientific questions or solve a problem, 3) analyze and represent data using appropriate mathematical techniques, 4) identify and describe patterns in collected data, and 5) explain the results of an experiment or scientific study using appropriate rationale in Unit 2, and again in Units 7 and 8 (Curriculum Units 2, 7, and 8, 2014). In Unit 6, the teachers began separating the reading and writing skills into two categories. The first two were grouped as analysis/synthesis skills, and the third was labeled as communication (Curriculum Units 6, 7 and 8, 2014). Appendix H shows how the PLC defined the skills in the final unit of the revised curriculum (Curriculum Unit 8, 2014).

The teachers negotiated and re-negotiated the meaning of NGSS as they revised each successive curriculum unit. The revised curriculum presents an evolution of their meaning making. As the year progressed, the teachers were more explicit in defining how students would demonstrate their skills. Their articulation of the skills gradually included more language that was similar to the NGSS science practices and crosscutting concepts, and their revised curriculum included more opportunities for students to engage in a variety of science practices.
In summary, the biology teachers pursued their joint enterprise of negotiating the meaning of NGSS and revising the biology curriculum by building each curriculum unit around a similar design structure. Seven of the eight curriculum units were built around guiding question(s), opportunities for exploration and sense-making via engagement in science practices, content assessment(s), and written skills assessment(s) scored using a revised version of the World Studies Skills Rubric. As the teachers negotiated and re-negotiated the meaning of NGSS in each successive curriculum unit, their descriptions of skills became more explicit and included more of the language used in NGSS practices and crosscutting concepts.

Research Question 3

How do biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum?

Claim 3.1. The biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum as marked by a central tension between content details and skills.

Evidence for claim 3.1. Teachers described their experience of reform as marked by various tensions. The most pervasive tension was between content and skills. In the focus group interview and both individual interviews, all six teachers described experiencing tension between the amount of content details and the skills.

During the focus group interview, teachers explained that they initially viewed content and skills as distinct and separate. This separation is reified in teachers’ assessment. As described in the preceding section, the teachers assessed students in two ways. Students typically took a content assessment and a skills assessment scored using
a revised version of the World Studies Skills Rubric (Revised Curriculum, 2014). The distinction between content and skills was also reified in the road map. Figure 12 shows where the teachers wrote, “maybe sep [separate] content versus skills” (Photograph, 8-29-13) on the side of the road map. This reification expresses not only a distinction, but a tension.

*Figure 12. PLC’s initial separation of content and skills expressed on road map. (Photograph, 8-29-13)*

The tension stemmed from the teachers’ perceptions that adding skills (NGSS practices) would require removing some content given the time constraints of the school year. Art explained this perception:

The emphasis on skills, which has been at the core of everything that we're doing, … that was sparked by the NGSS … It's still a major source of frustration, because there's only so many minutes we get with these folks … Bringing in the content literacy, the reading and writing … it's just tough. It seems that a lot of things that I really like are mutually exclusive (Art, Individual Interview, 10-24-14).
As Art negotiated his own individual meaning of NGSS, he described feeling as though content and skills were mutually exclusive. Given limited time, he felt some content must fall away in order to include skills. This was frustrating for him.

Kate described her experience and the experience of others’ in a similar way:

It's … hard because we've been teaching things the same way for so long … I still find the importance of them knowing this content … we … have to have that balance … it's mainly just us letting go of things. (Kate, 5-16-14)

Like Art, Kate felt they needed to let go of some content, but it was hard, because the content was important and familiar to them. Kate explained in her final interview that they also loved their science content and that made it particularly difficult to let go.

It's hard, I think for all of us, because we love our content. I mean, that's why we're science teachers. But we [are] … kind of making that shift of yes, content is important, but what's really important is that you can do something with that content. (Kate, Individual Interview, 11-7-14)

It was difficult for the teachers to let go of their familiar and beloved content even though they valued students’ ability to do something with the content – to engage in science practices.

Letting go of content was particularly difficult for Paula, who identified as a traditional teacher who strongly valued content. Paula said:

It was a struggle for me. But I think it was a struggle for everybody, but it was a struggle for me … because I want the content … Are we teaching kids to be thinkers and citizens of the world, and are we giving the kids who maybe want to go into science things, are we giving them enough information? I don't know, I
don't know … I do think it's very, very important to get them to be thinkers.

Don't get me wrong – I don't want to boo-boo, hiss-hiss any of that. But there's the other side of me that says, ‘Are we teaching them enough [content]?’ (Paula, Individual Interview, 6-4-14)

Paula expressed a deep tension between content and skills, but the tension she and others described was not content or skills. Rather, the teachers described a tension between content details and skills. They valued both content and students’ ability to use content, but felt that emphasizing skills would necessitate the omission of some of the details traditionally associated with the content. The following paragraphs illustrate this more nuanced description of each teacher’s experience of tension between content details and skills and how teachers negotiated the meaning of NGSS amidst this tension.

Amanda described making a big mental shift away from requiring students to know content details toward helping students make an evidence based argument.

It’s just been a huge mental shift, from … knowing facts and things that are detail oriented versus why does this matter, what can I do with this information, how can I communicate my knowledge versus you know, answering just this is a right, this is a wrong versus, here's my opinion and here's the things that I have, the scientific evidence and support and research that I have … We're still worried about the content, but [there is] less emphasis on all the details of the content versus, why that content is relevant. (FGI, 4-24-14)

Amanda and her colleagues were still concerned with content, but she felt they had shifted to teaching content in a way that was less focused on minutia, and more focused on why science content knowledge is relevant.
Art also described a change in mindset. He let go of content details after asking himself whether it was really the details that he wanted his students to know:

It was the difference between do they know prophase, metaphase or can you tell me about a tumor. That's kind of the mindset that we've taken to this year … What do I want my kids to know … has been the biggest thing for me. (FGI, 4-24-14)

However, Art found it difficult to give up details he deemed important. The tension is evident in the following quote in which he verbalizes the temptation to squeeze in the details:

You still try and squeeze it all in, and it's just, it's just something that you have to accept. There is going to be a line in the sand if you're gonna go with this communication piece, that you're gonna have to let go of a lot, which was super tough to do, like, my kids may not have heard of osmosis yet, and they're seventeen, and that freaks me out, but I'm gonna guess they'll be okay. (Art, Individual Interview, 6-12-14)

Kate also found it difficult to not just give content details to her students even though she and her colleagues valued the skills.

It was hard for me to let go of some of this content, like teaching mitosis yesterday and not saying any of the actual phases … It's like, ‘Oh, but I just want to give it to you.’ … There is tension between this content and then these … skills, and we're trying to do both of them, and we're not perfect at it … The content is less … I feel like the kids are better able to understand it because there's not all of this other stuff … we're filling the gaps with these … skills that we think
are in a sense, more valuable than the memorization of content … We want them to walk out of our doors with, not memorizing mitosis, but that they can understand why somebody has cancer. (Individual Interview, 11-7-14)

Though Art and Kate struggled to eliminate content details (e.g., the phases of mitosis), they both felt that moving away from these details would make room for their students to learn something more valuable about the development of cancer through engagement in skills.

As the PLC moved away from content details toward skills, Nancy and Reese described seeking a balance between the two. At the end of the year, Nancy reflected on the changes that had been prompted by NGSS. She described continuing to wiggle back and forth between details and skills, but felt that overall, the curriculum was less focused on memorizing details and more focused on understanding big ideas through engagement in practices.

NGSS allowed for more … skills, and so how could we use that to step back from the drill and kill small facts to thinking about information, asking questions and exploring? … The focus on content is less about the little details, and more about … understanding the big ideas … I think in some cases perhaps, some kids need those details to understand the big ideas, and so I think we'll have some wiggle room back and forth trying to figure out the right balance for our kids, but overall, less focus on memorizing details, more focus on understanding big ideas.

(Individual Interview, 6-3-14)

Reese described the pursuit of balance as more difficult. She felt as though they had failed in some way because they had not been able to do it all.
There's less like, factoid stuff that is mandated, but in order to really teach it well, you still have to at least present some of that information … Striking balance, I think, is hard, and maybe that's just through our own interpretation of the standards, and the way that we've chosen to implement them, kind of finding balance between, like, the content and the skills … How deep do we want and can we go with the content itself? … We've failed in a sense of being able to do everything. (Reese, Individual Interview, 6-3-14)

Nancy’s and Reese’s comments indicate that negotiating the tension between content details and skills required negotiating how much detail students needed to understand the big ideas and seeking a balance between the two.

Each teacher clearly experienced tension between content details and skills, but each teacher’s individual experience of that tension was somewhat unique. Paula described experiencing perhaps the most significant tension. She detested the PLC’s emphasis on reading and writing and questioned whether students were getting enough content. However, she did come to view skills as important. At the end of the year, she reflected on her experiences and what she learned amidst the tension between content and skills.

[It] kind of took me a while to get … this NGSS stuff – what it was, what it meant, and why it was important … I will still always go back to ‘I'm thinking we're missing some content.’ … Last year in biology, it was really heavy into skills, and I will admit … I do not like the reading and writing section of it period. I detest that, but it's important … Throughout the process of looking at the NGSS with the
biology PLT, even though I still drag my feet with the reading and writing, it's important. I see it. (Individual Interview, 6-4-14)

While each teachers’ experience of negotiating the tension between content details and skills was unique, all members of the community described experiencing this tension in some way as they made sense of NGSS and revised their curriculum. Wenger (1998) views the tensions that exist within communities as a context for the negotiation of meaning. The PLC’s experience of tension between content details and skills provided a context for their negotiation of the meaning of NGSS. The following quote explains how the tension between content details and skills created this space for the teachers to make sense of the new standards, relinquish minutia, and engage students in science practices.

We look at those standards … for NGSS, and obviously our kids need to know those things, but the level, the depth at which they need to know those … is so much lower … You don't need to know all of these details, but it would be pretty important for you to know, in general, what is cancer? And how does that happen? … Not what is the specific order of amino acids for this protein? … Not the details … Teaching that so that they can apply it and understand it in their everyday lives is so much more important and valuable than knowing the structure of DNA, and you know, all of these things that are important but not the most important … I mean, thinking about how that's changed of relinquishing the details that don't seem to be necessary, but putting in practices for them to use the content that they know. (Amanda, Individual Interview, 11-6-14)
In summary, the biology teachers described their experience of negotiating the meaning of NGSS and revising their curriculum as marked by tension between content details and skills. The teachers viewed science content knowledge and NGSS practices, which they referred to as skills, as separate and distinct. They felt that in order to emphasize skills, they would need to let go of some content details that were a part of their pre-NGSS curriculum, e.g., memorizing the phases of mitotic division, the chemical equation for photosynthesis, etc. The teachers experienced tension as they let go of beloved and familiar content, but amidst the tension, the teachers were able to make sense of NGSS and revise their curriculum in ways that de-emphasized minutia and engaged students in science practices. 

Amanda provided this summary of their accomplishments:

We've gotten rid of so much content, especially detail-wise, and we've been wanting to do that for a while, of just like, okay, do they really need to write the equation for photosynthesis? That seemed, I mean, it is, it's completely irrelevant, they don't need to know that, but knowing what photosynthesis is, and why deforestation is a problem to our environment, that's something that they need to know. So that's really been our shift, and our building shift, and the great thing about the NGSS shift. (Amanda, Individual Interview, 6-2-14)

**Claim 3.2.** The biology teachers described their experience of negotiating the meaning of NGSS and revising their curriculum as stressful and exhausting; they persevered because they valued the revisions they were making to their curriculum.

**Evidence for claim 3.2.** Teachers tended to describe their experience of negotiating the meaning of NGSS and revising their curriculum in terms of strong emotions – those of stress and exhaustion. During the focus group interview, the teachers explained that one
of the reasons their experience was so difficult was that they decided to revise all of their curriculum in one year even though the district science coordinator had suggested a three-year transition.

Reese: I think it was tough because … this group is sort of like if we're going to do it, we're going to do it all, and we're going to do it now as opposed to you know [the district coordinator] has told us, ‘you have like 3 years.’

Art: Three years to transition.

Reese: … But we're sort of like, no, if we believe this is the right thing to do, we're doing it.

Kate: And we were excited about it, and you don't want to lose that momentum when you're excited about the new standards. (FGI, 4-24-14)

Though some later described the decision as “crazy” (Kate, Individual Interview, 5-16-14) and “too big, too fast” (Paula, Individual Interview, 6-12-14), the teachers were excited about the new standards and decided to revise their whole curriculum in one year.

The revision was no small undertaking. The biology teachers did not merely tweak old curriculum units. As seen in the prior comparison of pre- and post-NGSS curriculum, teachers made significant changes (Curriculum Unit 2, 2012-2013; Curriculum Unit 2, 2013-2014). When asked to describe in their own words what they changed about their curriculum, all of the teachers exclaimed in unison, “Everything!” (FGI, 4-24-14). Changing everything meant that there was a lot of work. The following paragraphs describe the teacher’s individual experience of how difficult it was to change everything and why they persevered in spite of the difficulty.
Nancy, a veteran teacher, likened the experience to her first year of teaching: “We worked really, really hard to get that [the revised curriculum] up and running, so yeah, it was, you know, it's like being a first year teacher, all over again, but probably even worse than my first year teaching” (Nancy, Individual Interview, 11-26-14). It was particularly difficult for Nancy, who identified her role in the PLC as that of an encourager. In many ways, she was a visionary who spearheaded the PLC’s reform efforts and encouraged the biology teachers to feel this work was possible. So it was difficult for her to see her fellow PLC members so stressed out; she felt responsible. She explained, “The hardest part was … watching my colleagues trying to implement it, and me watching them be so uncomfortable and stressed out … I was extremely worried about their stress levels and feeling very responsible for their stress levels (Nancy, Individual Interview, 6-3-14).

The biology teachers were quite stressed. They did not want to do things halfway; they did not want a mediocre product. As Reese explained, they wanted to do things really well, and that made the experience even more stressful.

Stressful, overwhelming, those are words that come to mind … It was a huge undertaking. We don't really want to do things halfway, if we're going to do it, we want to do it … really well, and so some of that stress and overwhelming-ness of it, we kind of self-imposed, just because of our personalities (Reese, Individual Interview, 11-5-14).

Art described his experience as moderately stressful for a similar reason:

If you're gonna go, go hard … I think it's a do or do not. It's a Yoda situation … It was all kind of tough. I mean, I put it all at like a six or a seven, which is like, moderate stress. (Art, Individual Interview, 6-12-14)
The stress took a toll. At the end of the year, Amanda said: “Everybody is exhausted … There's just been so many times that I've been overwhelmed, and discouraged, and just worn out from this year” (Individual Interview, 6-2-14). However, the teachers pressed on because they felt the end product, the revised curriculum, was what was best for their students. Amanda explained, “It's where we've been wanting to go” (Amanda, Individual Interview, 6-2-14). Kate said, it “has been hard, but it's what's best for kids, and sometimes what's best is not always the easiest” (Kate, Individual Interview, 5-16-14).

In the following excerpt from her final interview, Reese reiterated how difficult the experience had been and explained how the PLC was able to persevere in spite of their stress and exhaustion.

It's a lot of work. It's not … just going back to old stuff and modifying or revising little bits here or there. It's literally starting from scratch again and again. And that's just, that's a lot! I think our PLT was able to do that because we have a bunch of people that really believe in this vision of moving away from, I don't want to say away from content, but kind of … away from just memorizing isolated pieces of information and moving toward students being able to think about information and use information and apply information, and talk about things well. (Reese, Individual Interview, 11-5-14)

Despite the amount of work, the PLC persevered because the teachers believed in their vision – a reimagined curriculum that de-emphasized minutia and provided students opportunities to engage in science practices.
In summary, the biology teachers described their experience of negotiating the meaning of NGSS and revising their curriculum in one year as stressful and exhausting. Nancy, Kate, and Paula described it as *hard*. Art said it was *tough*. Amanda and Reese described it as *overwhelming*. Several found the experience *stressful*. Nancy, who identified as an encourager, found the experience particularly stressful because she felt responsible for others’ stress. Still, the teachers persevered because they valued the revisions they were making to their curriculum. They could have slowed or postponed their reform efforts, but they did not. They believed in what they were trying to accomplish (Paula, FGI, 4-24-14). As Amanda explained, it was where they had been wanting to go (FGI, 4-24-14). They kept the end product in mind (Art, 6-12-14), and supported one another throughout the challenges of reform (FGI, 4-24-14).
Chapter 5

Discussion

The purpose of this study was to understand how secondary biology teachers in a mature, effective PLC negotiated the meaning of NGSS as they revised their curriculum. The study was guided by the following three sub-research questions:

1. How do the Biology PLC’s interactions with other communities influence how the biology teachers negotiate the meaning of NGSS as they revise their curriculum?
2. How do the biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum?
3. How do the biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum?

This chapter is divided into five major sections, one section for each of the three sub research questions, a discussion of the limitations of the study, and a concluding discussion of the study’s contributions and implications. Each of the first three sections provides a summary of the interpretations and a discussion of how the interpretations compare and contribute to the relevant literature discussed in Chapter Two. The chapter concludes with a summary discussion of how this study contributes to our understanding of science teacher PLCs as a potential venue for science education reform and implications for science teacher education, professional development, and future research.

Research Question 1

How do the Biology PLC’s interactions with other communities influence how the biology teachers negotiate the meaning of NGSS as they revise their curriculum?
Summary of the interpretations. The Cross View Biology PLC interacted with other communities within their building and their district. Their interactions with these other communities influenced how they negotiated the meaning of NGSS and revised their curriculum. However, the Cross View Biology PLC minimized the potential influence of other Biology PLCs in the district by providing leadership in negotiating only the sequence of NGSS topics, but not specific standards. Given the three PLC’s different stages of development and disparate views of reform, attempting to create a more specific, district-wide curriculum might have presented a barrier to reform.

Negotiating at such a broad level allowed the Cross View Biology PLC to minimize this potential barrier and meet district requirements for NGSS alignment and common semester assessments, while revising their own curriculum in ways that were consistent with their local community and building-level goals.

The Cross View Biology PLC’s historic collaboration with their building’s World Studies and Language Arts PLC had a greater influence on how the biology teachers negotiated the meaning of NGSS. When NGSS was released in 2013, the Biology PLC adopted and revised the World Studies Skills Rubric to assess students’ science writing. The Biology PLC’s use of this rubric influenced the biology teachers’ prioritization of the following science and engineering practices: obtaining, evaluating, and communicating information, and engaging in argument from evidence. The teachers placed a secondary emphasis on analyzing and interpreting data and constructing explanations. Where the biology teachers indicated intentions to emphasize these practices, they also frequently planned to assess students’ written work, e.g., their arguments and explanations, using a revised version of the World Studies Skills Rubric. The biology teachers equated the
skills assessed by the rubric, e.g., describing and analyzing evidence and making claims supported by that evidence, to the NGSS science practices. The rubric served as a bridge that allowed teachers to form connections between the familiar – their historic collaboration with the World Studies PLC and the skills assessed by the World Studies Skills Rubric, with the unfamiliar – the NGSS and the recommended science practices.

**Comparison and contributions of the interpretations to the literature.**

Wenger (1998) asserts that communities do not exist in isolation; they exist within and among other communities. The practices of one community affect, and are affected by, other communities. In this case, the Cross View Biology PLC’s practice was affected by their interactions with other Biology PLC’s in their school district and their school building’s World Studies and Language Arts PLC.

The Cross View Biology PLC’s historic collaboration with the World Studies PLC and their use of the World Studies Skills Rubric is central to this story of how the biology teachers negotiated the meaning of NGSS. Their story contributes to our understanding of how mature PLCs might practice in the absence of a university facilitator or professional development affiliation. It is an important exemplar because many science teacher communities do not have university facilitators helping them revise their curriculum, yet much of our current understanding of science teacher PLCs comes from studies of communities supported by a facilitator. These facilitators helped science teachers co-develop learning progressions (Furtak & Heredia, 2014), assess students’ work (Richmond & Manokore, 2011), and engage in analysis of practice activities (Roth et al., 2011). Facilitators are viewed as a critical support in the general teacher PLC literature (Grossman et al., 2001; van Es, 2012). Even with facilitator support, teachers
in a cross-grade math and science PLC struggled to work across disciplines and grade levels, and to assess students’ work in ways that made an impact on their teaching practice. In contrast, this PLC’s practice was independent; there was no external facilitator, and the teachers were not participating in a university-based professional development program. The Biology PLC sought and fostered collaboration with the World Studies and Language Arts PLC. The biology teachers viewed this collaboration as critical to their efforts negotiating the meaning of NGSS and revising their curriculum. The collaboration was particularly influential in the Biology PLC’s ability to engage and assess students in the following science practices: obtaining, evaluating, and communicating information, engaging in argument from evidence, analyzing and interpreting data, and constructing explanations. These interpretations suggest that mature, effective science teacher PLCs that identify and utilize existing local resources and foster strong collaborative relationships with other mature, reform-oriented PLCs may be capable of making sense of reforms and revising their curriculum in meaningful ways even without the support of an external facilitator or other affiliate. The following paragraphs further describe how this mature PLC’s sense-making contributes to our understanding of science teacher PLCs as a venue for reform.

The professional support of teacher colleagues, administrators, and state and local policymakers is critical for effective education reform (Lynch, Pyke, & Grafton, 2012; Roehrig et al., 2007). While the state had not adopted NGSS at the time of the study, the Biology PLC did have strong local administrative support. The district science coordinator valued NGSS, required district science teachers to adopt NGSS, and gave biology teachers time to collaborate and discuss revising and aligning their curriculum.
The district science coordinator provided support for reform efforts; however, he also created a potential barrier to reform because his request could have led to contrived collegiality (Hargreaves, 1994). Forced collaboration and requirements to implement a particular curriculum in response to administrative directives limits teachers’ ability to make curriculum decisions based on what they think would be most helpful for students.

It would have been particularly difficult for the three district Biology PLCs to create and enact a district-wide curriculum given the three PLC’s disparate views of reform as reform is impeded when teachers’ beliefs are not in harmony with reform ideals (Cronin-Jones, 1991; Czerniak & Lumpe, 1996; Savasci & Berlin, 2012).

It would have also been difficult for the Cross View Biology PLC to create and enact a district-wide curriculum given the three Biology PLCs differing stages of PLC development. One of the Biology PLCs in the district was newly formed. PLC’s in the earlier stages of development tend to be more focused on the establishment of group norms than the rich collaborative work required to develop an understanding of new policies and approaches and to achieve clearly defined goals for improving student learning (Bolam et al., 2005; DuFour, Dufour, Eaker, & Many, 2006; Grossman et al., 2001; Kruse et al., 1995; McLaughlin & Talbert, 2006).

The Cross View Biology PLC minimized these potential barriers to reform by negotiating only the sequence of NGSS topics, not specific standards, at the district level. Richmond & Manokore (2011) also suggested that PLCs might enable teachers to minimize barriers to science teaching. In their study of two elementary PLCs (working with the support of a facilitator), participants found ways to achieve their science teaching goals while still meeting district demands to prioritize math and language in
their Reading First schools. The present case study contributes to the literature by providing a powerful example of how a mature, effective science teacher PLC minimized potential barriers to science education reform and allowed teachers to revise their curriculum in ways they felt were consistent with reform ideals and what was best for their students’ science learning. Importantly, the Cross View Biology PLC did so without the support of an external facilitator. The PLC’s maturity and strong sense of community allowed them to find their voice at the district meeting and to express agency in directing their own reform efforts.

The study also contributes a powerful example of how a PLC’s reform efforts might be influenced by their use of shared resources and collaborative relationships with other communities. Teachers often rely on existing curriculum and accompanying teacher resources to guide their planning and teaching (Ball & Cohen, 1996), learn about reform based practices (Schneider & Krajcik, 2002), and make and justify sound pedagogical decisions (Schneider & Krajcik, 2002). In this case study, NGSS had just been released, and there were minimal existing curriculum resources. In the absence of previously developed, NGSS aligned curriculum, the Biology PLC drew upon an existing local resource, the World Studies Skills Rubric. The biology teachers viewed the skills assessed by the rubric as the same as some of the NGSS practices, and frequently used a revised version of the rubric to assess students’ ability to engage in these practices. In this way, the rubric served as a boundary object – a bridge that made new joint endeavors possible (Star & Griesemer, 1989). Boundary objects are flexible enough to adapt to the needs of the different communities employing them, yet robust enough to be recognizable across communities. When Furtak & Heredia (2014) investigated how a boundary object
created in one learning community was used in another learning community, it was difficult for the second community to make sense of the object (a learning progression for natural selection) within their context. In contrast, the biology teachers in this study were able to make sense of and use the boundary object, the rubric. The rubric enabled the biology teachers to form connections between the familiar World Studies skills and the unfamiliar NGSS science and engineering practices. The continued collaboration between the two communities, particularly their efforts to jointly negotiate definitions of the skills assessed by the rubric, was critical to the Biology PLC’s ability to revise and use the boundary object in meaningful ways within the context of science and NGSS reform recommendations. The use of a boundary object that focused the teachers’ initial reform efforts on a few, rather than all, science practices, may have been important in making the PLC’s joint enterprise more manageable. This echoes Furtak & Heredia’s (2014) suggestion that a focus on fewer dimensions might have helped a learning community struggling to coordinate their work around a learning progression.

Research Question 2

How do the biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum?

Summary of the interpretations. Each teacher filled a unique role within the PLC. The teachers were able to clearly and consistently describe their role and the roles of others within the PLC because they had previously negotiated and mutually agreed upon these roles. The teachers’ participation was consistent with the roles they described. Each teacher participated in the PLC by making a unique contribution to the
community’s joint enterprise of negotiating the meaning of NGSS and revising their curriculum.

Prior to revising their curriculum, the biology teachers met to discuss the meaning of the new standards. They developed a road map – a year-long plan of action that reified their meaning-making and guided their curriculum reform efforts. The road map became a part of the teachers’ shared repertoire. It was an enduring tool that guided their curriculum reform efforts throughout the year. As the teachers revised their curriculum, they built each unit around a similar design structure: guiding question(s), opportunities for exploration and sense-making via engagement in science practices, content assessment(s), and written skills assessment(s) scored using a revised version of the World Studies Skills Rubric. The revised curriculum was a less traditional, more student-centered curriculum that engaged students in science practices and supported development of conceptual understanding, not memorization of minutia. The teachers negotiated and re-negotiated the meaning of NGSS as they revised each curriculum unit. Over time, the teachers were more explicit in defining how students would demonstrate their skills, and their articulation of the skills gradually included language that was similar to the NGSS science practices and crosscutting concepts.

**Comparison and contributions of the interpretations to the literature.**

Wenger (1998) asserts that active engagement in meaning making within a community allows leaners to develop competence in the community’s enterprise and to shape the context of their learning. Teachers participating in developing professional learning communities must define their role within the group and establish group norms of interaction before they can work collaboratively to achieve goals focused on student
learning (Bolam, et al., 2002; DuFour, et al., 2006; Grossman et al., 2001) or assume communal responsibility for their own learning (Kruse, et al., 1995). Teachers participating in mature PLCs can work together to make sense of instructional policies, curriculum materials, and new approaches to their own professional development (Kruse et al., 1995). However, there are few studies of mature science teacher PLCs, and few, if any studies of mature science teacher PLCs attempting to negotiate the meaning of science education reforms and revise their own curriculum aligned to the reforms. This case study contributes a description of how science teachers might successfully negotiate roles within their PLCs without the help of an external facilitator. In this case, the teachers had an explicit conversation about how they felt they could contribute to the community’s joint enterprise. This study also contributes a description of what roles teachers might need to fill within a PLC that is trying to make sense of reform recommendations and revise their curriculum. In this case, pursuit of their joint enterprise required encouragement (provided by Nancy), flexible thinking and technology support (provided by Art), curriculum revision and alignment (provided by Kate), new unit and daily lesson plans (provided by Amanda), new resources (provided by Paula), and considerable organization (provided by Reese). The teachers expressed competence in their roles and recognized and valued the contributions of others. They developed a sense of belonging; they worked collaboratively to achieve goals focused on students’ science learning and assumed communal responsibility for their own learning.

One way the biology teachers expressed this communal responsibility for their own learning was to discuss their individual interpretations of the standards and to reify their collective meaning making through the creation of the road map. The road map
became an enduring tool that guided the teachers’ reform efforts. Similar tools have been created in past reform eras. Teachers in a Louisiana professional development program developed a year-long plan for integrating new instructional practices, authentic investigations and alternative assessments (Radford, 1998). However, the teachers did so with significant support from a three year professional development program. The literature also includes descriptions of how teachers have made sense of new reforms by developing criteria to determine whether curriculum plans could help students achieve desired outcomes (Lynch, 1998) and building a curriculum framework for one unit based on a single standard (Lynch, et al., 2003), but again, the teachers did so within the context of a teacher preparation or professional development program. This study demonstrates that teachers within a mature, effective science teacher PLC were able to make sense of reforms through the creation and use of a year-long plan of action that captured their meaning making and guided their curriculum revision.

The substantive curriculum revisions that the Biology PLC made are significant. Building each unit around a similar design structure made the task more manageable, but what is most remarkable is that they made significant, reform-oriented revisions. Sometimes teachers feel they are already teaching in reform oriented ways, even if they are not; they do not think they need to revise their current curriculum and practice, and so they do not (Donnelly & Sadler, 2009). In contrast, this PLC made fundamental revisions. Their revised curriculum was a more student-centered curriculum that engaged students in science practices and supported their development of conceptual understanding. The literature review includes examples of PLCs that have made significant reform-oriented changes (Roehrig & Kruse, 2010; Wallace & Kang, 2004),
but these PLCs were working with support from an external facilitator or professional development program. Larkin et al.’s (2008) study provides a rare example of a mature learning community in science education; the teachers implemented an inquiry-oriented science curriculum, but they implemented an existing curriculum. Because it was a retrospective study, it does not explain how teachers negotiated the meaning of the reforms. The present study contributes a description of how one PLC made significant reform-oriented revisions to their curriculum and how they negotiated and re-negotiated the meaning of NGSS as they revised each successive curriculum unit. It describes how a mature, effective PLC was be able to make sense of science education reform recommendations, abandon old ideas, and reimagine their practice.

Research Question 3

How do the biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum?

Summary of the interpretations. The biology teachers described their experience as marked by a central tension between content details and skills. They viewed science content knowledge as distinct and separate from NGSS practices, which they referred to as skills. They valued both, but felt that incorporating practices necessitated the omission of some of the content details associated with their more traditional, pre-NGSS curriculum. They experienced tension as they let go of beloved and familiar content. Each teacher’s experience of negotiating the tension between content and skills was unique. The tension between content details and skills created a space for the teachers to negotiate the meaning of NGSS. Amidst the tension, the
teachers were able to make sense of NGSS and revise their curriculum in ways that
deemphasized minutia and engaged students in science practices.

The biology teachers also described their experiences as stressful and exhausting. Though the district science coordinator had suggested adopting NGSS over a three-year transition period, the teachers were excited about the new standards and chose to revise all of their curriculum in one year. They made significant, substantive revisions to their curriculum that they described as more similar to starting from scratch than merely revising. Every teacher described this experience as difficult, but they persevered because they valued the revisions they were making to their curriculum. They kept the end product in mind and supported one another throughout the challenges of reform.

**Comparison and contributions of the interpretations to the literature.** The Cross View Biology PLC embodies the characteristics of a mature, effective PLC as defined by Bolam et al., (2005), Kruse et al., (1995), and Stoll et al., (2006). However, the teachers’ experience of tension between content and skills is similar to the tension between content and pedagogy that Grossman et al., (2001) described during the developing stages of an interdisciplinary learning community. Grossman and colleagues described this as the essential tension, and suggested that developing communities must navigate this tension. The present study suggests that even mature communities must negotiate tensions anew in the midst of reform. As the biology teachers negotiated the tension between content details and skills, they also negotiated the meaning of NGSS. This is consistent with Wenger’s (1998) assertion that the tensions that exist within communities provide a “fertile ground for learning” (p. 214).
The teachers’ experiences of reform as stressful and exhausting are similar to those experienced by the teachers in Larkin et al.’s (2008) retrospective study of how a community of secondary science teachers implemented and sustained a new inquiry oriented science curriculum. Both communities felt constrained by limited time and found starting from scratch difficult, though the teachers in the retrospective study were actually implementing an already developed curriculum. Both communities resolved the dilemma of limited class time, described by Anderson (2007), in a similar way. The teachers in the Larkin et al. (2008) study resolved the dilemma by focusing less on content coverage and more on inquiry-based approaches that supported comprehension. The teachers in the present study resolved the dilemma of limited class time and the associated tension between content and skills by omitting content details and prioritizing a few NGSS practices. When considered together, these two studies of mature, effective science teacher PLCs suggest that these learning communities are capable of implementing meaningful and lasting science education reform, but the process of doing so will not be without difficulty. Teachers will need to identify and negotiate the tensions that arise as they try to make sense of reform recommendations and revise their curriculum.

Limitations

This study is limited by the boundaries of the case, time and the participants’ practice. This investigation began just after the release of NGSS at a time when there were few existing NGSS aligned curriculum and resources. The biology teachers negotiated the meaning of the standards and revised their curriculum with limited ability to draw upon existing NGSS aligned curriculum and resources. The timing of the
investigation also meant that the biology teachers were unable to reach out and collaborate with other science teachers who had already adopted and implemented the new standards. This provided a unique opportunity to explore how a science teacher community approached negotiating the meaning of a new science education reform document. However, science teacher communities adopting and implementing NGSS in the future will have access to more resources, such as Krajcik et al.’s (2014) 10-step guide to designing NGSS aligned lessons and the many practitioner resources available from NSTA.

The data used to describe participants’ practice also warrants consideration when thinking about how the interpretations and implications might be transferred to other contexts. Data collection was limited to the meaning making that occurred within, and along the edges of, the Biology PLC. The majority of the teachers’ practice, and thus the majority of the data, came from the teachers’ interactions during PLC meetings, the teachers’ meaning making as reified in their revised curriculum, and interviews about their experiences of collaboratively negotiating the meaning of NGSS. However, the teachers also collaborated in pairs and smaller groups throughout the week, and with individuals in other tangential communities (e.g., teachers in their shared planning team). Data from these interactions was not collected or considered, but may have influenced the teachers’ meaning making. Researchers and practitioners considering the transferability of the interpretations and implications of this study should carefully consider community context, particularly the ways in which the community’s context is similar and dissimilar to the context in this study and the potential ways that the community’s unique context might influence its practice.
A final word about participants’ practice as a potential limiting factor: A critique of this study might be that no data was collected within the teachers’ classrooms. However, I do not view this as a limitation. The data provide ample evidence that the biology teachers’ practice was consistent with their PLC’s revised curriculum. During PLC meetings, teachers discussed their practice and assessed students’ work. In PLC emails, teachers shared tips with, and asked questions of, their colleagues as they implemented the revised curriculum. As I collected data, I was frequently in the building and casually observed moments of teaching, even though there was no formal data collection in these moments. The teachers really were implementing their revised curriculum. The reader can be confident that the revised curriculum was the enacted curriculum.

Conclusion

This study addresses previously described gaps in the literature by describing how secondary biology teachers in a mature, effective PLC negotiated the meaning of NGSS as they revised their curriculum. The teachers in the Cross View Biology PLC minimized potential barriers to reform, including a lack of support for NGSS at the state level and a district requirement that all district level Biology PLCs give a common semester assessment, despite disparate stages of development and views of reform. The teachers negotiated the meaning of NGSS and revised their curriculum in ways that were consistent with their local building and community level goals. They utilized an existing resource – their historic collaboration with their building’s World Studies and Language Arts PLC and a boundary object – the World Studies Skills Rubric in their negotiation of meaning. The rubric served as a bridge that allowed the teachers to form connections
between the familiar skills assessed by the rubric and the unfamiliar NGSS science practices. The teachers’ use of the rubric also influenced their prioritization of a few NGSS science practices.

As the teachers revised their curriculum, each teacher contributed to this joint enterprise by filling a unique, previously negotiated role. The teachers created a tool, a year-long plan of action that guided their curriculum revision. They built each revised curriculum unit around a similar design structure that afforded students opportunities for exploration and sense-making via engagement in science practices.

The teachers experienced tension between content details and skills. Amidst the tension, they were able to reimagine their practice as less focused on minutia and more focused on the development of conceptual understanding through engagement in NGSS science practices. Revising their curriculum in such substantive, significant ways was not without difficulty. The teachers described the experience as stressful and exhausting. However, they persevered because they valued the end product of their collaborative reform efforts – a revised curriculum.

These interpretations describe how a mature, effective science teacher PLC negotiated the meaning of NGSS, revised their curriculum in meaningful ways, and enacted a curriculum that was less traditional, less teacher-centered, and less focused on content minutia. The Biology PLC created a curriculum that was reform-oriented – more student-centered and more focused on developing students’ conceptual understanding of science content through engagement in NGSS science practices. Significantly, and in contrast to existing literature, they did so without the support of an external facilitator,
professional development program, or other affiliate and without the benefit of existing, reform-based curriculum.

When the interpretations of this study are considered in the context of existing literature on K-12 science education reform implementation and K-12 professional learning communities, they indicate that mature, effective science teacher PLCs are a potentially powerful venue for science education reform. The study does not counter the general consensus that nascent or developing PLCs must work through the difficult early stages of PLC development before they are capable of working collaboratively to achieve goals focused on student learning (Bolam et al., 2002; DuFour et al., 2006; Grossman et al., 2001). However, it does suggest that working through those difficult early stages may be well worth it. It suggests that mature, effective biology PLCs are capable of making significant reform-oriented revisions to their curriculum and should be viewed with more than the cautious optimism suggested by Hargreaves (1994) and Nelson (2008).

**Implications**

This study provides several important implications for science teacher education, professional development, and future research. These implications are presented in the following paragraphs.

**Implications for science teacher education.** If science teacher PLCs are to reach their potential as a venue for science education reform, then science teacher educators and science teacher preparation programs can and should prepare preservice teachers to participate in their future PLC(s). This study suggests how they might do so.
Identifying mature, effective science teacher PLCs and encouraging preservice teachers to observe and engage in peripheral participation in these communities may help preservice teachers view their future PLC as a potentially valuable collaborative community in which they wish to participate. Science teacher educators might encourage preservice teachers to attend their host teacher’s PLC, and encourage host teachers to discuss their PLC’s work with their mentee. However, preservice teachers’ experiences may vary depending on the PLCs stage of development. Explicit discussion of community development accompanied by opportunities to observe and engage in peripheral participation in their host’s PLC may prepare them to participate in their future PLC, regardless of their observed PLC’s stage of development.

**Implications for professional development for practicing science teachers.**

This study suggests important implications for professional development for practicing science teachers. If science teacher PLCs are to reach their potential, then practicing teachers need high quality professional development that allows them to participate in, and contribute to, their PLC’s joint enterprise. The interpretations of this study imply the following:

1. PLCs have the potential to contribute to teachers’ sense of agency and their ability to propose solutions that minimize potential barriers to reform. Professional development that helps PLC members identify potential barriers to reform and brainstorm possible solutions may help teachers view potential barriers as surmountable and help them voice and act on possible solutions.

2. In highly functioning PLCs, members contribute in unique ways and have specific roles. At Cross View, these roles were previously negotiated through explicit discussion
of how each member felt he or she could contribute to the PLC. Professional development opportunities that allow teachers to identify and build upon their strengths may help them negotiate their role within their PLC’s joint enterprise.

3. Teachers draw upon existing resources. This was evident in the Cross View Biology PLC. The teachers identified and utilized an existing resource – their historic collaboration with the World Studies and Language Arts PLC, and the World Studies Skills Rubric. Professional development that supports teachers’ examination of their own context may help teachers identify and draw upon existing resources, and work collaboratively with other communities to achieve goals focused on students’ science learning. This is particularly important for two reasons. One, teachers’ responses to reform are influenced by how teaching and learning are organized in their schools (Coburn, 2001). Two, opportunities to co-develop a resource may make the resource easier for the community to utilize in their own context (Furtak & Heridia, 2014).

4. Community created tools that reify teachers’ negotiated meaning of reforms can guide their reform efforts. The Cross View Biology PLC created a road map, a year-long plan of action that captured their meaning making and guided their curriculum revision. The map was an enduring tool that became a part of the PLC’s shared repertoire of resources. Professional development opportunities should support teachers’ development and/or use of tools that can be used in their joint enterprise of reforming their practice.

5. In implementing NGSS, teachers should initially prioritize a few practices. Focused professional development opportunities that encourage teachers to start small may make reform seem more manageable. This is consistent with Furtak & Heredia’s (2104) suggestion.
6. Tensions should be viewed as potential sites of learning. The Cross View Biology teachers experienced tension between content details and skills. Professional development programs should provide science teachers opportunities to extend their knowledge of science through engagement in science practices and to plan lessons that would allow their students to do the same. Providing opportunities for them to experience three dimensional science learning might help them to view and use the dimensions in a more connected way.

**Implications for future research.** This study may represent the potential of the ideal community more than the reality of most communities. This was investigation of one purposefully selected, mature, effective PLC; it was, in many ways, a best case scenario of a PLC working towards science education reform. If science education reform is going to be successful, then we need to know more about what is possible when science teacher PLCs at varying stages are faced with implementing reforms.

More research about science teacher learning communities is needed. Future studies should examine: 1) what resources other communities have utilized in negotiating the meaning of reform, 2) what tools other communities have developed to help them revise their curriculum, 3) how other communities have been influenced by their interactions with others, 4) what tensions other communities have experienced, and 5) how teachers in other communities have negotiated tensions. Communities in different contexts or in different stages of development may face different barriers, have different abilities and resources, experience different tensions, and therefore need different supports. Studies of beginning, developing, and mature science teacher PLCs are needed; these studies need to examine how each community attempts to revise their curriculum in
reform-oriented ways. These studies would shed light on the supports needed by PLCs in various stages of development as they attempt to implement NGSS.

Research about the efficacy of professional development for practicing science teachers participating in science PLCs should follow. Studies should examine the impact of the professional development activities implied in this and other studies of science PLCs. Future research should examine how various professional development activities impact teachers’ participation in their PLC, their reified meaning-making, their reimagined practice, and their experiences of the professional development.

Finally, longitudinal studies that investigate the development of science teacher PLCs over time are needed. Osborne (2013) suggested that it takes at least two years for teachers to develop an understanding of the rationale for new practice and to implement the new practice(s) effectively (Osborne, 2013). Larkin et al.’s (2008) study is a longitudinal study, but it is retrospective, and does not describe teachers’ meaning making through time. Longitudinal studies of science teacher learning communities would support descriptions of how a PLC’s meaning making develops over time and in response to a changing world that may present new ideas about science, new learning theories, new resources, and new science education reforms.
References


American Association for the Advancement of Science. (1989). *Benchmarks for science literacy.* Washington, D.C.


Appendix A. Data Collection Matrix

**Research Question:** How do secondary biology teachers in a mature, effective PLC negotiate the meaning of NGSS as they revise their curriculum?

<table>
<thead>
<tr>
<th>Secondary Research Questions</th>
<th>Link to CoP Framework</th>
<th>Data Sources</th>
<th>Date of Data Collection</th>
</tr>
</thead>
</table>
| 1. How do the Biology PLC’s interactions with other communities influence how the Biology teachers negotiate the meaning of NGSS as they revise their curriculum? | • Practice as boundary  
• Practice as locality  
• Identity in practice  
• Identity shaped by participation, nonparticipation and belonging | • Observation notes and transcribed audio from PLC meetings, including those held in concert with World Studies  
• An old and a revised unit of curriculum  
• Email communication  
• Boundary objects and tools e.g., writing rubric, and road map  
• Transcripts of the group and individual interviews  
  • Interview 1: Q: 2c, 3, 8-13  
  • Interview 2: Q: 3, 5-8  
  • Interview 3: Q: 5-6 | • 2013-2014 school year  
• Spring and Summer 2014 interviews |
| 2. How do the Biology teachers participate in their PLC as they negotiate the meaning of NGSS and revise their curriculum? | • Practice as meaning negotiated through participation and reification  
• Practice as community  
• Identity in practice | • Observation notes and transcribed audio from PLC meetings  
• Email communication  
• Photographs of whiteboarding  
• Curriculum materials including drafts, critical feedback and revisions  
• Transcripts of the group and individual interviews  
  • Interview: Questions(Q): 1-7  
  • Interview 2: Q: 1,2  
  • Interview 3: Q: 4-6, 10 | • 2013-2014 school year  
• Spring and Summer 2014 interviews |
| 3. How do the Biology teachers describe their experience of negotiating the meaning of NGSS and revising their curriculum? | • Practice as meaning negotiated through participation and reification  
• Practice as learning  
• Identity in practice  
• Identity shaped by belonging identification and negotiability | • Transcripts of the group and individual interviews  
  • Interview 1: Q: 14-21  
  • Interview 2: Q: 9-16  
  • Interview 3: Q: 1-10 | • Spring and Summer 2014 interviews |
Appendix B: Interview Protocols

Interview 1: A 90 minute Group Interview of all PLC Participants

*Say to the participants:* Thank you for agreeing to speak with me. The purpose of this interview is three-fold. The first purpose is to understand how you (as a PLT) feel you have come to understand the NGSS. The second is to understand how your interactions with other communities have influenced your reform implementation efforts, and the third is to understand what you (as a PLT) have learned in light of your efforts to adopt and implement NGSS. Please keep in mind that there are no right or wrong answers; I just want to understand your thinking. Do I have your permission to record on this day, (say date), 2014?

**Interview Questions:**

*Say to the participants:* Thank you. Let’s begin with a discussion of how you have come to understand the NGSS.

1. How would you describe to an outsider how your PLC works? RQ1 *(Ask the following probing questions as needed.)*
   a. How do you make instructional decisions? **RQ1 a, b**
   b. How do you resolve disagreements? **RQ1 b, c**
   c. How do you distribute the work that needs to be completed? **RQ1 b, c**

2. Last summer, your PLT and the other biology PLTs in the district met to discuss NGSS and develop a broad overview of what you wanted to accomplish during the 2013-2014 school year. Please explain how you created this ‘road map’ and how it has or has not guided your reform efforts. **RQ1, RQ2 (Ask the following probing questions as needed.)*
   a. How did you arrive at this version? **RQ1: a, b**
   b. How did you use this road map? **RQ1: a, b**
   c. How did having the road map help or not help you revamp your biology curriculum? **RQ1: a, b; RQ2: a**

3. Beyond this initial collaboration with your fellow district teachers, what other kinds of professional development or support have you received to help you interpret or implement the NGSS? **RQ1: b (and RQ2: a if the teachers indicate collaboration with other communities)**

4. Please tell me how you (as a PLT) have negotiated (or come to understand) the meaning of the NGSS? **RQ1: a**

5. How would you describe the changes that you have made to the biology curriculum this year? **RQ1: b**

6. Sometimes, in revamping the curriculum, you have modified last year’s curriculum (as in the DNA unit), but at other times, you have started almost from scratch (as in the unit on cells). How do you decide what units need more significant redesign? **RQ1: a, b**
7. NGSS emphasizes crosscutting concepts, disciplinary core concepts and science and engineering practices. You have said, ‘we can’t do everything at once’. What did you decide to focus on and how did you make that decision? **RQ1: b**

*Say to the participants:* The next several questions are about how your PLT’s interaction with other communities has or has not influenced your reform efforts.

8. How has your collaboration with the other biology teachers in the district influenced your efforts to revamp your curriculum? **RQ2: a, b**
   
   a. Designing a common assessment seemed challenging. Can you tell me more about this, specifically how it impacted your reform efforts or how your reform efforts impacted the assessment? **RQ2: a, b**

9. Let’s talk about your interaction with the world studies department, next. **RQ2: a**
   
   a. How did your collaboration with the world studies department begin?
   
   b. How has your collaboration with the world studies department, particularly the use of the writing assessment rubric and your joint focus on description, analysis and communication supported and/or not supported your efforts to implement the NGSS?

10. All PLTs in your building work with the executive council (EC). **RQ2: a**

   a. How would you describe the role of the EC in supporting PLTs?

   b. How has the EC influenced your work this year?

11. How have administrators influenced your reform efforts? **RQ2: a**

12. Early in the year, a special education teacher asked for help in understanding the new writing tasks. Have you continued to communicate with the special education faculty about the revised curriculum, and if so, how has your work with those teacher shaped your PLT’s reform efforts? **RQ2: a**

13. How has the required EOC assessment influenced your implementation of the NGSS? **RQ2: a**

*Say to the participants:* The following questions are about what you (as a PLT) have learned through your experiences this year as you have implemented the NGSS.

14. Please think back to the beginning of the 2012-2013 school year. What was the PLT’s vision for science teaching? What was the PLT’s vision for student learning? **RQ3: a**

15. How would you describe the PLT’s vision for science teaching and student learning at the beginning of this year? **RQ3: a**
16. What about now – as you think ahead to next year do you have a fresh vision of science teaching, and if so, please describe it? How about for student learning? **RQ3: a, b**

17. What has your PLT learned through this process of beginning to implement the *NGSS*? **RQ3: a-c**

18. What has been the most challenging aspect of your implementation efforts? **RQ3: c**

19. How were those challenges eased or compounded by the collaboration within the PLT? **RQ3: c**

20. If you could push rewind and rewrite the road map how would it be the same or different? **RQ3: a, b**

21. What else, if anything, do you want to change for next year? **RQ3: b**
**Interview 2: A One Hour Individual Interview of each PLC Participant**

_Say to the participant:_ Thank you for agreeing to speak with me, _(name)__. The purpose of this interview is similar to the last, but today, the focus is on you as an individual participating in the PLT. Again, please keep in mind that there are no right or wrong answers. I just want to understand your thinking. Do I have your permission to record on this day, (say date), 2014?

**Interview questions:**

_Say to the participant:_ Thank you. Let’s begin with a discussion of your role in the biology PLT as you have all worked to understand and implement the NGSS.

1. How would you describe your role in the biology PLT? **RQ1: c**

2. How would you describe others’ roles? **RQ1: c**

_Say to the participant:_ The following questions relate to your participation in and interaction with other communities and how that has or has not influenced your reform efforts.

3. You also participate in another disciplinary PLT. *(Note: These questions do not apply to Paula or the preservice teachers.)*
   a. How is the other PLT implementing NGSS in ways that are similar to or different from your biology PLT’s implementation efforts? **RQ2: a**
   b. How has your participation in the other PLT influenced your participation in this PLT? **RQ2: b**
   c. How has your participation in both PLTs shaped your thinking about the reforms? **RQ2: b**

4. *(Note: Ask Paula this question instead of 3)* How has your participation in the biology PLT, and your resultant understanding of the NGSS, influenced your oceanography curriculum or instruction? **RQ3: a**

5. *(Note: Ask the preservice teachers this question instead of 3 or 4)* How has your preservice teacher education program influenced your participation in this PLT that is trying to align its curriculum with the NGSS? **RQ2: a, b** *(Ask the following probing questions as needed.)*
   a. How has your teacher education program addressed the NGSS?
   b. Can you describe a time when you felt like the teachers in the PLT were struggling to make sense of something or redesign the curriculum and your felt like your were able to help?
   c. Can you describe a time when you felt like the teachers in the PLT were struggling to make sense of something or redesign the curriculum and your felt like your were able to help?
6. *(Note: Ask the full time teachers this question)* Two preservice teachers participated in your biology PLT. How has their participation influenced the PLT’s reform efforts? **RQ2: a**

7. *(Note: Ask Nancy this question)* How has your role as EC liaison influenced your participation in the biology PLT and vice versa? **RQ2: b**

8. Do you personally participate in other communities that you feel have influenced your reform implementation efforts, and if so, how? **RQ2: b**

_Say to the participant:_ The following questions are about what you have learned through your participation in the biology PLT.

9. Please think back to the beginning of the 2012-2013 school year. What was your vision for science teaching? What was your vision for student learning? **RQ3: a**

10. How would you describe your vision for science teaching and student learning at the beginning of this year? **RQ3: a**

11. What about now – as you think ahead to next year do you have a fresh vision of science teaching, and if so, please describe it? How about for student learning? **RQ3: a, b**

12. What have you learned through this process of beginning to implement the NGSS? **RQ3: a-c**

13. What aspect of understanding and implementing NGSS has been the most challenging? **RQ3: c**

14. How was that challenge eased or compounded by your participation in the PLT? **RQ3: c**

15. What differences do you see between the *National Science Education Standards (NSES)* and the *NGSS*? **RQ3: a**

16. What changes have you made in your teaching this year? How have those changes been initiated or supported by the PLT? **RQ3: a-c**
Interview 3: A 1 Hour Individual Interview of each PLC Participant

Say to the participant: Thank you for agreeing to speak with me, __(name)__. The purpose of today’s interview is to continue our discussion of your personal experiences in the biology PLT and to clarify some of your past responses. As always, please keep in mind that there are no right or wrong answers, I just want to understand your thinking. Do I have your permission to record on this day, (say date), 2014? Thank you.

Interview questions:

1. Some teachers identify themselves as a content expert or a sage on the stage. How would you describe your own identity as a teacher? **RQ3: a**

2. How has your teacher identity changed over the course of the last year? **RQ3: a**

3. How has your participation in the PLT influenced or not influenced those changes? **RQ3: a**

4. (Note: Ask this of the most senior teacher.) As a veteran teacher you have experienced many reforms. What has this experience been like for you? **RQ1: c; RQ3: a-c**

5. (Note: Ask this of the teachers who have been at the school the longest.) You have been a part of this PLT for roughly a decade.
   a. How would you describe your experience of changing well established curriculum? **RQ1: a-c; RQ2: a, b; RQ3 a-c**
   b. What do you think has enabled the PLT to implement the NGSS? **RQ1: a-c; RQ2: a, b; RQ3: c**

6. (Note: Ask this of the early career and preservice teachers) Can you describe your experience as a young teacher (or preservice teacher) working within a PLT implementing the NGSS? **RQ1: c; RQ2: a, b; RQ3: a-c**

7. What has been the most rewarding aspect of negotiating the meaning of and implementing the NGSS? **RQ3: c**

8. How has your participation in the PLT been a part of that success? **RQ3: c**

9. Please describe a meaningful experience within the PLT or within your teaching as a result of your involvement in the PLT. **RQ3: c**

10. I’d like to look at _________(document) that you created with the PLT. Can you talk me through _________? **RQ1: a**

11. In _________(a past interview, particular PLT meeting or email communication) you mentioned_________, can you tell me a little more about that, please? (This
question added to clarify. The research question it answers will depend on the particular circumstance.

Note: This later portion of this interview will be used for member checking.

Say to the participant: Before I go, is there anything else you would like to share or explain in regard to how you came to understand and implement NGSS as a participant in the biology PLT?

Say to the participant: Thank you! I truly appreciate your time today and throughout the year.
Appendix C: IRB Approved Recruitment Script

Hi, __________!

My name is Ellen Barnett. I am a former high school biology teacher, and now a doctoral student in science education at MU. My advisor, Dr. Pat Friedrichsen and I would like to investigate how science teachers work collaboratively within a professional learning community (PLC) to design, implement and assess science lessons. I am writing to ask if you would be interested in participating in this research study. I would be observing and recording your PLC’s regularly scheduled weekly planning session. I would also ask for copies of planning documents. These might include lesson plans, Power Points, student worksheets, lab sheets, study guides and tests. I envision the final research product as a paper/poster that I might submit for presentation/publication. The findings of this research would be valuable to other science teachers, science teacher educators and building administrators who are interested in how effective teamwork can produce high quality lessons that support student learning. Would you be interested? If so, I would certainly provide more detailed information. In fact, I would be happy to meet with you at your convenience at your school for lunch or coffee, my treat, to discuss the project and answer any questions.

Please know that your participation or lack thereof is voluntary, would not affect your employment and would be confidential.

Thank you so much for your consideration. I look forward to hearing from you!

Sincerely,

Ellen Barnett
Appendix D: Participant Consent Form  
University of Missouri  
Project: A Case Study of a Professional Learning Community  
Participant Consent Form

Purpose of the Project: The purpose of this research project is to describe how the members of a high school biology professional learning community (PLC) work collaboratively to design, implement and assess science lessons.

Nature of Participation: During this year long research project you would be observed during your PLC’s meetings. No additional duties would be required of you during the summer and fall of 2013. The PLC meetings will be audio recorded. If the team plans or organizes their ideas on a whiteboard, the whiteboard will be photographed. Copies of planning documents, including lesson plans, PPTs, student worksheets, lab sheets, study guides and tests will be collected to trace the process from planning to instruction to assessment. The researcher would be included in the PLCs group emails regarding planning. During the spring and summer 2014 you will be asked to participate in one 90-minute focus group interview and two one-hour interviews. All interviews will be audio recorded. No student data would be collected.

Participation is Voluntary: Your participation is strictly voluntary. Your participation or lack thereof in no way affects your employment. You may choose to terminate your participation at any time without question or consequence.

Confidentiality: Your participation will be kept confidential. When data is collected in a group setting the researcher cannot guarantee confidentiality. All publications and presentations will use pseudonyms. All data will be stored on the researcher’s password protected computer and will be kept confidential.

Compensation: You will be compensated with $100 cash after completing the focus group interview.

Risks: There are no risks associated with participation in this research greater than any risk inherent in your typical teaching duties.

Benefits: The findings would be valuable to other science teachers, science teacher educators, and building administrators who are interested in how PLCs can produce high quality lessons that support student learning.

Questions: If you have any questions about this research study please feel free to contact the investigator, Ellen Barnett at (573) 268-1027, or by email at eb4nd@mail.missouri.edu or her advisor, Dr. Pat Friedrichsen at friedrichsenp@missouri.edu. For additional information regarding human participation in research, please feel free to contact the -UMC Campus IRB Office at (573) 882-9585.

* * * * *
Appendix E: Biology PLC’s Cancer Stations

Station 1- Breast Cancer

(Females Only!)

Anything that increases the chance of developing a disease is called a risk factor.

Risk factors for breast cancer include the following:
- Age (older = more risk)
- Age at the start of menstruation (younger = more risk)
- Age at which you have your first child (older = more risk)
- Number of first-degree relatives (mother, sisters, daughters) with breast cancer (more = more risk)
- Number of previous breast biopsies (whether positive or negative) (more = more risk)
- At least one breast biopsy with abnormal tissue present (more = more risk)

Other potential risk factors may include the following:
- Age at menopause
- Dense breast tissue on a mammogram
- Use of birth control pills or hormone replacement therapy
- A high-fat diet
- Drinking alcohol
- Low physical activity
- Obesity
- Environmental exposures

Breast cancer may also be caused by inherited gene mutations. Hereditary breast cancers account for approximately 5% to 10% of all breast cancers. Specific hereditary predispositions for breast cancer are linked to inheriting a mutation in either the BRCA1 or BRCA2 gene.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Cancer as where it started and not spreading</td>
</tr>
<tr>
<td>I</td>
<td>Higher numbers indicate more extensive disease: Larger tumor size and/or spread of the cancer beyond the organ in which it first developed to nearby lymph nodes and/or tissues or organs adjacent to the location of the primary tumor</td>
</tr>
<tr>
<td>II</td>
<td>The cancer has spread to distant tissues or organs</td>
</tr>
</tbody>
</table>

Female breast cancer survival rates at different stages (2003-2009)
Station 1 Questions:

1. Genetic testing is now available to determine if a woman has inherited the BRCA1 or BRCA2 mutation, which increases their chance of developing cancer.
   A. Why might a woman want to be tested for this gene?
   B. Why might a woman choose not to be tested for this gene?
   C. If you are a female, would you want to be tested? Why?

2. Look at the provided data
   A. Describe the trend in breast cancer survival rates and stage in which cancer is detected.
   B. Why is early detection so important?
   C. What are some methods of early detection?

3. Breast self-exams are one method of early detection, we’d like all of our female students to read the instructions for performing self-exams. Use the models of breasts to practice finding lumps.

   Station 1 – Testicular Cancer (Males Only!)

Most testicular cancers are found by men themselves. Also, doctors generally examine the testicles during routine physical exams. Between regular checkups, if a man notices anything unusual about his testicles, he should talk with his doctor. Men should see a doctor if they notice any of the following symptoms:

- a painless lump or swelling in a testicle
- pain or discomfort in a testicle or in the scrotum
- any enlargement of a testicle or change in the way it feels
- a feeling of heaviness in the scrotum
- a dull ache in the lower abdomen, back, or groin
- a sudden collection of fluid in the scrotum

These symptoms can be caused by cancer or by other conditions. It is important to see a doctor to determine the cause of any of these symptoms.
Look at the provided data to answer the following questions:

1. At what age is a man most likely to be diagnosed with testicular cancer?
2. Describe the trend in testicular cancer survival rates and stage in which cancer is detected.
3. Why is early detection so important?
4. What are some methods of early detection?
5. Because most testicular cancers are found by men themselves, we’d like of our male students to read the instructions for performing self exams. Use the models of testes to practice finding testicular lumps.

Testicular cancer survival rates at different stages (2004-2010)

Localized - Confined to Primary Site

Regional - Spread to Regional Lymph Nodes
1. Why is it important for scientist who research cancer to have this type of data?

2. In terms of funding, how would you suggest the funds to be allocated?
   a. Why might the population have differences in opinions as which types of cancer research their tax dollars should go towards?

3. Looking at the data draw a conclusion about cancer incident rate vs. cancer death rate.
   a. Give a possible reason for this conclusion.

4. Using 2 different sets of data draw one conclusion (inference). (Ex: Based on the higher lung and bronchus cancer rates in males than females, males must smoke than females)

---

**Station 2**

### Estimated Cancer Deaths in the US in 2013

<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>Men 306,920</th>
<th>Women 273,430</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung &amp; bronchus</td>
<td>26%</td>
<td>26%</td>
</tr>
<tr>
<td>Prostate</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>Colon &amp; rectum</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>Pancreas</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>Liver &amp; intrahepatic bile duct</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Leukemia</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Esophagus</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Urinary bladder</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Non-Hodgkin lymphoma</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Kidney &amp; renal pelvis</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>All other sites</td>
<td>24%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Cancer Death Rates* Among Men, US, 1930-2009


- Breast
- Colon and rectum
- Lung & bronchus
- Uterine corpus
- Melanoma of the skin
- Liver
- Thyroid

*Age-adjusted to the 2000 US standard population and adjusted for delays in reporting.

Cancer Death Rates* Among Women, US, 1930-2009

- Uterus
- Breast
- Lung & bronchus
- Stomach
- Ovary
- Colon & rectum
- Pancreas

*Age-adjusted to the 2000 US standard population.
STATION 3 – SMOKING

Look at the information on the lab bench and answer the following questions:

1. What is the relationship between smoking and cancer death rates?
2. What type of cancer is most directly caused by smoking?
3. Why is smoking not just a personal health issue? Why is it also a social issue?
4. Do you think it is important for the government to enforce tobacco control efforts (i.e. city smoking bans, smoking age, etc.)? Explain why or why not?

Tobacco use remains the single largest preventable cause of disease and premature death in the US. Each year, smoking results in an estimated 443,000 premature deaths, of which about 49,400 are in nonsmokers as a result of exposure to secondhand smoke. Smoking also accounts for $153 billion in health care expenditures and productivity losses annually.9

Youth Tobacco Use

A majority of smokers become addicted to tobacco before they are legally old enough to buy cigarettes. Adolescents are more sensitive to nicotine and appear to be more easily addicted.10 While there are different trajectories to smoking uptake from adolescence to adulthood, there is evidence that most smokers who become regular and heavy smokers start before 18 years of age.1 In addition, because the likelihood of developing smoking-related cancers such as lung cancer increases with the duration of smoking, those who start at younger ages and continue to smoke are at higher risk for tobacco-related illness and death.1

Current Patterns and Trends in Cigarette Smoking

- In 2011, data from the Youth Risk Behavior Survey (YRBS) showed that 18.4% of high school students reported current cigarette smoking (smoking on at least one day in the past 30 days) and 6.4% reported frequent smoking (smoking on 20 or more days in the past 30 days) (Table 1A, page 4).
- Trend data from the YRBS showed a sharper drop (40% decline) in cigarette smoking prevalence in high school students between 1997-2003 (from 36.4% to 22.0%). However, between 2003-2011, the percentage decline was about half as much (an 18% drop, from 22.0% to 18.1%). Similar findings were observed based on the University of Michigan's Monitoring the Future survey results (Figure 1A).13
- Cigarette smoking varies by race/ethnicity among 12th graders, with prevalence being highest among non-Hispanic whites, followed by Hispanics/Latinos, and the lowest among African Americans (Figure 1A).

Figure 1A. Cigarette Smoking Trends*, 12th-graders, by Race/Ethnicity, U.S., 1977-2011

* Used cigarettes in the past 30 days. Percentages are two-year moving averages (data for specified year and previous year have been combined).
Source: Monitoring the Future survey 7th, 10th, 12th graders, University of Michigan, American Cancer Society, Eunice Energy Research, 2012.
Trends in Tobacco Use and Lung Cancer Death Rates* in the US

*Age-adjusted to 2000 US standard population.

• Reduction in cigarette smoking among youth is an important factor in reducing prevalence and addiction in adulthood. Smoking among high school students peaked in the late 1990s and has since been declining, though the rate of decline has slowed since 2007.

• It is thought that the increase in smoking from 1991 to 1997 is a reflection of increased expenditures on aggressive youth-targeted marketing and promotions by tobacco companies during the early 1990s.

• The subsequent decline is thought to be due to increased price of cigarettes as well as comprehensive tobacco control efforts. However, slower rate of decline in recent years may reflect increased tobacco industry marketing expenditures and promotions and declines in funding for comprehensive tobacco control programs. Patterns were similar for all racial/ethnic groups.
Living a healthy lifestyle (ie healthy diet and exercise) are known to reduce the risk of cancer. Using the data answer the following questions:

1. What is the relationship between healthy lifestyle and amount of education.
2. What might be some explanations for this relationship?
3. Why might this be a social issue?

Prevalence of Leisure-time Inactivity* by Educational Attainment, Adults 25 and Older, US, 2011

*Percent of adults that met neither the aerobic activity nor the muscle-strengthening according to the 2008 Federal Physical Activity Guidelines for Americans; estimates are age-adjusted to the 2000 standard population Source: Behavioral Risk Factor Surveillance System, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 2012.
Consumption of Three or More Vegetable Servings by Educational Attainment, Adults 25 and Older, US, 2011

Consumption of Two or More Fruit Servings by Educational Attainment, Adults 25 and Older, US, 2011

Source: Behavioral Risk Factor Surveillance System, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, 2012.
Early detection methods are available for most types of cancer, however, some of these tests/early detection methods can be quite expensive if you don’t have health insurance. Refer to the data at the table and answer the following questions:

1. **What trends do you see in health insurance status and use of early detection methods.**

2. **What are some potential problems for our society if individuals don’t have the ability to utilize early detection methods?**

---

**Trends in Annual Mammography Use by Health Insurance Status, US, 2000-2010**

<table>
<thead>
<tr>
<th>Year</th>
<th>Uninsured</th>
<th>Insured</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>28</td>
<td>58</td>
<td>55</td>
</tr>
<tr>
<td>2005</td>
<td>25</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td>2010</td>
<td>17</td>
<td>55</td>
<td>51</td>
</tr>
</tbody>
</table>

A mammogram within the past year among women ≥40 years; estimates are age-adjusted to the 2000 US standard population. Source: National Health Interview Survey, National Center for Health Statistics, Centers for Disease Control and Prevention.
Trends in Pap Test Prevalence* by Health Insurance Status, US, 2000-2010

Trends in the Prevalence of Fecal Occult Blood Test* by Health Insurance Status, US, 2000-2010

*A Pap test within the past three years among women age 21-65; estimates age-adjusted to the 2000 US standard population.
Source: National Health Interview Survey, National Center for Health Statistics, Centers for Disease Control and Prevention.
Look at the skin cancer fact sheet and write down four facts that you found most interesting.

Examine the mole model/picture to practice looking for the warning signs. Notice how the cancerous moles exhibit irregular borders deeper in the skin. Do you have any moles that resemble these?

List three problems that UV rays can cause.

What are two ways that you can protect yourself from skin cancer?
Melanoma is a malignant skin tumor involving the skin cell pigment producing melanin. Moles can resemble malignant melanomas that are the most dangerous type of the skin cancers and can spread rapidly. One feature of melanomas is easy injury with bleeding, however there are other characteristics that could indicate melanoma. The good news is that if caught early enough and treated, melanoma is curable. Many people have moles, and most moles are not cancerous and do not cause a problem. A mole that exhibits any of the characteristics outlined below should be evaluated immediately by your primary physician or a dermatologist.

The basic ABCDE warning signs to determine whether a mole is a melanoma are as follows:

A. Asymmetry: one half unlike the other half
B. Border Irregularity: irregular, scalloped, poorly defined
C. Color: varied from one area to another, shades of tan and brown, black; Sometimes white, red or blue
D. Diameter: greater than 6mm, but can be smaller
E. Evolving: looks different from the rest or changing in size, shape, color

In addition, there are other features of melanoma such as surface changes (bleeding, oozing, scaliness) or signs of itchiness, pain, or tenderness.

After examining the mole, if your doctor thinks the mole is a melanoma, then a biopsy will be performed for further analysis.
Appendix F: Biology PLC’s Cancer Webquest

Understanding Cancer: Webquest

Directions
Copy the following URL into your web browser:
http://www.cancer.gov/cancertopics/understandingcancer/cancer/page1
Read the information above each slide in addition to the information in each slide to answer the following questions. Use the red arrows above the information to move forward or backward through the slides.

1. What is the common characteristic of ALL types of cancer?

2. Cancer can be classified in one of four ways. For each type of cancer, list 2 locations in the human body where each type of cancer might be found.
   a. Carcinoma
   b. Sarcoma
   c. Lymphoma
   d. Leukemia

3. What happens to damaged cells:
   a. During normal cell division?
   b. During cancer cell division?

4. What is a tumor? Why do tumors increase in size?

5. Suppose your neighbor has just been diagnosed with a malignant tumor.
a. His doctor told him that his tumor has “metastasized”. What does this mean?

b. How is a malignant tumor different than a benign tumor?

6. Early detection of cancerous cell growth can definitely prevent cancer from developing and being potentially harmful. What kinds of cancer to the following screening techniques detect?
   a. Pap smear
   b. Mammogram
   c. PSA test
   d. Colonoscopy

7. What is a biopsy?

8. A cancer diagnosis typically is assigned a “stage”. What factors determine the stage of cancer?
9. Suppose your neighbor, who was diagnosed with a malignant tumor, was told he was in “Stage III”. Using the graph on slide 23, determine his chance of surviving 5 years.

10. What types of things contribute to the development of cancer?

11. Things that cause cancer are known as carcinogens. Cigarettes and tobacco use are the leading carcinogens in America. List all of the cancers that cigarette smoking has been correlated with.

12. Look at the graph regarding low strength radiation. Why is there a concern regarding tanning and the development of cancer?

13. Use slide 30 and your brain to explain why the choices you are making TODAY can affect your health (or lack thereof) in the FUTURE.

15. Describe the relationship between aging and cancer development, as depicted in the graph on slide 38. Propose an explanation for this relationship.

16. Some lifestyle choices can affect your chances of developing cancer. Answer the questions below about preventing cancer through a healthy lifestyle.

**Tobacco Use**

a. If you smoke one pack of cigarettes a day (one pack typically has 20 cigarettes), what is your risk of developing cancer compared to a non-smoker? [Use the graph on slide 53 to answer this question]

**Sun Exposure**

b. List three ways you can reduce your risk of skin cancer.

**Diet**

c. Using the graph on slide 55, describe the impact of smoking and alcohol consumption, compared to engaging in only one of these behaviors.
d. Using the graph on slide 56, compare the incidence of colon cancer in the United States to Germany and Japan. What inferences can you make about the dietary habits of the citizens of each country?

e. What types of foods may reduce your risk of developing cancer?

17. It seems that everyone knows someone who has cancer. Does this mean that there is a cancer epidemic? Explain.
Appendix G: Revised Cell Structure Lab

In this lab, you will look at various types of cell and tissues under the microscope. At each lab station, there are directions for how to prepare the slide, as well as pictures of what you should see in the microscope on medium or high power. Fill out the chart below.

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Picture – Draw what you see in the microscope and include additional observations.</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elodea</td>
<td></td>
<td>1. Notice that the cell wall is a rectangular and rigid structure, what could be some possible functions for a cell wall in plants?</td>
</tr>
<tr>
<td></td>
<td>*Label the cell membrane, cytoplasm and cell wall.</td>
<td></td>
</tr>
<tr>
<td>Pond Water</td>
<td></td>
<td>2. Did you draw a unicellular or multicellular organism and how do you know?</td>
</tr>
<tr>
<td></td>
<td>*Label the cell membrane, cytoplasm, and nucleus.</td>
<td></td>
</tr>
<tr>
<td>Cheek Cells</td>
<td></td>
<td>3. Did you draw a unicellular or multicellular organism and how do you know?</td>
</tr>
<tr>
<td></td>
<td>*Label the cell membrane, cytoplasm, and nucleus.</td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td></td>
<td>4. Bacteria cells do not have a nucleus, but they do have DNA. Where would the DNA be located in the bacterial cell?</td>
</tr>
<tr>
<td></td>
<td>*Label the cell membrane and cytoplasm.</td>
<td></td>
</tr>
</tbody>
</table>

5. List the similarities and differences between unicellular and multicellular organisms.
Using the information provided at the lab benches about each tissue type and the microscope slide, fill in the chart below:

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Picture – Draw what you see in the microscope and include additional observations.</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td></td>
<td>6. How does the cells’ structure/shape help them to carry out their function?</td>
</tr>
<tr>
<td>Skeletal Muscle</td>
<td></td>
<td>7. How does the cells’ structure/shape help them to carry out their function?</td>
</tr>
<tr>
<td>Nervous Tissue</td>
<td></td>
<td>8. How does the cells’ structure/shape help them to carry out their function?</td>
</tr>
<tr>
<td>Organ or Tissue of choice:</td>
<td></td>
<td>9. How does the cells’ structure/shape help them to carry out their function?</td>
</tr>
</tbody>
</table>
In this section of the lab, you will examine the cells of the common aquarium plant *Anacaris* or Elodea.

1. Place 1 drop of water on the microscope slide.
2. Pluck 1 leaf from the Elodea plant and place upside down in the water drop.
3. Place a cover slip over the leaf

In this part of the lab, you will examine human cheek cells.

1. Very gently scrape the inside of your cheek with the toothpick.
2. Smear this cheek slime in the middle of a dry microscope slide.
3. Stain the cheek cells by placing one drop of iodine over your check slime. This will help “stain” the cell & its structures.
4. Place the cover slip over the tissue (hint: place cover slip at an angle to force out as many air bubbles as possible).

In this part of the lab, you will examine Bethel Park pond water.

1. Place one drop of the pond water (try and extract some “pond gunk” in your dropper) on a dry microscope slide.
2. Place the cover slip over the pond water (hint: place cover slip at an angle to force out as many air bubbles as possible.)
Bone

Functions:

- **Protection** — bones can serve to protect internal organs
- **Structure** — bones provide a frame to keep the body supported
- **Movement** — bones provide a leverage system for, skeletal muscles, tendons, ligaments and joints to function together to move body parts
- **Blood production** — the marrow, located within the long bones (examples: femur, humerus) produces blood cells
- **Storage**— bones are mineral, hormonal (proteins) and fatty acid (lipids) reserves for the body

Compact tissue forms the outer shell of bones. It consists of a very hard (virtually solid) mass of bony tissue arranged in repeating layers. Spongy bone tissue is located beneath the compact bone and consists of a meshwork of bony bars (proteins) with many interconnecting spaces containing bone marrow.
Skeletal Muscle

Function:
- Movement- skeletal muscles are responsible for voluntary movement of body parts

Skeletal muscle is made up of muscle cells, sometimes called "muscle fibers". These fibers are long, cylinder-shaped cells. There are proteins within these muscle fibers (called actin and myosin) that allow for muscle contraction and relaxation. These muscles are attached to bones by tendons, so when muscles contract or relax, bones move with them.

Structure of a Skeletal Muscle
Nervous Tissue

Functions:

- Carry messages around the body
- Sensory input (ex: sensation of pain, temperature changes, etc.)
- Muscles and organ function (ex. voluntary movement or involuntary processes like your heart beating or digestion)

Nerve cells, called neurons, are very long and are branched at each end. These branches extend to all areas of your body.
Nervous System Diagram

- Brain
- Spinal Cord
- Brachial Plexus
- Musculocutaneous Nerve
- Radial Nerve
- Intercostal Nerves
- Splanchnic Nerve
- Lumbar Plexus
- Sacral Plexus
- Femoral Nerve
- Sciatic Nerve
- Ulnar Nerve
- Median Nerve
- Median Nerve Branches
- Peroneal Nerve
- Common Peroneal Nerve
- Deep Peroneal Nerve
- Superficial Peroneal Nerve

Neural Tissue
Location: Brain; spinal cord; nerves
Function: Conduction of nerve impulses

- Cell body
- Nucleus
- Dendrite
- Axon
- Nodes of Ranvier
Choose one of the following organs/tissues to look at under the microscope. Use the laptops provided to research the function of that organ and fill in the last row of your chart.

<table>
<thead>
<tr>
<th>Organs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stomach</td>
</tr>
<tr>
<td>Kidney</td>
</tr>
<tr>
<td>Liver</td>
</tr>
<tr>
<td>Lung</td>
</tr>
</tbody>
</table>
Appendix H: Biology PLC’s Definitions of Skills as Objectives

**Reading/Writing:**

*Analysis/Synthesis*

1. Use analysis and synthesis to better understand scientific texts and other informational sources:

2. Apply the skills of analysis and synthesis to write conclusions for experimental investigations and scientific studies.

**Communication**

3. Communicate your analysis, synthesis and evaluation of scientific texts, informational sources, and experimental investigations both in oral and written form.

**Scientific Investigation**

1. Demonstrate the ability to ask questions to further learning (OWL- Observe, Wonder, Learn).

2. Design and conduct investigations to provide evidence for scientific questions or solve a problem.

3. Analyze and represent data using appropriate mathematical techniques.

4. Identify and describe patterns in collected data.

5. Explain the results of an experiment or scientific study using appropriate rationale.

**Modeling**

1. Create a model (physical, visual, analogies, verbal, demonstrations, etc.) to illustrate your understanding of specific scientific concepts.

**Research Skills**

1. Gather relevant and reliable information from multiple authoritative sources.

2. Demonstrate appropriate in-text citations, and create a list of references.
VITA

Ellen Barnett was born and raised on a small farm in Salem, Missouri, USA. A lover of nature, she obtained a B.S. in Pre-professional Zoology from Northwest Missouri State University (NWMSU). When she accepted an unexpected opportunity to teach a biology lab at NWMSU, she fell in love with teaching science, and obtained an M.S.Ed. in Science Education. She taught middle school science at Christian Fellowship School in Columbia, MO, and physical science and biology at Boonville High School in Boonville, MO. While teaching, she enjoyed mentoring preservice teachers and decided to pursue a doctorate and a career as a science teacher educator and researcher.

Ellen and her husband of 20 years have two children. Ellen and her family will reside in San Antonio, Texas as Ellen accepted a tenure-track assistant professorship in science education in the College of Education at Trinity University. Ellen is thrilled to partner with Trinity University and their community partners in education in preparing science teachers to teach in the San Antonio community and beyond.