LESSON STUDY AS PROFESSIONAL DEVELOPMENT WITHIN SECONDARY PHYSICS
TEACHER PROFESSIONAL LEARNING COMMUNITIES

by

TONYA MONIQUE NICKI COLLINS

DENNIS W. SUNAL, COMMITTEE CHAIR
JANIE HUBBARD
SARA TOMEK
JEREMY ZELKOWSKI
MELISA FOWLER

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ABSTRACT

Two Professional Learning Communities of physics teachers from different high schools voluntarily participated in Lesson Study as a means of professional development. The five teacher-participants and one participant-researcher partook of two Lesson Study cycles, each of which focused on student physics misconceptions. The Lesson Study resulted in two topics of physics: projectiles and gravitation. The researcher aimed to determine what happens to secondary physics teachers who undergo Lesson Study through this phenomenological case study. Specifically, (1) What is the process of Lesson Study with secondary physics teachers? and (2) What are the teacher-reported outcomes of Lesson Study with secondary physics teachers?

Overall, Lesson Study provided an avenue for secondary physics teachers to conduct inquiry on their students in an attempt to better understand student thinking and learning. As a result, teachers collaborated to learn how to better meet the needs of their students and self-reported growth in many areas of teaching and teacher knowledge. The study resulted in twelve hypotheses to be tested in later research centering on idealizing the process of Lesson Study and maximizing secondary physics teacher growth.
DEDICATION

This dissertation is dedicated to my husband, Craig who held my hand through the stress and a pillow to shield himself from the yelling. This dissertation is further dedicated to my children who surely feel the sting of all the special events missed and the minutes that turned to hours and turned to days that Mom was not available. Finally, this dissertation is dedicated to my many students who inspire me to learn more and teach better; it is you that continuously inspire me to become my best.
LIST OF ABBREVIATIONS AND SYMBOLS

Mtg.  Meeting
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CHAPTER 1

INTRODUCTION

Evolution of Physics Teachers and Teaching

Traditionally, the vocation of a physics teacher was a static profession at all levels (McDermott, 1993; Perkins et al., 2006; Reif, 1995, 2008). For decades, college physics teachers taught in lecture halls to droves of students (Cuban, 1993), lecturing content connected to textbooks that they or their colleague had a hand in writing (McDermott, 1991). This traditional physics instruction consisted of “teacher[s] lecturing to students; assignments [which are] back-of-thechapter-type homework problems with short quantitative answers, and grades […] largely based on exams containing similar problems” (Wieman & Perkins, 2005, p. 2). In response, student learning was minimal and focused on memorization (McDermott, 1991). Class size and teacher habits fostered a teacher-centered culture within most physics classrooms. This tendency towards a teacher-centered classroom was underscored by many teachers’ belief that physics at both secondary and college levels, when dotted with occasional visual illustrations or example, made physics understandable for students (McDermott, 1993; Perkins et al., 2006; Reif, 1995, 2008). Thus, physics was often taught with disregard to or misunderstanding of the needs involved for student learning to occur. Research-based strategies were not a concern as curriculum catered to the teacher needs for teaching but not the student needs for learning (Cuban, 1993; MacIsaac & Falconer, 2002; McDermott, 1991).
In the 1980’s, status quo in teaching physics began to be questioned, and physics teachers using reformed methods surfaced. Researchers found that teacher-centered strategies were deficient; they concluded that teacher-centered methods have disconnected theory from practice, failing to link physics students with physics understanding (Wieman & Perkins, 2005; Van Heuvelen, 1991). Researchers such as Van Heuvelen (1991), Hestenes (1997), Hake (1998), McDermott (1993), and others pushed to change teacher-centered instruction through educational research in both college and high school physics teacher training. A new model of a student-centered classroom, at both the college and high school levels, emerged. While this “new school” of physics was not the norm, it became an agreed upon goal by the community of physics education researchers (Hestenes 1997; MacIsaac & Falconer, 2002; McDermott, 1993; Perkins et al., 2006; Reif, 1995, 2008; Van Heuvelen, 1991).

The old-school mold of teacher-centered instruction has been gradually reshaped and broken by many progressive teachers of physics. Over the past three decades, a better understanding of how students learn, coupled with the unique strategies for physics instruction, revolutionized ideas about teaching physics. Small pockets of U.S. physics classrooms containing innovations such as student-centered learning, inquiry labs (McDermott, 1993), modeling (Hestenes, 1997), and interactive teaching (Hestenes, 1997) appeared. New approaches to teaching physics fueled physics learning at all levels, from professor to secondary teacher to secondary student. Reformed teaching was observed and measured as it proliferated the U.S. physics classrooms at both college and secondary levels at the turn of the century (MacIsaac & Falconer, 2002).

In an effort to make a reformed physics classroom the norm, Van Heuvelen (1991) contended that policy must be implemented to better prepare physics teachers to teach physics.
Van Heuvelen recommended physics teacher preparation courses to meet the specific needs of future high school physics teachers. In response, many programs for physics teacher training were implemented and continue to be fine-tuned in colleges and universities (“Physics teacher education coalition,” 2016).

In spite of new and plentiful opportunities for physics teacher training, a significant shortage of quality secondary physics teachers exists (White & Tyler, 2008). Pay scales and the prestige of other professions often pull potentially high-quality physics teachers into other occupations such as physicist or engineer (White & Tyler). Many current physics teachers decided to teach only after completing a degree program in an applied field of science, thereby circumventing the improved physics teacher degree programs. Thus, high quality physics teacher candidates, who choose to pursue the occupation of physics teacher, are often only trained in physics or science and not as teachers of physics (White & Tyler).

The majority of physics teachers have degrees in other science fields. The American Institute of Physics reports that during the 2008-2009 school year, out of a sample size of approximately 27,000 teachers in U.S. high schools, 57% were self-described physics specialists, 35% had a major or minor in physics, and 11% had a major or minor in physics education (White & Tyler). These college graduates often entered their physics classrooms ill-equipped to teach, lacking the teaching pedagogy necessary to help their students learn.

At a high school level, a small percentage of individuals with degrees in physics or engineering become science teachers. The science major who chooses to teach high school must obtain a certification with an adequate amount of educational coursework before becoming a classroom teacher. Potential teachers participate in a brief practicum period to practice teaching the content under the tutelage of a mentor science teacher. In most states, this process is
mandated by the state education board or teacher certifying body. Rarely is there a fully trained educator/physics major who chooses the profession of a high school physics teacher and is wholly trained in both content and the needed teacher knowledge.

In contrast to teachers who are strong in content and weak in teaching, teachers who are asked to teach outside of their content expertise need additional training in content. Many biology and chemistry teachers must fill the vacant positions of physics teachers yearly. These transitioning science teachers must learn physics content often while teaching physics to students.

Many current and incoming secondary physics teachers are lacking teacher knowledge on how to teach physics. This specific type of knowledge, where content knowledge combines with pedagogical knowledge originally titled and described by Schulman (1986), is referred to as pedagogical content knowledge (PCK). Shulman “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching” (p. 9). Shulman specifies two components of PCK as knowledge of representations of subject matter and knowledge of student conceptions with an understanding of the accompanying learning difficulties. As few as 11% of new teachers hired to teach secondary physics have adequate content knowledge and teacher PCK (White & Tyler, 2008).

Alternate certification programs in physics and other STEM fields provide additional tracks for inadequately trained physics teachers to enter the classroom. Over one third of these teachers are fast-tracked or quickly licensed on these alternate programs of certification; an even higher percentage of physics teachers are filled through these alternate certification programs (Kee, 2012). Without specific pedagogical training, pedagogical knowledge is deficit. The typical U.S. high school physics teacher begins with a deficit of either content knowledge or
pedagogical knowledge. Either of these insufficiencies in teaching physics leads to faulty pedagogical content knowledge, and flawed PCK contributes to inadequacy in teaching physics (Thornton & Sokoloff, 1998).

Gaps and errors in physics understanding lead to faulty teaching and learning of physics concepts. Much research points to a cycle of physics misconceptions as one generation teaches the next (Lee, 2010; Mayer & Chandler, 2001; McCloskey, 1983; Minstrell, 1989; Reif, 2008; Trowbridge & McDermott, 1980/1981; Van Heuvelen, 1991; Van Hise, 1988). Misconceptions, or classic alternative conceptions contrary to scientific understandings, result from common sense understandings in response to life experiences. Because they are common sense, many teachers lacking adequate content knowledge and many untaught students hold tightly to these beliefs. If scientific understandings of physics are not used to alter these misconceptions, misunderstanding teachers will endorse misconceptions in misunderstanding students. Although physics misconceptions are difficult to change, much research both delineates the common misconceptions and explains the best practices to change them in physics students (Lee, 2010; Moreno, 2004; Reif, 2008; Smith, diSessa, & Rochelle, 1993/1994).

A significant need exists to provide means for development and refinement of secondary physics teachers who often lack foundational content knowledge, pedagogical knowledge, and physics-specific research–based methods to teach students. One solution, professional development, is used to transform teachers and their teaching (Fernandez, 2002; Lieberman, 1995; Supovitz and Turner, 2000; Gerard, Varma, Corliss, & Linn, 2011). In contrast to the customary whole-school, top-down and often disconnected process of classical professional development (Clarke & Hollingsworth, 2002; Saito & Atencio, 2013; Sunal et al., 2001), research indicates professional development is most productive as a collaborative model (Abdal-
Much like student learning, teacher learning is most effective in an active, problem-solving environment while collaborating with other teachers (Abdal-Haqq, 1998). Social interactions are shown to support the construction of teacher knowledge (Rock & Wilson, 2005), making collaboration a viable characteristic of any teacher development initiative.

One research-proven method of endorsing this needed collaboration in teacher professional development is the implementation of Professional Learning Communities (PLCs) (Stoll et al., 2006). These communities of practice group teachers into collaborative units for a common purpose. PLCs can be used to establish a school-wide culture that makes collaboration “expected, inclusive, genuine, ongoing, and focused on critically examining practice to improve student outcomes” (Stoll et al., 2006, p. 224).

PLCs of physics teachers give members opportunities to build rapport while collaborating on physics goals, traditionally student learning goals. PLCs are adequate discussion forums and planning arenas. PLCs do not, however, provide a stage for scientific inquiry into teaching practices. Active learning in the context of teaching physics is recommended by the research to best facilitate teacher growth (Abdal-Haqq, 1998). Thus in addition to the collaboration established in PLC, another step towards specific physics teacher development, incorporating an inquiry-based approach to teacher learning, is needed. Research supports the need for professional development aligned with the particular needs of physics teachers through teacher-initiated contextual teaching and learning (Lewis, 2002; Perry & Lewis, 2009; Rock & Wilson, 2005).
Problem Statement

Many science teachers are ill-equipped to teach physics in the secondary classroom due to a lack of conceptual training through coursework or a lack of physics-specific PCK training. Deficiencies in content knowledge often result in weak physics teachers and an inability to recognize physics misconceptions in their students. Deficiencies in physics PCK often results in an inability to change student understandings of physics concepts. Physics teachers of all levels and experiences need opportunities to strengthen their weaknesses. Some teachers need more content knowledge. Other teachers need pedagogical understandings and skills. Still others need opportunities to refine their skills through interactions with other physics teachers.

Although professional development is plentiful, physics teachers are not being supported with professional development that is specific and targeted at their needs. Moreover, the modality used for delivery places teachers in an artificial microcosm of learning as merely a receiver of information (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). Physics teachers need opportunities to be exposed to physics learning research and to have collaborative opportunities with physics teacher colleagues to strengthen both content knowledge and PCK as active learners.

Administrations have taken one step in this direction as they have encouraged Professional Learning Communities (PLCs) within content areas. These PLCs are used to collaborate on common assessments and scheduling of the units surrounding these assessments. These PLCs are further used to diagnose assessment data. Although a viable and research-supported type of professional development, this model is still lacking. PLCs serve to build comradery and collaboration. PLCs fail, however, to meet the variety of needs of the physics
teachers in the communities by ignoring the need for scientific inquiry to construct and strengthen physics teacher knowledge and skill.

**Purpose Statement**

Teachers must learn and grow in their understanding of how to best teach physics through the means of collaborative professional development in the context of teaching physics. The purpose of this phenomenological case study was to understand the implementation of the teacher-initiated, collaborative professional development of Lesson Study within two high school PLCs of physics teachers within a large suburban school system in the southeast.

**Research Questions**

1. What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity?
   a. How do teachers engage individually and in groups during the Lesson Study process?
   b. What are the teacher-reported responses to Lesson Study as a professional development opportunity?

**Research Design**

This qualitative research study is a phenomenological case study of Lesson Study implemented into two PLCs of physics teachers in a large school district in the southeast U.S. This collaborative professional development used the classroom as a laboratory of inquiry for teachers to better understand student learning of physics as they taught and observed a carefully constructed and collaboratively written lesson.

Neighboring high schools’ physics PLCs were selected for the study according to the following criteria. First, the principals and department chairs of five high schools were contacted. Two principals that thought Lesson Study might be a good fit for their physics
teachers informed the researcher. Next, the researcher inquired of the science department chairs as to the status of PLCs among their physics teachers. Each of the science department chairs self-reported a well-established system of PLCs in the science department. The researcher then solicited each of the PLCs of physics teachers within the selected high schools to volunteer for the professional development of Lesson Study and the accompanying research of this process. Cohorts of physics teachers from two high schools, two teachers from one and three teachers from another, met these criteria and volunteered to participate. These two PLCs, from neighboring high schools, came together as one group to serve as Lesson Study participates.

The five participants were then introduced to the process of Lesson Study and consented to participate in the research. The Lesson Study group met weekly over the course of a semester and participated in two cycles of Lesson Study. This participation culminated in the writing and teaching of two Research Lessons. Throughout the Lesson Study professional development, audio recordings of the meetings and journal entries served as data sources for the researcher to code and analyze. This qualitative data analysis served to help the researcher better understand the process and viability of Lesson Study as a means of professional development for this group of two PLCs of physics teachers.

Assumptions

The literature showed that in other contexts, Lesson Study could meet the needs of groups of teachers as a viable and valuable means of professional development (Lewis, 2000; Rock & Wilson, 2005; Saito & Atencio, 2013; Sato & McLaughlin, 1992). It specifically contributed to the growth of teachers’ pedagogical content knowledge (Fernandez, 2002; Rock & Wilson, 2005; Wagner, 2003) and teacher understanding of content (Lewis, 2002). Teacher self-confidence for teaching improved as a result of Lesson Study (Rock & Wilson, 2005). Stigler
and Hiebert (1999) made the point that Lesson Study provides benchmarks against which teachers can measure their own practice, compare it with colleagues, and grow toward a newly conceived image of teaching. Research implications suggested that physics teachers might also benefit from Lesson Study in that it could prove to be a good fit for professional development, contribute to teachers’ PCK development, enhance content knowledge understanding, and improve teacher self-confidence in teaching physics.

In addition to assumptions established by the literature on Lesson Study, this study incorporated the following assumptions:

1. Professional collaboration is an effective form of professional development.
2. Teachers use professional collaboration as a professional development model of learning through the process of social engagement.

**Significance of Study**

This study serves a purpose in the field of science education in that it provides a rare opportunity for the education community to experience Lesson Study as a collaborative means of professional development as applied to two secondary physics teacher PLCs. This research explains the process of Lesson Study. This study further provides a better understanding of the value of both the collaborative and PLC models for professional development specific to Lesson Study. It provides new insight into the process of developing secondary physics teacher PCK. This research helps administrators and stakeholders in judging the value of Lesson Study as a potential form for future professional development, providing insight to guide the spending of professional development funds.
Limitations of the Study

This research is limited by the short duration of implementation of fewer than six months. The sample size was small, with only two PLCs combined to make one Lesson Study group with five total physics teachers. In addition, the researcher was a participant in the study serving as the one who explained and guided the process of Lesson Study as teachers experimented, discussed, and learned. Specific to a southeastern U.S. suburban community of physics teachers, this study provided a strong example of the type and degree of professional development enrichment that can be implemented within preexisting PLCs of physics teachers. More research is needed to support the generalizability of the study. Thus, the same result may not be obtained when Lesson Study is implemented across school system lines.

Obvious limitations in the research exist. Most prevalent is the fact that to date, no research of implemented Lesson Study is published. One strong occurrence of Lesson Study, Physics First, was implemented with high school physics teachers. Some reports detailing meetings and feelings regarding this three-year occurrence of Lesson Study were reported in a newsletter, but no peer reviewed articles or published research exists to date (Chandrasekhar, 2007; Volkmann, 2007; West and Volkmann; 2008). Content-specific groupings of teachers are rare even in K-8, with mathematics dominating those that are in place (Lewis, 2002). Most research available for Lesson Study was regarding K-8 teaching. No research on U.S. applied Lesson Study in a secondary school was found.

This research study, which investigated and interpreted Lesson Study experiences with two PLCs of secondary physics teachers, served as a hypothesis-generating study- not a hypothesis-testing study. The focus was on generating hypotheses for future study. The scope
of research was limited to external variables such as field notes, interviews, journals, and thick description by the researcher. These external variables may be perceived as a limitation.

**Philosophical Assumptions**

**Ontological Assumptions**

Ontological assumptions refer to the nature of reality of the subject that is being researched. In qualitative research, the research embraces multiple realities (Creswell, 2013). Research was informed by the principles of constructivism. The multiple perspectives of participants were represented in such a way as to represent a variety of realities, each unique to the participant. These themes served to structure the reporting of research.

**Epistemological Assumptions**

Van Manen (2007) viewed knowledge as embodied in text, understanding, being, and was known by experience. To begin with, phenomenological texts served as sources of knowledge, yet in phenomenological text, meaning was embedded in the text. Van Manen (2007/2011) explained that phenomenological knowledge-as-text has cognitive, pathic, conceptual, and informative dimensions. Knowledge serves as understanding. It is active and reflective participation in the meaning of the text or occurrence. Van Manen (2011) explained that knowledge is also being, as phenomenological knowledge results from the end of phenomenological reflection, and culminates in the achievement of personal, formative knowledge.

Knowledge is known by experience (Van Manen, 2007). The researcher was motivated to become a part of the research by co-existing with the group of participants. The study itself was conducted necessarily in the habitual setting of the participants. As Guba and Lincoln (1994) elaborate, the researcher tried to minimize the “distance” or “objective separateness” between the
researcher and the participants (Creswell, 2013, p. 20). The researcher used quotations from interviews and interactions as the primary source of data from the perspective of a trusted “insider” (Creswell, 2013, p. 21). True to social constructivism, reality was “co-constructed” between the researcher and the participants and “shaped by individual experiences” (Creswell, 2013, p. 36).

**Axiological Assumptions**

The researcher revealed her values by actively reporting all values and biases with the research and the data gathered (Creswell, 2013). These values and biases were delineated as either the researcher's, the participant’s, or both and are acknowledged to shape the research. Per social constructivism, a narrative literary style was used both to gather information and to present data.

**Methodological Assumptions**

These procedures were decidedly “inductive, emerging, and shaped by the researcher's experience” (Creswell, 2013, p. 22). Thus, the researcher consistently adjusted research questions and approaches as the emergent data mandated. This flexibility allowed an increased number of understandings to be generated from the study.

**Theoretical Framework**

Cognitive constructivist theory and social constructivist theory together established a theoretical framework for this research. Although similar in nature, cognitive constructivist theory can be attributed to John Dewey and Jean Piaget; social constructivist theory can be contributed to Vygotsky. Cognitive constructivist theory claims that knowledge is not an accumulation of transmissions, rather it is constructed by individuals (Abdal-Haqq, 1998; Good & Brophy, 2008; Iran-Nejad, 1995; Richardson, 1997; Young & Collin, 2004). Constructivists
emphasize the importance of relating new content to the individuals’ prior knowledge (Good & Brophy, 2003; Iran-Nejad, 1995; Richardson, 1997). Abdal-Haqq (1998) explained that in constructivism, learning is characterized by “active engagement, inquiry, problem solving, and collaboration with others” (para. 2).

Constructivists, such as Bruner (1990) and Vygotsky (1978), recognized that influences on individual knowledge construction were derived from and preceded by social relationships. Good and Brophy (2003) contended that “in addition to emphasizing that learning is a process of active construction of meaning, social constructivists emphasize that the process works best in social settings in which two or more individuals engage in sustained discourse about a topic” (p. 412). In social constructivist theory, learning is derived from social interactions within cultural contexts as shared by a group and ultimately internalized by the individual (Richardson, 1997). Individuals construct knowledge in “transaction with the environment, and in the process, both the individual and the environment are changed” (Abdal-Haqq, 1998, para. 7).

Constructivist theory focuses on metacognition as an essential aspect of constructing knowledge. Learners clarified their understandings socially and reflected on the ways they constructed knowledge (Kaufman, 1996). Within social constructivism, knowledge was “fostered and facilitated by the way in which career practitioners, seek…approaches that are closer to the everyday situations of practice” (Young & Collins, 2004, p. 374). Thus, social constructivism underscored that knowledge is constructed in response to social interactions. Social constructionists asserted that knowledge is both a “pre-condition for thought and a form of social action; that the focus of enquiry should be on interaction, processes, and social practices” (Young & Collin, p. 377). Thus, the theory of constructivism, with an emphasis on social
constructivist principles, provided a framework supporting the use of the Lesson Study as a means of professional development.
CHAPTER 2
LITERATURE REVIEW

Introduction

A better understanding of the nature of physics teachers and their teaching was necessary to establish a degree of fit for Lesson Study as a means of professional development for a group of high school physics teachers. Until now, the target population of physics teachers had not received professional development that was in context with their teaching, nor had they received professional development that was specific to teaching physics. Physics teachers, teacher learning, and professional development was examined in research literature.

The literature review first considered the nature of the teacher and the learning necessary to enable these teachers to grow professionally. Next, characteristics of professional development were examined to establish the needed criteria for this research target population of physics teachers. From there, in response to current organizational structures particular to the sample, Professional Learning Communities were studied as an initial professional development model fit. Then, Lesson Study as implemented in both Japan and adapted to the U.S. was explored. Gaps in the literature were found, revealing that Lesson Study had not been adequately applied to secondary physics teachers. Finally, physics teaching was examined with an eye toward the physics misconceptions that must be overcome to facilitate the learning of science relevant to Lesson Study participants’ topic foci.
Numerous studies were conducted on Lesson Study as implemented in Japan and other southeastern Asian countries (Chong & Kong, 2012; Fernandez, 2002; Lewis, 2002; Isozaki, 2015; Saito, Hawe, Hadiprawiroc & Empedhe, 2008; Saito & Sato, 2012; Sato & McLaughlin, 1992; Stigler, 2010; Stigler & Hiebert, 1999). These studies were referenced to provide the foundation of the process of Lesson Study. The primary focus, however, was on Lesson Study as implemented in the United States and as adapted to the American teacher. Most of these U.S. studies took place in elementary and occasionally middle school teacher groups. Most significantly, secondary groupings and science groupings of Lesson Study research were included to best anticipate the viability of this professional development in a group of secondary physics teachers.

**Characteristics of Teachers**

To best understand the learning of teachers and their professional development needs, it was necessary to examine the characteristics of teachers in general. They proved to be isolated professionals (Huberman, 1993; Lewis, 2002; Puchner & Taylor, 2006). This feature presented challenges to reach teachers, convince them that changes are needed, obtain their buy-in to professional development, and meet their specific needs.

**Isolation**

Teaching is one of the few occupations whose practitioners are isolated from one another (Huberman, 1993; Puchner & Taylor, 2006; Sato & McLaughlin, 1992). Flinders (1988) conducted a qualitative case study of secondary classroom teaching in two high schools with six teachers in which he found that isolation was a shared condition of teaching. Teachers both accepted this condition and embraced it. Isolation became “an adaptive strategy for teachers because it protects the time and energy required to meet immediate instructional demands” (p.
Isolation was a prevalent characteristic in teachers (Huberman, 1993; Puchner & Taylor, 2006; Sato & McLaughlin, 1992).

Teachers were separated in both practice and thought for the majority of their time on the job. As a general rule, they planned alone and taught alone, with no input from other teachers and no output to other teachers. They did not customarily share what they learned or what they needed with other teachers next door or down the hall. Teacher knowledge thus pooled in individual classrooms and seldom watered the fields of others’ students.

U.S. educational researcher Richard Elmore insisted that isolation is the enemy of improvement (Lewis, 2002), yet few U.S. teachers had regular opportunities to work with other teachers on the improvement of classroom instruction. Research showed that only 5-13% of all U.S. teachers at all levels visited each other’s classrooms (Lewis, 2002). Rock & Wilson (2005) argued that teacher knowledge can only be constructed in response to social interaction such as collaboration with colleagues. Yamagata-Lynch (2003) contended that professional development must be situated in the participant’s school setting, as teacher knowledge cannot be disassociated from practice. Also, in the light of Vygotsky’s social constructivism (year), teachers should be “engaged in activities that necessitate interacting verbally and require that they often communicate with both novices and experts in their field of study” (Rock & Wilson, 2005, p. 79).

Research such as the qualitative case study by Puchner and Taylor (2002), nevertheless, underscored the importance of building collaboration in an effort to overcome isolation while safeguarding the teacher’s sense of control of her classroom and her teaching. Puchner and Taylor (2002), furthermore, recognized that Lesson Study, even in its early stages of
implementation, served to foster collaboration among teachers. Professionalism of an occupation was characterized by learning and continued growth within the occupation.

**Professionalism**

Teachers had been struggling to earn the societal title of professional for years (Fernandez, 2002; Lieberman, 1996). Andy Hargreaves (2000) presented the development of professionalism as transitioning through four historical ages to include the “‘pre-professional’ (managerially demanding but technically simple in terms of pedagogy); the ‘autonomous’ (marked by a challenge to the uniform view of pedagogy, teacher individualism in and wide areas for discretionary decision making); ‘collegial’ (the building of strong collaborative cultures alongside role expansion, diffusion, and intensification); and the ‘post-professional’ (where teachers struggle to counter centralized curricula, testing regimes and external surveillance, and the economic imperatives of marketization) (as cited in Day, 2002, p 600).

Teaching in the United States is regarded as less professional than many other professions, including doctors, lawyers, and engineers. Lieberman (1995) pointed to the fact that teachers were not perceived to have a practice that requires them to develop practical knowledge and specialized pedagogical knowledge of the same caliber of a medical practitioner. Teachers are seeking, however, to develop their practice into one viewed as professional (Ishii, 1996; Ito, 1990/1992; Nitobe, 1994). Teachers are looking for avenues to develop the necessary types of knowledge needed to grow professionally. Teachers are seeking power to select and initiate personal professional development to achieve a professional status. As Clarke and Hollingsworth (2002) explained, the needed shift in professional development is one of agency, to shift teachers from bystanders to active learners who are accountable for their individual reflective professional growth.
Tschannen-Moran (2009) conducted research on professionalism through surveys of 80 teachers using a subscale of the School Climate Index regarding administrative styles. Teacher professionalism was found to be related not only to the professional orientation of school leaders, but also to faculty trust. Tschannen-Moran recommended administrative authority with a professional orientation, which gives teachers discretion and autonomy in their work.

As professionals, teachers learn and better themselves, meeting the challenges of educating students in the face of the ever-changing society. As professionals, the mission of the science teacher is to assess and formulate avenues to prepare today's youth for the technological age of the present and the future.

**Procedure and Practice**

Left in isolation, science teachers tend to teach the way they were taught (Lewis, 2002; Rock & Wilson, 2005). When trained in science content, teachers learned to teach from professors at universities whose primary focus was often research, not how to best teach students. Teachers were subjected to, and in turn learned to emulate, this often inept style of teacher-centered lecture (Peters, 1982; Puchner & Taylor, 2006; Sunal et al., 2001; Thornton & Sokoloff, 1998; Van Heuvelen, 1991). The framework for future high school science teachers was established through modeling and defining "science teacher" methods.

In both teacher methods classes taken by these future science teachers, and in professional development in-services of current teachers, teaching methods were often illustrated out of context, not allowing teacher pedagogical content knowledge to develop unadulterated. Teachers needed opportunities to learn the best methods of teaching science by example in context with the content of science in which they taught or would teach (Lewis, 2002; Nielsen et al., 2008; Puchner & Taylor, 2006; Stigler & Hiebert, 1999; Sunal et al., 2001). Only then would
science teachers be properly equipped to teach content using methods that maximize student learning.

In practice, science teachers were often more comfortable with, and therefore developed habits of teaching content separate from the best practices for student learning. This practice appeared as a disconnected lecture with little student involvement or feedback, placing the teacher as the "sage on the stage." In response, research on student learning clearly indicated that teacher professional development should serve to develop teaching aptitude with research-based teaching strategies. In reality, however, disconnected professional development opportunities proved to be further opposed to combining methods of science teaching and research on student learning (Chong & Kong, 2012; Clarke & Hollingsworth, 2002; Isozaki, 2015; Saito & Atencio, 2013).

**Nature of the Scientist**

Scientists customarily researched and experimented in solitude (Collinson & Cook, 2004, 2006). Although some projects demanded that scientists work on teams, within the team, each scientist was assigned a facet or mini problem to solve. More often than not, scientists competed with other scientists instead of partnering for a common goal (Dickau, Kouneiher, Barbachoux, Masson, & Vey, 2012).

For the science student to become a science teacher, they often left behind much of the example of what a science teacher is and does. They were often trained in ways that would equip them to become scientists instead of teachers, yet they used content often outside of the teaching methods they experienced as a foundation to teach students. Supovitz and Turner (2000) argued that the culture of isolation must be transformed into a culture of sharing and collaboration if science education is going to improve.
Enthusiastic and Frustrated

Physics teachers were customarily excited about their content, yet were frustrated by the lack of understanding of physics by their students (Van Hise, 1988). Much evidence was used to support the fact that many factors work against physics learning, most notable of which is brain development (Van Hise, 1988). Common sense misconceptions are strongly embedded in student thinking and difficult to dislodge (Hestenes, Wells, & Swackhamer, 1992; McCloskey, 1983; Smith, diSessa, & Rochelle, 1993/1994).

Meeting the Needs of the Physics Teacher

Although collaborative professional development may be initially uncomfortable and often protested by teachers, education researchers found that specific design characteristics of professional development suited the physics teacher. To link content to research-driven pedagogy, professional development design encouraged the physics teacher to move away from isolation and toward collaboration; undergirding the professionalism of the occupation; supporting scientific inquiry; and enabling teachers to learn about research-based best practices (Borko, 2004; Dooner & Clifton, 2008; Lewis, 2002; Puchner & Taylor, 2006). A professional development model served as a foundation to each of these.

In a study examining scientific inquiry of secondary science teachers, Breslyn and McGinnis (2012) compared the conceptions and enactment of inquiry between science teachers in different content areas. In this mixed-methods study of 60 National Board Certified Teachers, the authors found that differences did exist. Using situated cognition to guide their investigation, the researchers found that secondary science teachers were in alignment with scientists in their specific content field in the ways in which they approached inquiry. These secondary science teachers portrayed inquiry in distinct ways. Breslyn and McGinnis found that physics teachers
were more likely to use Modeling and mathematical equations to describe physical phenomena. Physics teachers used experimentation to develop an equation or model that would predict behavior. In sharp contrast, other content area science teachers used different distinct strategies. Biology and earth science teachers approached inquiry with an emphasis on the theme of Students Conducting Scientific Investigations (SCSI), mirroring classical scientific method closely. Chemistry teachers were found to categorize their inquiry most frequently focused on content knowledge acquisition with a secondary focus on SCSI. Finally, science teachers of multiple content areas were able to hold multiple techniques and views of inquiry, each aligning to the respective field.

**Teacher Learning**

In every profession, the professional continues to grow, learn, and apply learning to his or her occupation. In the area of teaching, the teacher was often left to innovate and solve problems during the few moments of time extracted from their already overloaded schedule of teaching duties. Teachers needed to be granted opportunity and support to learn and continue to hone their craft.

Researching for the National Center for Research on Teacher Education (NCRTE), Kennedy (1991) studied teacher candidates and practicing teachers for three years through a variety of induction and in-service programs using mentors to gather qualitative data. Kennedy and colleagues found that, regardless of the approach to teacher development studied, most programs were unable to substantially change the ideas teachers had when they began the program. Teachers’ initial ideas were limiting and persistent. These ideas inhibited teachers' ability to understand new ideas about teaching, student learning, and the teachers’ role in connecting to diverse learners. Lortie and Clement (1975) further contended that years of being
a student socialized teachers to the role of teacher, defining the standard. This standard proved to stick with teachers (Kennedy).

Vygotsky's (1986) Sociocultural Theory gave support to this process. Vygotsky argued that, not unlike children, all people must learn in the context in which the knowledge must be understood and applied. In other words, teachers too must learn in a social environment. Vygotsky (1986) purported that learning happens on two progressive levels. First, the learner must learn from people such as a teacher mentor or colleague, which he terms "interpsychological." Second, learning must be internalized or happen "intrapsychologically". He applied these levels of learning to all aspects of learning, to include the formation of concepts and the adaptability of methods which were presented as pedagogy in teachers. Sfard (1998) also contended that learning occurred in context and in a collaborative setting. Sociocultural Theory stood contrary to a "sit and get" in-service. Sociocultural Theory opposed simple textbook learning on how to teach and mandated both social interactions and relevant cultural application to transform either of these attempts at teacher development to true teacher learning. Teacher learning must occur in order for the practice and implementation of new learning to become infused in teacher knowledge.

**Teacher Knowing: Practical Knowledge**

Grimmett & MacKinnon (1992) explained that practical knowledge or craft knowledge focuses on cognitions or thoughts that motivate teachers’ actions. Practical knowledge refers to the “integrated set of knowledge, conceptions, beliefs, and values teachers develop in the context of the teaching situation” (p. 141). In a specific one-year research study on practical knowledge, Lederman (1999) focused on the nature of science with five secondary biology teachers ranging in experience from two to fifteen years. This multi-case study investigated the relationship of
teachers’ understanding of the nature of science and their classroom practice. Lederman identified factors that facilitated or impeded the relationship. The study found that teachers’ conceptions of science do not automatically influence their classroom practice. Beginning teachers were wholly disjointed in their beliefs and their practices. More experienced teachers were more likely to exhibit classroom practices consistent with their stated views about the nature of science. Through interviews, Grimmett & MacKinnon found that experienced teachers were not intentional when teaching in ways that were in accordance with their perceptions of the nature of science. Teachers' conceptions of the nature of science often did not guide classroom practice (Lederman).

Schon (1987) argued that culturally, practical knowledge was seen as less valuable than scientific or rational knowledge. Although book knowledge was valuable on some level and often more quantifiable, it is irrelevant to many aspects of the practice of teaching. Van Manen (1995) supported the importance and validity of practical knowledge in teaching and teacher education. He contended that both practical knowledge and reflective practice must be strongly implemented in the arena of teacher learning to provide the necessary transformative learning that links practical knowledge, practical reflection, and action in teaching (Van Manen). This linkage served to develop teacher knowledge (Van Manen).

**Teacher Knowing: Pedagogical Knowledge**

The second form of teacher knowledge, pedagogical knowledge, was first established during the context of college classes for teacher training. In teacher certification programs, pre-service teachers were taught about both how their students learn and how they, as teachers, can best nurture learning in their students. Pedagogical knowledge is the deep understanding of the methods of teaching and learning and how these methods are used to achieve overall educational
purposes (Koehler, 2011). This generic form of teacher knowledge applies to all levels and types of student learning. Pedagogical knowledge applies to classroom management as well as lesson development, implementation, and assessment. Pedagogical knowledge was shown to require understandings of cognitive, social, and developmental theories of learning as they apply to any learning environment (Koehler, 2011).

One example of pedagogical knowledge involved pedagogy that was specific to a variety of cultures in the classroom. In a synthesis of classroom-based research on the implementation of culturally relevant pedagogy, Morrison, Robbins, and Rose (2008) examined 45 studies from 1995 to 2008. This qualitative research base was suggested to be used for teachers of all experience levels to create a picture and subsequent understanding of a culturally relevant pedagogy enacted in a classroom (Morrison et al.). Pedagogical knowledge of all sorts was developed. As Risma (2011) explained, as teachers become reflective practitioners, as they think and inquire and conceptualize, reflection allows them to become not only proficient users of pedagogical knowledge but creators and disseminators of this valuable type of knowledge (Risma, 2011).

**Teacher Knowing: Subject Matter Knowledge (SMK)**

Outside the realm of how to teach was the realm of what to teach, the subject or content knowledge. It was knowledge of content that provided the necessary and specialized understandings for teachers who needed a depth of content mastery in a specific field such as math, science, or social science. Knowledge was once the primary focus of a teacher's knowledge base to teach (Shulman, 1986). Although much research supported the importance of this foundation, subject matter knowledge served only as a piece of the foundation to successful teaching and learning (Cochran, 1991).
Leinhardt and Smith (1985) investigated the subject matter knowledge (SMK) of four novice and four expert teachers in elementary mathematics. With a focus on fractions, researchers used interviews, card-sorting tasks, observations of lessons, and transcriptions of videos to acquire data for qualitative study. The researchers concluded that although expert teachers seemed quite similar in their knowledge of subject matter, their classroom presentations often differed significantly.

As Osborne (2014) claimed, "while content knowledge is a necessary condition for good teaching, it is not a sufficient condition" (p. 192). Coupled with the knowledge of what to teach must be the knowledge of how to teach; together these cohabitate to produce the interactive and valuable pedagogical content knowledge.

**Teacher Knowing: Pedagogical Content Knowledge (PCK)**

Shulman (1987) designated PCK as a primary component of “the knowledge base for teaching.” (p. 675). Grossman (1990) perceived PCK as consisting of knowledge of strategies and representations for teaching particular topics and knowledge of students’ understanding, conceptions, and misconceptions of these topics. Marks (1990) also broadened Shulman’s model by including in PCK, knowledge of subject matter, as well as knowledge of media for instruction. Van Driel, Verloop, and de Vas (1997) explained that “PCK implies a transformation of subject matter knowledge, so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice” (p. 675).

In a long-term chemical education research project in the Netherlands that focused on chemical reactions, Van Driel, Verloop, and de Vas (1997) applied a grounded theory approach to their qualitative research design to study three cycles of experimental courses of teacher development. The study identified elements of PCK which were used to support student
understanding. The study provided general guidelines to design teacher training programs aimed at the development of PCK. Van Driel, Verloop, and de Vas stressed the need for teacher training programs to give teachers opportunities to study specific topics in science content from a teaching perspective. Overall, this investigation classified teaching experience as the chief source of PCK, with adequate subject-matter knowledge prerequisite.

In a mixed methods study of Malaysian science teachers, Halim and Mohd (2010) examined teachers’ PCK of specific physics concepts. This study required the student-teachers to write lesson plans in isolation for a two-hour period and then be immediately tested on content prior to an interview within three weeks of the lesson plan writing session. Twenty-eight pre-service teachers took part in the research. This study found that these pre-service teachers had limited conceptual understanding and were unable to transform what knowledge they did have into viable teaching strategies. Focusing on the three main components, “conceptual difficulties of students, teaching goals (knowledge of curriculum), and orientation in teaching of PCK” (p. 637), as first proposed by Shulman (1986), Halim and Mohd investigated their participants and found that without strong conceptual understanding of the physics concepts, PCK was inept. Specifically, the lack of content knowledge made the pre-service teachers unaware of student physics misconceptions. Many other researchers concurred that content knowledge was linked to pedagogical content knowledge (Geddis, 1993; Halim and Meerah, 2002; Van Driel, De Jong and Verloop, 2002)

In response to a study of self-reported changes in pre-service science teachers’ conceptions of both subject matter and pedagogy, Lederman, Gess-Newsome, and Latz (1994) concluded that pre-service teachers failed to integrate these two forms of knowledge. The authors suggested that teaching experience linked to subject matter tended to blur the division
between pedagogical knowledge and subject matter knowledge (Lederman et al.). The development of PCK, was shown to be inhibited prior to teachers reaching this stage of understanding. Veteran science teachers, however, have differing results. Sanders, Borko, & Lockard (1993) concluded that experienced science teachers, when teaching a topic outside of their specific scientific field or area of certification, seemed to be sustained by their depth of general pedagogical knowledge, allowing them to teach adequately, even with limited PCK.

In a qualitative study using clinical interviews, Clermont, Krajcik, and Borko (1993, 1994) investigated the PCK of chemistry teachers regarding instructional strategy during demonstrations. They concluded that experienced teachers had a far superior variety of illustrations and strategies specific to particular topics. Experienced teachers, furthermore, were more flexible in their choices when catering to student needs in comparison with novices.

Pedagogical Content Knowledge (PCK) is knowledge of how to teach and is cultivated while teaching content (Shulman, 1986). Anderson and Clark (2012) concluded that PCK develops in context of other knowledge areas (in particular, SMK), but, once formed, becomes a knowledge domain in its own right from which teachers can draw. Loughran, Milroy, Berry, Mulhall, & Gunstone (2001) defined PCK as "the knowledge that a teacher uses to provide teaching situations that help learners make sense of particular science content" (p. 289). PCK is structured and strengthened as teachers integrate content knowledge with careful consideration of pedagogical knowledge specific to the concept. It is thus a synthesis of teachers' pedagogical knowledge and their subject matter knowledge accompanied by the judgment and experiences that come from practice. PCK joined all forms of teacher knowledge, allowing the teacher to specifically cater the best teaching and learning practices for both the content and the student in a particular learning environment (Shulman, 1986). Dudley (2013) explained that PCK includes
an overall understanding of content as it interacts with the subject, the curriculum, the teaching approach, the student population, individual student characteristics and experiences, and student misconceptions. Moreover, according to Shulman (1986), PCK links content with the specific "most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations… [which make representations] comprehensible to others" (p. 9).

PCK in science involves a synergy of content knowledge coupled with teaching pedagogy and experience. PCK is a form of knowledge that makes science teachers "teachers" rather than scientists (Gudmundsdottir, 1987a, b). Cochran (1997) contended that "teachers differ from scientists, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used" (para. 6). Thus, science teachers assimilate content knowledge, pedagogical knowledge, experience, and student knowledge within the confines of the science classroom in order to maximize the learning of their students. It is PCK that "distinguishes a teacher from a content specialist" (Magnusson et al., 1999, p. 95).

**Physics Teacher PCK: A Specialized Science PCK**

A teacher of physics requires specialized PCK domains. MacIsaac and Falconer (2002) claimed that "physics PCK is developed through specialized training and experience in physics teaching and is extended through professional development such as physics curricular workshops, professional physics teaching journals, associations and meetings, and books about physics teaching" (p. 484). Shulman (1987) and Cochran (1991) concurred that teachers critically reflecting on and interpreting content knowledge resulted in the creation of pedagogical content knowledge (PCK). Cochran (1991) explained:

This transformation occurs as the teacher critically reflects on and interprets the subject matter; finds multiple ways to represent the information as analogies, metaphors,
examples, problems, demonstrations, and classroom activities; adapts the material to students’ abilities, gender, prior knowledge, and misconceptions; and finally tailors the material to those specific students to whom the information is being taught. (p. 5)

The time and actions spent doing physics and looking at the world through the eyes of a teacher of physics are molded through reflective experience to form physics teacher PCK. One must be vested in content-specific domain to grow and learn in this way. For instance, Cochran (1991) argued that PCK “is highly specific to the concepts being taught, is much more than just subject matter knowledge alone, and develops over time as a result of experience in many classroom settings with many students” (p. 10). Friedrichsen and colleagues (2009) found that teaching experience without teacher education did not appear to contribute to the development of PCK.

Van Driel and Berry (2012) claimed that PCK “goes beyond the acquisition of instructional strategies and techniques, per se, to include an understanding of how students develop insights in specific subject matter” (p. 27). Sperandeo-Mineo, Fazio, and Tarantino (2006) developed this idea further, concluding that “knowledge transformation is not a one-way process from subject matter knowledge to pedagogical content knowledge, as literature suggests, but a bidirectional process involving deepening of subject matter knowledge and increasing awareness of pedagogical issues” (p. 235). These processes proved to be specific to the content of the science teacher, culminating in PCK that was unique to the physics teacher.

Reviews of the literature by Grossman (1990), Tamir (1988), and Magnusson et al. (1999) determined that there are five components of science PCK:

1) Orientations toward science teaching
2) Knowledge and beliefs about science curriculum
3) Knowledge and beliefs about students’ understanding of specific science topics
4) Knowledge and beliefs about assessment in science
5) Knowledge and beliefs about instructional strategies for teaching science (p. 97)

Two of these, the third and fifth components, are of special interest to the teacher of physics. The third component, knowledge teachers must have about students, was broken down into two subparts: requirements for learning specific science concepts and the areas of science which students find difficult. This component encompassed student misconceptions. Wandersee, Mintzes and Novak (1994) stressed that misconceptions have differing levels of resistance to change and that the science teacher must be able to “differentiate between the concepts that might require high-powered conceptual change strategies and those that are equally likely to yield to well-planned conventional methods” (as cited in Magnusson et al., 1999, p. 105).

Highly specialized PCK requires the physics teacher to be extremely familiar with the content as well as experienced with what preconceptions and difficulties students have with the specific physics content. The development of appropriate PCK for physics teachers seemed to be dependent on subject matter knowledge (Magnusson et al., 1999; Sperandeo-Mineo et al., 2006), which was wholly insufficient without fine-tuned, highly specific PCK for teaching physics.

For the fifth component of PCK, knowledge of topic specific strategies, Magnusson et al. (1999) emphasized the appropriate selection of topic-specific representations such as "illustrations, examples, models, or analogies" (p. 111). Magnusson et al. (1999) contended, "An effective teacher must judge whether and when a representation will be useful to support and extend the comprehension of students in a particular teaching situation" (p. 111-112). Duit et al. (2007) argued that physics has an extremely high level of abstraction and idealization, and models were needed to communicate the concepts, distinguishing physics from other sciences (Duit et al.). Each model chosen had the propensity to reinforce proper conceptions and to
correct misconceptions, and only the physics teacher with strong PCK was able to use the models or representations appropriately and teach where the usefulness of the model was exhausted.

A physics teacher must possess a different PCK from a biology, chemistry, or social studies teacher. Examples of specific PCK which are only viable for physics include modeling, a computational lab environment, and meta-reflection which forces students to reflect on their thinking during problem solving (Sperandeo-Mineo et al., 2006). As Sperandeo-Mineo and colleagues (2006) contended, there is a defined group of teacher competencies which serve to form a knowledge base for physics teacher PCK.

As Van Driel and Berry (2012) asserted, PCK is highly "topic, person, and situation specific" (p. 26). This reality was first observed in published physics teacher research by Hashweh (1987). Hashweh (1987) conducted a study of the knowledge constructs of three physics teachers and three biology teachers. This study showed that each of the teachers was aware of multiple strategies and methods for teaching their own area of science; they were inept at mentally securing specific strategies for teaching difficult concepts in the other area of science. Analogies and examples were more effective in each teacher's field of expertise. This study confirmed that PCK is specific to content specificities and not encompassing teaching in general. Van Driel et al. (1997) argued that teachers who teach outside of their field or even specific unfamiliar topics have little knowledge of student preconceptions or potential problems and "have difficulties selecting appropriate representations of subject matter" (p. 679). Hashweh (1987) further concluded that subject matter knowledge outside of a teacher's field of teaching was not only a distraction, but also a source of student misconceptions.

Physics PCK was developed as physics teachers taught students physics, and as they thought about their own experiences as examples through which to better understand physics
concepts (Berg & Brouwer, 1991). In practice, Sanders (1993) concluded that pedagogical knowledge provided the framework for teaching that is “filled in by content knowledge and pedagogical content knowledge...when teachers taught within and outside their science area” (p. 733).

A final note on physics teachers PCK speaks to the reality that all teachers and teacher experiences are different. Although there are foundational principles of physics PCK that are universal, the application of these principles may look different from one classroom to the next (MacIsaac and Falconer, 2002; Van Driel et al., 1997). Some elements or trends surface regularly, but representations such as personal experience make every physics teacher’s PCK toolbox distinct. Van Driel et al. concluded that “experienced science teachers’ PCK may differ considerably, even when their subject-matter knowledge is similar and when they teach the same curriculum; these differences appear from the use of different representations and instructional strategies during classroom practice” (p. 681). A primary example of differentiated experience which leads to differentiated physics teacher PCK was seen in the classic teachable moment. A physics teacher PCK must be deep enough to undergird spontaneity. As MacIsaac and Falconer (2002) confirmed, “physics teachers require a thorough knowledge of course content so as to be able to shift the lesson content in line with students’ thinking, often resulting in very nontraditional sequences; such shifts require expertise in identifying and underscoring real-world examples as they spontaneously arise” (p. 484).

**Status of Secondary Physics Teachers’ Development**

During the 2012–13 academic year, the American Institute of Physics collected data from a representative national sample of over 3,500 public and private high schools across the United States. With 2073 participating physics teachers, this study revealed that only 40% of the
teachers had ever had a physics teaching course in their preparation, either before or during their high school teaching career. Although over 90% self-reported confidence in basic content competency, only 59% felt that physics teaching was their specialty. Teachers reported looking to internet or textbook sources for content or teaching help most frequently, over 88% of the time. Physics teachers only asked a colleague 40% of the time they needed help. This could be a result of the isolation (Flinders, 1988) or the usual significant proximity from a single physics teacher at one high school to the nearest physics teacher at a neighboring high school.

At the University of Colorado in Boulder, Wieman and Perkins (2005) conducted a study with one semester of introductory physics students for non-science majors. The study found that when confronting nonobvious or counterintuitive fact, lucid lecture with explanatory demonstration only resulted in a 10% level of retention fifteen minutes after the conclusion of the class. This 10% level of cognitive change in response to lecture and demonstration was observed with faculty and graduate students, as well (Wieman & Perkins, 2005). A significant need was found in the research for professional development to support and transform the teaching of secondary physics in-service teachers.

**Professional Development Model**

Research verified characteristics of both successful and unsuccessful professional development. This literature review drew from international and domestic studies and establishes a model for professional development of the necessary features, as well as the recommended excluded features. Studies specific to science teachers were not plentiful but are well-represented here.

In a qualitative meta-analysis, Clarke and Hollingsworth (2002) examined three Australian studies to construct an Interconnected Model for professional development. The three
studies included the ARTISM study, a longitudinal investigation over 18 months of the professional growth of 18 mathematics teachers from three Catholic boy schools in suburban Melbourne, reported by Clarke, Carlin, and Peter (1992). The second study involved Exploring Mathematics in Classrooms (EMIC), a longitudinal study of six primary school teachers involved in a Victorian mathematics professional development program by Hollingsworth (1999). The third study was The Negotiation of Meaning Project, a review of a four-year compilation of classroom video data of 55 classes, grades seven through ten, of high school mathematics and science lessons by Clarke (1998, 2001). Using a framework to facilitate teacher change through professional development, the researchers concluded that professional development should be situated in realistic contexts, view teacher learning as a means to fulfill betterment as a practitioner of the art of teaching, and give recognition to the reality that teaching is both idiosyncratic and individual in nature.

Clarke & Hollingsworth (2002) concurred that teacher professional development must be situated in the context of teaching for teacher learning. Inappropriately, most professional development was found to be out of context and out of science content, tending to stand in opposition to or removed from student learning. With this disconnected model presented as common practice for science teacher development (Chong & Kong, 2012; Clarke & Hollingsworth, 2002; Isozaki, 2015; Saito & Atencio, 2013), new strategies being discovered or developed to connect content with pedagogy was the recommended goal.

In a qualitative research meta-analysis on professional development research, Borko (2004) found that overall, current professional development programs were not conducive to how teachers learn. She found evidence in two large studies that professional development, which included an explicit focus on subject-specific content and was followed up by support for
a year's duration, was highly effective. Both the Summer Math for Teachers (Schifter & Simon, 1992; Simon & Schifter, 1991) and the conceptual change science teaching project (Neale, Smith, & Johnson, 1990; Smith & Neale, 1991) lent support to these claims (Borko, 2004). Findings indicated that strong professional development communities, also referred to as Professional Learning Communities, were significant contributors to both instructional improvement and school reform (Borko, 2004; Little, 2002).

The research indicated that professional development for science teachers was customarily ill-fit (Borko, 2004) and many teachers resisted change (Sunal et al., 2001). Other research supported the idea that professional development should also be constructivist in nature (Gerard, Varma, Corliss, & Linn, 2011; Supovitz & Turner, 2000), allowing teachers to experience learning and positive growth in teacher self-efficacy (Chong & Kong, 2012; Sunal et al., 2001). The quantity of teacher professional development was strongly linked to both inquiry-based teaching practice and investigative classroom culture; research recommended professional development programs span one year or more (Gerard, Varma, Corliss, & Linn, 2011; Sunal et al., 2001; Supovitz & Turner, 2000).

Practice-based professional learning was not common in the U.S. (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Lewis, Perry, & Friedkin, 2012). Most professional development featured short duration and quick fixes for general teaching practice in the form of workshops or in-services (Clarke & Hollingsworth, 2002; Weimer & Lenze, 1994). "A-ha moments" in response to using the new technique seemed to be the only motivator for teachers to change their thinking and practice (Chokshi & Fernandez, 2004). This cycle served as a poor instructional approach to teacher change.
Next, to honor the view that teacher learning is paramount to the professionalization of teaching, research suggested that teacher learning should be foundational to the selection of and implementation of professional development programs. In a professional development system, the "students" are teachers, the ‘teachers’ are facilitators, and the ‘curriculum’ is the professional development program (Borko, 2004). This model was a learning paradigm for teachers. There was much deficit found regarding the current professional development model (Rock & Wilson, 2005). For example, recent international research found that the ‘one-shot' type of professional development outside of the context of the classroom failed to facilitate teachers re-shaping their practices, for the professional development remained disconnected from their daily routines (Cannon & Hore, 1997; Johnson, 2006; Saito & Atencio, 2013).

Borko (2009) found that professional development must focus in the context of Professional Learning Communities as a means of collaborative instructional improvement. As Little's (2002) research indicated, "strong professional development communities are important contributors to instructional improvement and school reform" (p. 936). Professional development communities must cultivate an atmosphere of trust. As Borko (2009) explained, to foster critical examination of teaching, discussions must emerge in an atmosphere of "trust, develop communication norms that enable critical dialogue, and maintain a balance between respecting individual community members and critically analyzing issue in their teaching" (p. 7).

Finally, in response to the reality that teaching was both idiosyncratic and individual in nature, teacher autonomy should not be sacrificed at the expense of collaboration. The original motivation for teacher development was the notion that teachers were not equipped or motivated to cause student learning to occur at a high enough level (Clarke & Hollingsworth, 2002). This deficit model served to lessen the professionalism of the occupation by ruling with fear. While it
was warranted that growth should occur throughout one's teaching career, it was not appropriate that administrators assume that teachers are inept and must be forced to change their ways. In contrast, numerous researchers argued for a self-regulatory model of professional development, granting teachers autonomy and the respect to assess their individual needs (Collinson & Cook, 2006; Sibbald, 2009; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006).

**Science Specific Professional Development**

Research on general professional development for all levels of teaching was prolific. Research on science-specific professional development was quite limited. These science professional development studies, however, were useful and generalizable to some degree to the secondary physics teacher. Some studies were conducted with university science teachers. As a case in point, Sunal, D. et al. (2001) used ethnographic and case study approaches to study the effectiveness of professional development programs in the science classrooms of university science teachers. This research pointed to a significant aversion to change of practice in many of these teachers. Implications revealed that personal efficacy was a more deeply held value than teacher efficacy and was related to the successful action in creating course change. Although this study was specific to college professors who experience different demands on their time to include research and publication, similarly extensive time demands are experienced by secondary teachers, suggesting relevance for secondary physics teachers.

In a meta-analysis of peer-reviewed technology-based professional development programs between 1985 and 2011, Gerard, Varma, Corliss, and Linn (2011) specifically looked at how comprehensive, constructivist-oriented professional development enhanced teachers' support for student inquiry science learning at all levels of K-12 education. This study found that professional development that was sustained beyond one year and engaged teachers in
constructivist-oriented learning experience enhanced students' inquiry science learning experiences in more than two-thirds of the teachers in the study. At all levels, teaching teachers through inquiry to teach students through inquiry proved successful.

Supovitz and Turner (2000) examined the relationship between professional development of teaching practice in the quantitative study of 3464 teachers and 666 principals across the U.S. and data from the National Science Foundation Teacher Enhancement program called the Local Systematic Change Initiative. This study revealed that the quantity of professional development in which teachers participated determined the degree of inquiry-based teaching practice and the investigative classroom culture. Specifically, teachers with no professional development employed inquiry-based practices four-tenths of a standard deviation less frequently than that of the average teacher. Teachers with between 40 and 79 hours of professional development had average teaching practices, and those with over 80 hours of professional development used inquiry-based teaching practices in frequency two-tenths of a standard deviation above the average teacher. Each standard deviation of increased content preparation a teacher reported was associated with a 20% increase in the participation of investigative classroom culture. This study was limited to K-8 science teachers and principals and may not apply completely to the secondary classroom.

Chong and Kong (2012) conducted a qualitative case study in which they explored the correlation between teacher self-efficacy and Lesson Study with ten teachers from math, humanities, and science of an all-girls high school in Singapore. In this study, the researchers confirmed positive correlation between Lesson Study and teacher self-efficacy. This study was further supported by other studies that linked teacher learning and teacher self-efficacy (Lewis, Perry, & Hurd, 2004; Puchner & Taylor, 2006).
Professional Learning Community

Findings indicated that strong professional development communities, also referred to as Professional Learning Communities (PLCs) were significant contributors to both instructional improvement and school reform (Borko, 2004; Little, 2002). These groupings of teachers by grade level or content area afforded increased autonomy to teachers (Fernandez, 2002). PLCs further provided long-term opportunity for professional development for teachers at all experience levels.

Historic Experiment: The Eight-Year Study

During the 1930's, the Progressive Education Association (PEA) conducted a comprehensive study and field investigation with 30 U.S. secondary schools known as the Eight-Year Study. Driven by apparent inadequacies in preparing students for adult life, schools needed the flexibility to try new curriculum that would better equip students for both college and other occupational opportunities. Pinar (2010) explained that when the participating schools disassociated their curriculum from the admissions requirements of colleges and universities, they were able to experiment with curriculum and pedagogy. This monumental study of school experimentation demonstrated that public schools could develop organizational systems that supported continued teacher development (Watrus, 2008).

The Eight Year Study served to build teams of teachers who transformed curriculum. These teams of teachers joined with students to plan new and relevant curriculum (Watrus, 2008). Professional development moved away from graduate courses and toward group meetings of teachers to engage in "ongoing conversation regarding the aim of education" (Pinar, 2010, p. 298). Leaders of this study recognized that collaborative effort of extensive discussions was highly supportive of teacher learning (Pinar, 2010). In Newlon's words, "curriculum and
instruction must grow from the inside out" (Cuban, 1993, p. 81). The educational innovator, Newlon, believed that the process of teachers collaborating and solving problem together was equally or even more important than the product of curricular change (Cuban, 1993). The Eight Year Study arguably emerged as the first complete and well-tested PLC model.

A PLC was a new take on an old entity; it was a more highly focused and directed Community of Practice. Over time, a primary emphasis of teachers and school personnel became the bettering of teaching and learning, often by concentrating on improving pedagogy and curriculum. Stoll, Bolam, McMahon, Wallace, & Thomas (2006) explained that this outlook of inquiry and reflection to structure a self-evaluating school culture was evident in Dewey's Laboratory School. Stoll et al. (2006) clarified, the idea of an effective PLC emerged from reforms and strategies of the early part of the last century as key features have remained prevalent and effective in educational reform.

Modern PLC

The modern PLC was reinvented to cater to today's teaching profession and current administrative and political mandates. PLC creates a community of inquiry where teachers reflect and solve problems with other teachers to discover and establish current personal best practice (Dudley, 2013). PLC is a created safe place for educators to experiment, to show vulnerability, and to share what works and what does not; in PLC, educators pool understandings and talents for the good of the group and for the good of the students whom they serve (Rismark, 2011; Senge, Cambron-McCabe, Smith, & Dutton, 2012). PLC claims to build community among teachers while increasing the quality of teaching and learning (Easton, 2012; Rismark, 2011; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006). Stoll et al. (2006) continue that PLC supports the experiment of educational practices, using subject matter and curriculum to gather
the data that forms the problems of inquiry. Stoll, Bolam, McMahon, Wallace, & Thomas (2006) contend, the purpose of educators' actions as supported by PLC is to enhance their effectiveness as professionals for the benefit of their students. PLC promises to "fundamentally alter teaching, learning, bureaucracy, and individualism that pervade so many schools" (Servage, 2008, p. 63). Servage (2008) argues that PLC produces transformative learning in teachers that spills over into the students in their classrooms; teachers grow through PLC not only as individuals, but as a community of learners in a Professional Learning Community.

In a study that addressed the relationship between Professional Learning Community and school culture, Hipp, Huffman, Pankake, and Olivier (2008) examined two schools using a qualitative case study approach as they developed Professional Learning Communities. They focused on the sustainability of the PLC. The authors identified some of the intricacies in building cultures of learning for adults and students. The authors began to identify some categories of activities and issues that must be developed before others can emerge; however, they conclude that the development of PLCs “seems so complex that to be able to describe discrete steps or stages is unlikely” (p. 173).

**Significance and Benefits of PLC**

Professional Learning Communities turn the mandates and traditions of education on their heads. PLC serves to give the teacher a voice and a choice in her practice. PLC allows groups of teachers to address current problems and find timely, effective solutions. PLC gives teachers power over their professional lives, bettering their work environment and the learning environment of their students. Riveros, Newton, and Burgess (2012) explain that Professional Learning Communities seek continuous improvement in student learning through ongoing
collaboration of teachers and administrators who concentrate their actions on improving practice and students’ achievement. PLC supports both teachers and students.

Evidence of the effectiveness of PLC implementation is strong, showing that teaching and learning practices and school climate are improved in response to PLC (Borko, 2004; Collinson & Cook, 2004). International evidence suggests that the development of PLC is strongly correlated with capacity building for sustainable improvement in schools (Stoll, Bolam, McMahon, Wallace, & Thomas, 2006). Domestically, Louis, Marks, and Kruse (1996) conducted an intensive study of 24 schools (eight elementary, eight middle, and eight high schools) which details evidence that schools operating with PLCs have a significant impact on both teacher classroom practice and student achievement. PLC affects positive change in teaching and learning (Dodd & Rosemaub, 1986; Dufour, 2006; Johnson, 2011).

DuFour, DuFour, Eaker, and Karhanek (2004) believed that a rise in test scores was inevitable if teachers collaboratively focused on student learning through both resources and practice. A Texas study identified 64 public high schools functioning as Professional Learning Communities with a mean length of functioning of 2.5 years. Of these schools, not only is student achievement enriched, but the study found that most schools improved their Mathematics and Reading/English Language Arts standardized test scores (Hughes & Kritsonis, 2007). PLC drives student learning in response to teacher learning.

In an international literature review, Stoll, Bolam, McMahon, Wallace, and Thomas (2006) examined the effect of PLC as a means of capacity building. They found that the progress of educational reform depends on teachers’ individual capacity, teachers’ collective capacity, and on the link with school wide capacity. PLC is shown to build the capacity for student learning which is defined as “a complex blend of motivation, skill, positive learning,
organizational conditions and culture, and infrastructure of support” (p. 221). Stoll et al. concluded that developing Professional Learning Communities might be a link to developing capacity for maintainable improvement.

PLC was shown to change the culture and perception of the overall school community (Seashore, Anderson, & Riedel, 2008). Stoll et al. (2006) acknowledged that PLC served to establish a school-wide culture that made collaboration “expected, inclusive, genuine, ongoing, and focused on critically examining practice to improve student outcomes” (p. 224). PLC was found to be instrumental in much more than curricular improvements and better teaching practices; it proved to be a tool to change the capacity of success of a school.

**PLC is Lacking in Some Ways**

From the beginning of PLC, the model was to focus on, develop, and refine curriculum (Dodd & Rosenbaum, 1986). This model depended on small groups of teachers working together with process being emphasized over product. Curriculum and staff development became vehicles to encourage all teachers to share actively, support each other professionally, and learn together (Dodd & Rosenbaum). The model did not mandate a focus on content or research on student learning within that content. The focus was extremely broad and unstructured with a goal of increased student learning. PLC was often a top-down mandate with administrative goals and expectations pushed upon teachers within the PLC (Dodd & Rosenbaum).

**Lesson Study as Professional Development**

**Origin of Lesson Study**

The Japanese culture spent decades exclusively developing their teachers professionally through the practice of Lesson Study (Lewis, 2000, 2002; Lewis, Perry, Friedkin, & Roth, 2012).
This method produced a highly ranked educational system based on numerous internationally normed measurements (Fendsterwald, 2013).

This professional development technique required teachers to collaborate on best lessons and fine tune these lessons with the goal of re-teaching the lesson in a more articulated state (Lewis, 2000, 2002; Perry & Hurd, 2006; Puchner & Taylor, 2006; Rock & Wilson, 2005). Teachers met to select and design every aspect of the lesson. One teacher was then chosen to teach the lesson for all to view. All teachers and many administrators witnessed the lesson being taught and the subsequent student reactions. During this process, pointed and extensive notes were taken by all witnesses. The teacher was not to be judged or critiqued. The lesson and student learning were the focus. Much feedback was gathered, and a debriefing occurred directly after the lesson, most often the same day, by all participants. A large degree of reflective feedback and consequential alterations in the lesson occurred subsequent to the meeting. After evaluating the lesson in detail and amending the lesson plan, another member then taught the modified lesson for all to observe. Another subsequent reflective debriefing occurred, and notes were made for further fine-tuning of the lesson as well as needed follow-up to the lesson. This lesson might have been retaught again during the current school week or during the same cycle of learning the following year. Not only was a model lesson created, but teachers experienced much learning through observation of students in their learning.

**Lesson Study in U.S. High Schools with U.S. Teachers**

In response to the International Study Center at Boston College’s monumental international study, the Third International Science and Mathematics Study (TIMSS) report in 1995, U.S. teachers and educators discovered the notion of Lesson Study. In response to this window into the novel and highly effective method of Japanese professional development,
teachers and educators were intrigued with the opportunity to professionalize their occupation and utilize a teacher-driven tool to develop their practice (Sato & McLaughlin, 1992). Lesson Study possessed many of the features that were recommended by U.S. educational researchers and organized these features into coherent and systematic processes (Chokshi & Fernandez, 2004). Lesson Study served to support the development of pedagogical content knowledge and was both situated and authentic (Wagner, 2003). Many U.S. educators, in turn, tried out this form of teacher-initiated professional development in the context of their school and school system (Lewis, 2002).

As the model in Japan suggested, Lesson Study was a best-fit for elementary schools. The majority of implementations in the U.S. were in the elementary setting (Dudley, 2013; Lewis, 2002; Rock & Wilson, 2005). Studies with pre-service teachers were implemented (Kartal, Ozturk, & Ekici, 2012). Few studies, however, were instituted in the secondary education culture. The majority of these were in the mathematics classroom (Dudley, 2013; Sibbald, 2009; Wang-Iverson, 2002). No studies to date have focused on Lesson Study exclusive to secondary science teachers. No studies to date have focused on Lesson Study with physics teachers at the secondary level.

Lewis (2002) elaborated that Lesson Study provided teachers the opportunity to think carefully about the learning in the light of a central goal. It also afforded teachers the opportunity to think deeply about long-term goals for students, to study the best available lessons, and to expand and deepen teacher content knowledge (Lewis, 2002). Even though Lesson Study did not guarantee access to content knowledge, it may have helped educators discover and define gaps in their understanding and may have provided a meaningful, motivating context for pursuing deeper understanding while learning from more knowledgeable peers.
(Lewis, 2002). Lesson Study facilitated the development of instructional knowledge, built capacity for colleague collaboration, and helped develop "the eyes to see students" (Lewis, 2002, p. 13).

In a qualitative grounded theory study of 700 urban students in Ontario, Canada, Sibbald (2009) studies three middle school teachers who discussed how Lesson Study contributed to their teaching. In their study, Lesson Study was positively linked to both student achievement and teacher self-efficacy. This study was specific to math teachers and took place in Canada; however, Canadian schools are similar to U.S. schools, and math is similar to the applied math of the physics classroom. Some potential generalization was warranted and urged more research within U.S. science classrooms.

In another study, Saito and Atencio (2013) posited that effective professional development should continue over the long term and was best suited for a school community that promoted teacher learning in a collaborative sense. In an international qualitative multi-case study with a sample of 13 schools which grew to 321 schools involved in Lesson Study from 2003 to 2008, Saito and Atencio (2013) found that the perception and belief of increased student learning perpetuated changes in teaching style. Lesson Study proved to be instrumental in prodding teachers away from lecture and a teacher-centered style of teaching and toward teaching that incorporated a social constructivist approach, requiring the establishment of dialogue in the classroom. Saito and Atencio (2013) found that Lesson Study served as a tool for challenging pedagogical practices and was most valuable when balanced with peer lesson observations.

In a three-year professional development initiative study, Rock and Wilson (2005) found that Lesson Study was shown to both increase teacher knowledge and skills and to change
instructional practice. During her Lesson Study in science classrooms in Japan, Lewis (2000) found that, remarkably, Japanese science teachers were able to transform their instruction from teaching as telling to teaching for understanding. More specifically, Japanese teachers were able to transform the science classroom of the 1950's into the ideal inquiry-based science classroom of the modern age through the use of Lesson Study (Fernandez, 2002).

Lesson Study Implementations in the United States

A handful of Lesson Study implementations have occurred in the United States. Lewis (2002) recounted the momentous event of February 28, 2000, when she had the opportunity to attend the first day of public Lesson Study in a U.S. school, at Paterson School Number Two, in Paterson, New Jersey. This inaugural day was the first of many attempts at the implementation of Lesson Study in different states, with differing curriculum, and in response to differing motivations.

Few full implementations were studied, and even fewer implementations were sustained. One source of data, a study conducted by Perry and Lewis (2009) in Bay Area School District in California, involved a sample of grades K-8 of an entire school district. This site was the second United States school site and the first district-wide implementation of Lesson Study. Authors relied on grounded theory and theory-driven research as they gathered interviews as well as both audio and video tapes over the course of four years. Practitioners were overwhelmingly positive and valued the professional development afforded them through Lesson Study. This case study noted that over the course of implementation of Lesson Study, participants transformed their view of the nature of Lesson Study from one of instructional product to one of a process for instructional improvement (Perry & Lewis, 2009).
Another implementation of Lesson Study took place with six elementary teachers in the southeastern United States, specifically in North Carolina (Rock & Wilson, 2005). This study employed a qualitative case study design featuring data sources of interviews, field notes, and reflection journals which culminated in a data matrix with a focus on change in participants' instruction. This study found that group planning was powerful. In Lesson Study meetings, group participants found value in reading and sharing professional literature which resulted in increased confidence in teaching. Lesson Study was supportive in instructional vocabulary, differentiated instruction, manipulative math instruction, knowledge of math learning stages, and helped to establish high student expectations. All participants reported strong affinity for Lesson Study and a perception of significant professional growth. They stressed that even though Lesson Study was more demanding than other means of professional development, "it was much more rewarding and proved to increase their professional understandings and competencies" (Rock & Wilson, 2005).

In two simultaneous studies, Fernandez (2002) examined fourteen K-8 urban school teachers in New Jersey and nineteen middle school lead teachers and staff developers from a single community school in New York City. Teachers were given much autonomy and much support from the literature in the study. Also, researchers provided protocol tools for participants. Data took the form of interviews, field notes, videotaping, and work artifacts in both groups. From here, the two sets of data diverged. The New Jersey group had access to a group of Japanese teachers who served as Lesson Study coaches. The New York City group used the standardization of standards-based curriculum materials as a binding force for Lesson Study. This research explored the feasibility of Lesson Study in the United States in light of data (Fernandez, 2002). Fernandez (2002) further addressed the difficulties in implementing Lesson
Study in the United States and suggested the possible reality that a systematic approach might be needed to "create a rich enough learning environment to support teachers in acquiring the research skills needed to carry out powerful Lesson Study" (p. 404).

In a qualitative case study, Cerbin and Kopp (2006) provided a model for using Lesson Study to improve pedagogical knowledge as well as general teaching in the college classroom. This three-year study culminated with 40 teams of Lesson Study groups on ten college campuses with some participants being science teachers in the field of biology. Cerbin and Kopp discovered and delineated necessary differences between the Japanese model of Lesson Study and the U.S. model. First, instead of the Japanese goals of character development, U.S. teachers found a useful focus at institutional aims such as problem-solving or aims linked to a specific academic discipline. Next, teachers focused on how students learn, not what students learn. Instructors reported benefiting most from the careful analysis process that collaboratively cultivated a mutual understanding of goals, teaching practices, as well as student learning.

**Bridging the Chasm between Japanese and U.S. Teachers**

Many philosophical differences exist between Eastern educators and U.S. educators. These philosophical differences were necessarily addressed to potentially adapt Lesson Study for implementation in the U.S. To begin with, in contrast to their counterpart, U.S. educators assumed that one must learn content knowledge before planning lessons. Eastern teachers believed that teachers must learn content knowledge through the process of planning lessons (Lewis, 2002).

The freedom to choose from broad categories of lessons was characteristic of the Japanese educator. Lesson Study worked because of the almost open-ended trust in teacher decision-making for the purpose of lesson articulation. The national curriculum of Japan,
furthermore, served to establish consistency of a few deep topics in each content area. In the U.S., however, significant and unspecific breath of content inhibited instructional coherency while limiting the instructional time and choices involved in building lessons (Perry & Lewis, 2009). Lesson Study was the best fit in Japan due to the centralized education system (Lewis, 2002). There was promise in light of standardized content groupings for Lesson Study participants in the U.S. high school; although not nationally standardized, this high school setting served as a microcosm of the Japanese Lesson Study model.

Due to the tradition of administrators evaluating teacher performance in teaching, U.S. teachers were driven to be critical of both their teaching and the teaching of others. Fernandez (2002) acknowledged that all teachers in her studies confessed being nervous when teaching in front of colleagues and even during the follow-up discussions after the lesson was taught. The means proved to warrant the ends as indicated by Japanese experience.

For Lesson Study to work, the mentality of the U.S. teachers had to change. U.S. educators had to follow the rules of Lesson Study and shift their focus to critique the lesson and not the one presenting the lesson (Chokshi & Fernandez, 2004; Lewis, 2002; Perry & Lewis, 2009). Japanese teachers found much value in critique while affirming, being critically honest and delivering critique effectively "only with politeness, concrete evidence, and precise language" (Chokshi & Fernandez, 2004, p. 524).

Encouragement of a potential fit in the U.S. was underscored in the reality that lesson ownership was diffused across the group of teachers who planned together (Chokshi & Fernandez, 2004). Also, healthy change in mindset might have allowed U.S. educators to attach a significantly different emotional meaning to both self-critical reflection and group critical reflection after a lesson was taught (Lewis, 2002). U.S. educators broached the mentality of
Japanese educators and began to identify and accept criticism regarding shortcomings as a way of showing competence, not accepting failure (Lewis, 2002).

Japanese teachers were convinced that Lesson Study improved their practice. Lewis’s (2002) research found through interviews that Japanese teachers valued both the specific feedback they had gained on their instruction and many specific teaching techniques learned from watching others’ research lessons. The small amount of research gathered on U.S. implementation of Lesson Study confirmed these sentiments in the Lesson Study experience of the U.S. teachers (Fernandez, 2002; Perry & Lewis, 2009; Rock & Wilson, 2005).

In contrast to U.S. teachers, Japanese teachers were concerned with the whole child, focusing broadly on developing students with specific foci on social, interpersonal, and aesthetic skills (Sato & McLaughlin, 1992). Sato and McLaughlin (1992) claimed that U.S. “educational purposes are framed primarily in terms of cognitive achievement and academic performance” (p. 360). Thus, a broader vision had to be adopted by U.S. teachers. Professional development was an expectation for Eastern educators outside of school time and even during regular school session (Sato & McLaughlin, 1992). U.S. teachers expect to be paid for every minute of professional development and not required to do anything off the clock (Sato & McLaughlin, 1992). Facilitating the time necessary to take part in Lesson Study in the U.S. was a point of needed problem solving. Volunteer programs and stipends to support Lesson Study's implementation helped.

**Viability with U.S. Professional Development Goals**

Literature regarding history and implementation of Lesson Study was addressed and understood prior to implementation of this professional development into the school and group of teachers. Once Lesson Study became a functioning method of professional development for a
group, data was gathered to dictate the worthiness of this method of professional development. Although student achievement was often the primary focus on professional development, researchers Cerbin and Kopp (2006) contended that increases in student achievement might be the least reliable data to collect. Instead, they recommended researchers focus on the goal of Lesson Study as teacher learning, arguing that there is an eventual trickle-down effect that will result in increased student learning. Researchers argued that the benefits of Lesson Study were vested in other areas of the teaching and learning process (Lewis, 2002; Chokshi & Fernandez, 2004).

The Japanese embraced broad, long-term goals when choosing to continue in the sole professional development of Lesson Study (Lewis, 2002). These long-term goals were seldom the perspective of policy makers or administrators held to annual data reviews that defined their competence and subsequently the competence of their teachers. Lesson Study was not the quick fix that so many on both sides of the educational fence were seeking. Lesson Study fostered a valid anticipation of the potential change of the culture of teaching and learning and the profession of teaching in the United States.

The act of the participation in Lesson Study to both observe mutually constructed lessons being taught and then to collaboratively debrief these lessons served to facilitate improvements in teachers' PCK (Dudley, 2013; Meyer, 2005). This process helped to develop improved collegiality among teachers (Taylor et al., 2005) and to elevate teacher confidence (Rock & Wilson, 2005). Along the way, a teacher-chosen change in beliefs occurred. It was this change process that produced the most meaningful and long-lasting professional development by cyclically inducing dissatisfaction with existing conceptions of science teaching and then collaboratively providing viable alternatives (Sunal, D. et al., 2001).
Most studies underscored that for Lesson Study or professional development of any kind to be effective and an agent for change, the implementation phase necessarily occurred for a minimum of one year as a regularly meeting professional development or for a single stretch of a 40 hour or more week (Gerard, Varma, Corliss, & Linn, 2011; Sopovitz & Turner, 2000). In contrast, Mutch-Jones, Puttick, and Minner (2012) used mixed methods experimental design to assess 16 middle school teams composed of a science teacher and a special education teacher divided into intervention and control groups through three cycles of Lesson Study. Most significant in their findings was that Lesson Study, supported thoroughly by determining the focus of the Lesson Study at the onset, might not take the one year plus mandatory duration to obtain significant results. Instead, they contended that a summer institute could provide professional development for effective teacher change in a condensed but authentic Lesson Study cycle.

The last detail for U.S. administrators to take to heart regarding the implementation of Lesson Study was the reality that they must be both involved and supportive of the process. Robinson, Hohepa, and Lloyd's (2009) meta-analysis found that the single most effective intervention that a school leader can make to improve standards of attainment was to become directly involved in the professional learning such as Lesson Study.

Lesson Study in Science: Physics

In interviews conducted by Lewis (2002), many Japanese teachers claimed that the innovative techniques used in their classrooms were exported from the United States. Strangely, although these research-proven effective techniques originated in U.S. model programs, they disseminated throughout a country with Lesson Study and all but died out in a country without Lesson Study.
Lesson Study served as a means of change in many sites in Japan (Fernandez, 2002; Lewis, 2000; Rock & Wilson, 2005; Saito & Sato, 2012) and now is beginning to act similarly in the U.S. (Holmqvist, 2011; Mutch-Jones, Puttick, & Minner, 2012; Perry & Lewis, 2009; Puchner & Taylor, 2006) by helping teachers move beyond critiquing their teaching to "actually seeing what is of value in this teaching to them as learners" (Fernandez, 2002, p. 400). Lesson Study shifts the role of the teacher from performer on the stage to facilitator in an active learning classroom. In practice, Lesson Study opened doors to critique instruction (not instructor) in the physics classroom that might otherwise have never been broached.

Lesson Study forced a change in the traditional habits of isolation of the physics teacher. Chokshi and Fernandez (2004) contended that the collaborative nature of Lesson Study allowed U.S. teachers to enrich and strengthen each other both in pedagogy and content knowledge. Lesson Study served to teach both scientists how to teach best and teachers, lacking content knowledge, how best to understand the science (Chokshi & Fernandez, 2004). Content knowledge was learned in an embedded context during the Lesson Study process (Chokshi & Fernandez, 2004).

To date, little professional development has better-equipped physics teachers to improve their teaching, but research by Chokshi and Fernandez (2004) showed that the effects of intensive work on just a few lessons through Lesson Study was quite far-reaching in improving teacher practice. Supovitz & Turner (2000) acknowledged that the science education reform movement emphasized the importance of professional development as a venue to elevate student science achievement. Physics teachers used their enthusiasm and shared with like minds to establish learning of true physics conceptions through Lesson Study.
Physics Misconceptions

To sculpt Lesson Study for the physics classroom, the author contends that one research-based focus, student physics misconceptions, be defined for participants. Research on student misconceptions was provided for participants and became the topic of both initial and ongoing meeting focus to provide the framework for each lesson product during Lesson Study. To maximize the learning by physics teachers in the process of Lesson Study, the goal of Lesson Study was undergirded by research. Specifically, the chosen goal for this Lesson Study of physics teachers was that of physics students' misconceptions pertaining to the motion of objects. These misconceptions tended to be significantly obstinate to change, pervasive in the student population, and consistent internationally (Kim et al., 2007; Thornton, & Sokoloff, 1998; Van Heuvelen, 1991; Van Hise, 1988).

Within the physics classroom, physics thinking often proves counter to traditional thought. In response, instead of accommodating these understandings, students tended to compartmentalize their understandings as classroom thoughts and regular world thoughts (Van Hise, 1988). Student misconceptions waged war in the hearts and minds of physics students, often thwarting scientific learning and obstructing the transfer of learning to life experiences. In response, teachers of physics sought to identify and combat these ill-fitted preconceptions with proven strategies.

Researching the implementation of a web-based tutorial and data-gathering tool, Kim et al. (2007) supplied a huge sample of international physics student learning and specifically student misconceptions in physics. Kim and colleagues (2007) were able to standardize understanding of student physics misconceptions as well as provided some data on specific effective strategies to defeat these misconceptions. Numerous research studies showed that
physics misconceptions were internationally experienced (Kim et al., 2007; Van Hise, 1988; Van Heuvelen, 1991) and are experienced at all levels of physics learning (Kim et al., 2007; Peters, 1982; Thornton & Sokoloff, 1995; Trowbridge & McDermott, 1980, 1981; Van Hise, 1988; Van Heuvelen, 1991). Van Hise (1988) found that in both her personal experience as a high school physics teacher in New Jersey and the teaching lives of her colleagues in the International Conference of Physics Educators in Tokyo, Japan, students had a tendency to memorize information and regurgitate it on tests. Van Hise also found that students only applied physics concepts within the confines of the physics classroom. The researcher found that after the students left the physics classroom, 34% of college students fell back to their old common sense, non-Newtonian worldview. Research also itemized physics misconceptions as those associated with gravity (Van Hise, 1988), Newton's Laws (Hestenes, 1997; Thornton & Sokoloff, 1995), velocity (Trowbridge & McDermott, 1980), acceleration (Trowbridge & McDermott, 1981), mechanics (Clement, 1982; Hestenes, 1997; Van Hise, 1988), and electricity and magnetism (Hestenes, 1997).

Students were shown to develop in a Piagetian fashion through four stages of physics thinking. Along the way, many misconceptions formed and persisted, even in the face of substantial evidence to their contrary. The fourth stage that equated to formal operations began in most children around eleventh grade. At this stage, some children began to correlate new physics concepts correctly to real world happenings. Many students, however, in Japan, England, Israel, and New Jersey experienced misconceptions that arose early and persisted throughout and long after a high school or college physics class (Van Hise, 1988).
Gap in the Research

All studies were short-term in nature except the Bay Area City School study that was midrange (Perry & Lewis, 2009). Lesson Study had to be taught and learned before consistent successful implementation had the opportunity to result in measurable gains in student achievement; thus, longitudinal studies were greatly needed. Most data were qualitative in nature with little attempt at triangulation. Although narrative type data were useful for judging practitioner perceptions, administration and district managers demand quantitative data in student achievement to sustain funding (Perry & Lewis, 2009).

Out of the three Lesson Study research studies reviewed, sample sizes were small and midsized for a teacher sample (Rock & Wilson, 2005; Fernandez, 2002). It should be noted, however, that large sample sizes with teachers instead of students are often distance and cost prohibitive. Although much research on Lesson Study was conducted in Japan, this research was culturally specific and not generalizable to the U.S.

No existing peer reviewed studies were found highlighting the use of Lesson Study as a form of collaborative, teacher-led professional development with high school physics teachers. Results from the Perry and Lewis (2009) and Rock and Wilson (2005) study pointed to the fact that teacher-initiated professional development served to illicit significant professional growth in many other groupings of teachers. One experience was that of a grant-funded Lesson Study with a focus on *Physics First* curriculum implementation that took place in Missouri designed to foster implementation of physics curriculum into the freshman high school classrooms of Missouri (Volkmann, 2007). This push for a sequence change spear-headed by Leon M. Lederman placed physics before biology or chemistry in science course order (Chandrasekhar, 2007). A few reports detailing meetings and feelings regarding this three-year occurrence of
Lesson Study were reported in the *A Time for Physics First* newsletter (Chandrasekhar, 2007; Volkmann, 2007; West & Volkmann; 2008). No peer-reviewed articles or research on these Lesson Studies were published to date. Chandrasekhar (2007) explained “the project’s immediate (3-year) goal is the design and implementation of a professional development curriculum resulting in a yearlong physics course in 9th grade classrooms (Physics First)” (p. 1). The focus was on the lesson and perfecting the lesson, not on the student learning (Volkmann, 2007). Physics First participants selected a pre-written lesson from the curriculum, revised it, taught it, discussed it, and revised it again. The Research Lesson was modified for teachers to teach standard lessons within their own classroom as the sole teacher present; then they debriefed with detailed narrative of the experience and their reflection on the experience within a focus group during the Lesson Study meeting (Chandrasekhar, 2007). This goal of Lesson Study was unique and considerably different from the student learning and teacher learning goals of traditional Lesson Study as seen in the literature (Rock & Wilson, 2005; Stigler & Hiebert, 1999; Supovitz & Turner, 2000).

To date, Lesson Study in the U.S. is lacking a strong foundation of research to define it as an effective professional development method for teachers; however, theoretically, Lesson Study meets all suggested criteria as delineated in teacher professional development research pointed at reform in U.S. education (Rock & Wilson, 2005). More specifically, Supovitz and Turner (2000) argued that the application of Lesson Study as a scientifically supported method of professional development holds promise as an instrument of change to the teaching and learning of science in U.S. public schools.
Summary

Japanese teachers consistently credited the implementation of Lesson Study as the key to individual, school-wide, and national improvement in the teaching profession (Lewis, 2000). Stigler and Hiebert (1999) further contended that variations in teaching methods across cultures were significant. These two facts, coupled, point to the conclusion that teaching implied student learning. The process of ongoing learning by teachers through collaborative, teacher-initiated professional development served both to professionalize their career and to ignite the teaching and learning processes of all of the learners in the learning community of the school.

Research from the venues of teacher learning, professional development, and Professional Learning Communities pointed to the likelihood that Lesson Study was a viable option for extensive teacher and, subsequently, student learning in a cohort of U.S. physics teachers (Perry & Lewis, 2009). Moreover, in reflection of the research which explained the characteristics of teachers and the barriers which they experienced to their learning, Lesson Study was a possible means to transform the teaching and learning within and among U.S. physics teachers through this collaborative model.

With no research to date specifically attempting and studying the professional development implementation of Lesson Study with a Professional Learning Community of high school physics teachers, a significant gap in knowledge existed. In response to much research internationally and to new and slowly accumulating positive and powerful research in the U.S., Lesson Study had the propensity to meet the many needs of these educators as well as their administrators and the stakeholders in their educational communities. As one U.S. participant shared, after being involved in Lesson Study, she developed a sense of connection that led her to
see colleagues' students as "our students," emphasizing Lesson Study as truly transformative for a community of learning culture within a school (Lewis, 2002, p. 13).
CHAPTER 3

METHODOLOGY

Introduction

In an effort to meet the needs of professional development for two groups of secondary physics teachers, Lesson Study was implemented. This Japanese form of professional development focused on collaborative learning among teachers to perpetuate ongoing learning in the area of both pedagogical content knowledge and subject-specific knowledge. Lesson Study served to refocus professional development on student learning, thereby revealing to the teachers changes they could make to enhance learning in the classroom. Physics teachers needed opportunities to be exposed to physics learning research and to collaboratively improve all types of their teacher knowledge. To vitalize teaching and learning in the physics classroom, teachers utilized Lesson Study, cultivating methods of transforming physics students’ misconceptions.

The phenomenological case study purpose was to explore the implementation of the teacher-initiated professional development of Lesson Study within two groupings of five high school physics teachers’ PLCs, at two different high schools, in a large suburban school system in the southeastern United States. The overarching question, framing the research study was “What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity?” The sub-questions were “How do teachers engage individually and in groups during the Lesson Study process?” and “What are the teacher-reported responses to Lesson Study as a professional development opportunity?”
Within the context of this phenomenological case study on the implementation of Lesson Study, two five-person cohorts of physics teachers were studied through teacher interviews, focus group discussions, field notes, written anecdotes, and journal entries. Qualitative data was obtained through quantitative surveys. Then, in an ongoing emergent design, data was analyzed according to Saldana’s (2013) two cycle approach to coding to include holistic coding, in vivo coding, and other emergent coding strategies to identify themes of understanding in data gathered in light of the research questions.

Methodology

This research was a qualitative study. As Creswell (2013) delineated, qualitative research uses an emerging approach to inquiry and data collection in a natural setting that is sensitive to both the people and places studied. This study granted the researcher the opportunity to explore the professional development of Lesson Study in a group of high school physics teachers to establish a complex, detailed understanding of their experience. Creswell (2013) further instructed qualitative data is to be both inductive and deductive to establish patterns that are deemed as themes. Finally, Guba and Lincoln (1994) designated the researcher as a reflexive participant in the study, actively giving voice to the participants through a thorough and complex description and interpretation.

Specific characteristics native to this study included the placement in a natural setting, the researcher as a key instrument, multiple methods, complex reasoning through both deductive and inductive logic, presenting participants’ meaning, emergent design (Guba & Lincoln, 1994), and a holistic account of the problem being studied (Creswell, 2013). This study took place in the natural setting of the respective participants’ schools which doubled as the place to facilitate the business of teaching and learning. The researcher served to both create the tools needed to
gather data and to be the guide for data acquisition. She used original instruments to collect data, drawing from multiple forms of data collection. The researcher’s reasoning served to establish patterns which became themes. These complex thought processes revealed the participants’ various meanings and viewpoints regarding the study.

As a qualitatively designed study, research was emergent in that, as Guba and Lincoln (1994) explained, it could not be closely prescribed. Numerous modifications occurred in response to data gathering and a need for exploring in different ways. These changes included changes in forms of data collection, participants in data collection, interview questions, and locations of data collection. Reflexivity allowed the researcher to be positioned within the research study as a participant-researcher (Guba & Lincoln, 1994). The background of the researcher informed the study, and the researcher revealed her personal stake in the study. Overall, in an effort to sketch the larger picture that emerged from the research, the researcher merged multiple perspectives to give a holistic account of the study.

Methods

This study was a phenomenological case study. In an effort to better understand the participants of the physics teacher professional development using Lesson Study, the researcher searched for the common meaning of their lived experiences (Creswell, 2013). In studying the phenomenon of Lesson Study, the researcher collected data from those who experienced this process of professional development from the perspective of those participants. In response to these sources of data, the researcher proposed to “develop a composite description of the essence of the experience for all of the individuals” (Creswell, 2013, p. 76).

It was the researcher’s intention to adhere to Husserl’s epoché by making no judgments as to what was real prior to reality being firmly founded on experience within the research
process, embracing an “intentionality of consciousness” directing consciousness toward an object, not independent of itself (Creswell, 2013, p. 77). In this hermeneutic phenomenological study, the researcher strove to interpret the data, not merely to describe it as in transcendental phenomenology coupling and interpreting through the culture to more completely understand the experience (Van Manen, 2011b).

**Special Population**

The populations of teachers investigated were all science teachers who taught physics in the same district in a southeastern state. The sample examined consisted of two groups of teachers of physics from each of two high schools in a large southeastern school district serving more than 150,000 students. Within this system, there were over 20 high schools, most with 2000-3000 students. Within these high schools, approximately 100-150 secondary science teachers taught at least one class of physics daily. All were certified to teach some content of science. Few were specifically physics certified, having passed a content-specific and physics-exclusive competency test. Most were broad-field certified or had passed a content test showing proficiency at a cursory level in many areas of science to include physical, earth science, and biology. Each broad-field certified teacher had a broad general understanding of all types of science as reflected by the state certification test. This most prevalent certification served to certify teachers who have little significant coursework in physics for teaching all science courses, including physics.

**Current Science Professional Development**

In the study sites within the school system, professional development, as a rule, was geared toward those outside of specialized scientific fields of teaching; it was generalized. This generalized professional development provided a cost-effective method of bringing in a single
consultant to reach as many educators as possible. In practice, this strategy often only targeted peripheral needs of teachers by introducing them to a new teaching or assessment tool that transcended all content areas. Most of these professional development opportunities, therefore, lacked the specificity to meet the needs of any type of science teacher. As Wei, Darling-Hammond, & Researchers contended, in-service training is the least effective source of learning for teachers (Adamson, 2010; Howey and Joyce, 1978; McLaughlin & March, 1978; Supovitz & Turner, 2000; Wood and Thompson, 1980).

Due to lack of specialization, physics teachers perceived a mismatch between their needs and the provisions of the professional development. Few administratively assigned professional development opportunities were embraced or valued by high school physics teachers. Consequently, few of these professional development opportunities were relevant or implemented by physics teachers (Supovitz & Turner, 2000).

Other non-mandated professional development did exist. Voluntary professional development opportunities were often supported by stipends. These opportunities included content exposure for Advanced Placement (AP) level teachers and supportive pairing for new physics teachers across the school system, in an effort to connect mentors to mentees. To the date of this research initiation, no misconception-focused or pedagogical content knowledge-focused professional development was designed and offered either voluntarily or mandatorily for this target population of physics teachers.

Because this school system was one of the larger school systems in the U.S., and every graduating senior was required to successfully complete physics, the needed number of physics teachers was disproportionately higher than the remainder of the country. To fill positions, many teachers were asked to teach outside their expertise. For example, many teachers trained to teach
in other fields such as biology or chemistry took the broad-field certification test and in turn taught physics (White & Tyler, 2015). Statistics from American Institute of Physics showed that over 40% of physics teachers had specialized in another academic field, primarily math, chemistry, or biology (White & Tyler, 2015). In areas where more physics teachers per capita were mandated, out of field placement was higher (White & Tyler, 2008). Other physics teacher positions were filled by professionals in science or engineering who took the broad-field or other content certification test with no science-specific or general pedagogical training.

Specific to this school system was a need to infuse the high school physics teacher with both solid content and solid best practice for teaching students. Professional development for physics teachers specifically was limited and non-specific. Moreover, the modality used for delivery placed teachers in an artificial microcosm of learning as a student, merely receiving information (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009).

Outside of specialized populations, no support on a county or school-wide level existed to build on teacher experience collaboratively and to enrich physics teaching. A limited online platform existed which served as a resource to formalize better curriculum with examples, to provide a curricular calendar, to vertically align with other grade levels, and to provide a skeletal grouping of activities. This teacher-only website, however, was primarily targeted for K-8 science content and, although a valid resource, failed to provide interactive support for physics teachers to refine either content or pedagogical content knowledge. It served merely as a holding tank for detailed standards and sample assessment questions.

**Current State of Professional Learning Community**

Trumpeted as a viable means of collaboration and professional development (Hughes, & Kritsonis, 2007; Johnson, 2011; Lee & Shaari, 2012), Professional Learning Communities (PLC)
sprang up in public schools. Content-area PLCs were meeting across most secondary schools one or more times per month. The degree of buy-in and general functionality varied widely throughout the county and throughout physics as a content area. Nevertheless, the PLCs for physics teachers at high schools within this county were incubating and growing. They specifically became highly functional collaborative units, focusing on common assessment and common teaching methods for best practice. With the limited time of approximately half an hour once or twice per month to meet within PLC, collaboration and professional support were ongoing. Many teachers’ learning needs were still unmet. PLC members continued to need specific clarification of understandings, solving problems toward best practice and student learning, targeted teaching to transform student misconceptions, and the opportunity to view each other’s teaching.

**Productive Method of Professional Development**

Lesson Study was employed as a productive method of professional development for teachers in other settings (Fernandez, 2002; Lewis, 2000; Perry & Lewis, 2009; Rock & Wilson, 2005; Sato & McLaughlin, 1992). This professional development strategy began in and continues to dominate Japanese school systems (Lewis, 2000; Sato & McLaughlin, 1992). After the Third International Mathematics and Science Study (TIMSS) ("TIMSS 1995 Home") and the publication of the international comparisons in math and science, U.S. teachers and educational stakeholders were inspired to implement Lesson Study in their school systems. In practice, Lesson Study used teacher collaboration to structure model lessons that were then taught in one classroom. The act of teaching these lessons and the learning associated with them by both teachers and students, were then studied through professional development.
Population and Sample

Adult Participants

The participants were selected in the fall of 2016 in response to the published teaching schedule for the school year. After inviting teachers to participate through an email sent to their department chairs in four district high schools (Appendix E), two high schools with a large physics teacher population were selected. Then, a maximum of five physics teachers from each high school were invited. A total of five physics teachers responded with interest and commitment. Two were from one high school Professional Learning Community (PLC) and three were from another high school PLC. These two groups were merged to become one cohort. Each teacher invited to participate in the Lesson Study professional development was required to teach a minimum of one section of honors level physics.

The district science department funded the Lesson Study professional development for the five physics teachers. Per budget (Appendix F), each teacher was provided with a stipend of $405 to participate in the Lesson Study. The stipend served to solicit buy-in from the teachers regarding both their professional growth and their attentive participation in the process for the fifteen hours that were spent on the Lesson Study process outside of contract hours.

After the participants were selected based on physics teaching criteria, they were required to attend a meeting to explain the Lesson Study process and the research plan, each committed to see the professional development through to the end of the cycle, and were designated as participants for the purpose of this study. Participants were then surveyed to obtain general teaching experience, educational experience, and physics experience demographics. Demographics, as illustrated in Table 1, were collated, summarized, and displayed in a completed Table 6 in chapter four. Each teacher was given a random pseudonym.
Each teacher’s contracted work day consisted of eight hours of teaching, planning, or duty such as cafeteria patrol or bus lane supervision. The actual time on campus before or after school increased the time commitment considerably from teacher to teacher. At each school, the day was divided into seven 53 minute periods which were taught from 7:10 am to 2:10 pm with approximately 6.5 minutes between each class. Each teacher taught five content classes, had one period for lunch and tutoring or advising commitments, and utilized one period for planning.

Weekly, each teacher had one half-hour mandatory professional development meeting scheduled after school on a set day of the week. Although this was the term used, many meetings did not meet the definition of professional development. Professional development meeting time blocks were often used for monthly faculty meetings. Although occasionally guest speakers who focused on teaching were invited, more often than not, meetings were used to disseminate information and temper morale. One professional development day per month was designated as a department meeting, again generally to disseminate logistic information as all science teachers were briefed by the Department Chair on upcoming assessments and protocols.

Table 1

*Education Levels and History of Adult Participants Format*

<table>
<thead>
<tr>
<th>Adult Participants</th>
<th>Years’ Experience</th>
<th>Educational Level</th>
<th>Educational History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clyde</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Julia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rodney</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warren</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
as mandated by the county or administration. Finally, two days per month were designated as professional development in the area of content and, in this case, physics.

In content meetings, physics teachers participated in a professional learning community to discuss how best to teach physics to their students. Many of these meetings involved analysis and planning in response to test data. Teachers also discussed the county curricular calendar and scheduled internal content-focused activities. Teachers had small windows of opportunity to discuss what they found worked best in teaching students the upcoming concepts and what did not work well in teaching students past concepts.

The atmosphere of meetings was casual and primarily focused on physics teaching. The time window was adhered to strictly, as teachers arriving on time and finishing on time were an accepted norm of the PLC functionality. Generally, teachers worked well together as the teachers within their PLC group were mostly static within the science department, and comradery had developed over time.

In the midst of teachers honoring the process of Lesson Study as they gathered data regarding the teaching and the learning of their students, the researcher gathered data on teacher-learning. Timeframe and the instruments used are detailed in Table 2.
Table 2

*Data Collection Instruments and Timeframe*

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Instrument(s)</th>
<th>Week(s)</th>
<th>Type of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity?</td>
<td>Stimulated Recall Notes, Member Checks, Meeting Notes, Field Notes, Teacher Journals, Investigator’s Journal, Teacher Interviews</td>
<td>1 – 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - 16</td>
<td>Qualitative</td>
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<td></td>
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<td>1 - 16</td>
<td>Qualitative</td>
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<td></td>
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<td>1 - 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 &amp; 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td>a. How do teachers engage individually and in groups during the Lesson Study process?</td>
<td>Stimulated Recall Notes, Member Checks, Meeting Notes, Field Notes, Teacher Journals, Investigator’s Journal, Teacher Interviews</td>
<td>1 – 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - 16</td>
<td>Qualitative</td>
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<td></td>
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<td>1 - 16</td>
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<td></td>
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<td>1 - 16</td>
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<td></td>
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<td>1 - 16</td>
<td>Qualitative</td>
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<tr>
<td></td>
<td></td>
<td>1 &amp; 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td>b. What are the teacher-reported responses to Lesson Study as a professional development opportunity?</td>
<td>Stimulated Recall Notes, Member Checks, Meeting Notes, Field Notes, Teacher Journals, Investigator’s Journal, Teacher Interviews</td>
<td>1 – 16</td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - 16</td>
<td>Qualitative</td>
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<td>1 - 16</td>
<td>Qualitative</td>
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<td></td>
<td></td>
<td>1 &amp; 16</td>
<td>Qualitative</td>
</tr>
</tbody>
</table>

The Lesson Study Cycle was scheduled and performed by participants directly linked to the current curricular calendar. Some flexibility for Research Lesson, the created and taught lesson for observation and study, was originally afforded based on the topic chosen by the participants and appropriate placement of that topic in the content schedule. Table 3 served to explain the Lesson Study Cycle schedule as suggested by the researcher for two cohorts of participants directly linked to the current curricular calendar. In application for the combined
PLCs, participants chose path one for their schedule. Some flexibility for Research Lesson, the created and taught lesson for observation and study, was afforded based on the topic chosen by the participants and appropriate placement of that topic in the content schedule.

Table 3

*Master Lesson Study Schedule*

<table>
<thead>
<tr>
<th>Topic</th>
<th>Week</th>
<th>Cohort Schedule 1</th>
<th>Cohort Schedule 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics 1D</td>
<td>1</td>
<td>Mtg: What is Lesson Study Protocol for your PLC?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Mtg 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Mtg 2</td>
<td>Mtg: What is Lesson Study Protocol for your PLC?</td>
</tr>
<tr>
<td>Kinematics 2D</td>
<td>4</td>
<td>Mtg 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Research Lesson 1</td>
<td>Mtg 1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>Mtg 2</td>
</tr>
<tr>
<td>Newton’s Laws</td>
<td>7</td>
<td>Mtg 1</td>
<td>Mtg 3</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Mtg 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Mtg 3</td>
<td></td>
</tr>
<tr>
<td>Forces</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Research Lesson 2</td>
<td>Mtg 1</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td>Mtg 2</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Interviews</td>
<td>Mtg 3</td>
</tr>
<tr>
<td>Energy/Power/Work</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impulse/Momentum</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Student Population**

In this suburban community, students were zoned to attend a specific high school by living in the district. Students predominantly ranged from age 15 to 18, with a 2015 population of well over 2000 in each high school. The total minority enrollment was 51%, and 35% were classified as economically disadvantaged ("US News and World Reports: Education," n.d.). The specific students involved in this study consisted of approximately 95% eleventh-grade students and 5% twelfth-grade students. Most of the senior students within the high school had
unsuccessfully taken physics as eleventh graders the year prior or had transferred from another school system. Each student in the study was enrolled in an honors level physics class. Other levels taught at the high schools included a lower level of college preparatory physics, Advanced Placement (AP) Physics 1 and 2, and Advanced Placement (AP) Physics C.

**School Demographics**

Each of the two high schools employed more than 100 full-time teachers with over 15 full-time science teachers. The schools further employed eight to ten administrators to include one principal, assistant principals, and two community school directors. Each school employed support staff of nearly 50 clericals, cafeteria, and custodial workers. Each school building was generally considered to be in excellent condition, with capacity at approximately 3000. The campuses had many features: e.g. a media center, commons area, two gyms, athletic fields, and field house.

**U.S. Lesson Study Variation**

In Japan, teachers are expected to work many more hours in the day than U.S. teachers. Their professional development through Lesson Study is a cultural requirement. Moreover, the Japanese culture is one of ingrained problem solving within and between teachers to meet the needs of the whole child (Lewis, 2000, 2002; Lewis et al., 2006). In the U.S., teachers are motivated primarily, if not exclusively, to build student academics. U.S. teachers work eight hour days, traditionally, and then go home to their own families and responsibilities. In order to bridge the cultural gap, the researcher secured a teacher stipend for participants’ extra hours outside of contracted time. A different focus, away from the *whole child* and onto physics misconceptions, was provided to participants. This focus provided a springboard for discussion and lesson writing in the form of physics teacher research literature. Participants were instructed
in Lesson Study protocol to insure that the focus on the lesson and student learning was maintained throughout the process, instead of the practice of critiquing other teachers.

**Positionality Statement**

The researcher was teaching physics in the district in question for six years. During that time, she was involved with realigning the standards for the district, writing and editing county assessments, authoring guiding documents for new physics teachers to the district, as well as teaching professional development courses in physics for other teachers.

The researcher was studying and researching Lesson Study for four years. During that time, she was mentored by an expert professor in Lesson Study who served as a collaborator throughout the Lesson Study implementation and during data analysis.

**Data Collection**

**Phase One**

At an initial meeting, Lesson Study was introduced to all participant teachers. Participants received literature explaining the history, process, and current usage of Lesson Study, as well as literature on physics misconceptions. The following week, an initial meeting was conducted. In this meeting, summaries and discussions of the literature occurred. Also, questions about timeframe and process specific to the implementation of Lesson Study within the specific school were discussed. All needed confidentiality and permission documents were signed and collected per Internal Review Board (IRB) mandates. Permission to gather research in the form of video-taped lessons being taught as well as subsequent discussion audio recordings and transcriptions and journals were attained by securing signatures on the Informed Consent for a Non-Medical Study form (Appendix C). This phase occurred during the first week of the school year.
Phase Two

During the second meeting, the participant researcher (PR) discussed in detail the process of Lesson Study and the expectations for participants in the research. Journals were distributed to participants as Google Docs, but physical notebooks were also offered, in case participants wished to handwrite their entries. All participants participated in an individual initial survey of experience (Appendix D).

Phase Three

During this phase, teachers met two or three times to design a lesson per Lesson Study protocols. A topic was selected, specific research was gathered, and a consensus was reached. The PR recorded all audio with two recording sources. The PR guided the inquiry process, as needed, toward the goal of the Research Lesson. A Research Lesson was written. A teacher was selected to present the Research Lesson at a scheduled date and time. All other participants scheduled time to observe the Research Lesson. Principals and other administrators were invited.

Phase Four

The selected teacher presented the lesson. All participants attended and focused on the observation of student learning. Participants took field notes and interacted with students minimally so as not to interfere with learning. After the lesson, all participants were given an individual hour to journal and debrief their experience. Lived Experience Descriptions (LED) were entered into the journals of participants allowing them to reflect on the experience of the Research Lesson taught and the interactions with students. Later that same day, all participants met during a working lunch and after to discuss the learning that occurred. In response to student reactions, learning, or lack of learning throughout the lesson, suggestions to amend the
lesson were made. Stimulated Recall (SR) using video excerpts were intended to be used in order to refresh the memories of the experience and springboard discussion. After viewing the video, participants agreed that student thinking was best revealed and SR best functioned using observation notes instead. Using these observation notes as SR, the group edited the lesson. Next, participants discussed central ideas regarding lessons and the order with which they should be taught. Participants confirmed a date to reteach the Research Lesson. This reteaching of the lesson was conducted by another teacher at another school. The second teaching was in response to easily modifiable edits. This lesson was witnessed only be the PR and one other participant observer. Both the PR and participant observer took notes. The PR summarized these notes and emailed the summaries to participants for review and reflection in their journal. This Lesson Study Cycle was repeated twice during the semester.

**Phase Five**

A week following the final Lesson Study debriefing, PR conducted closing surveys and interviews. PR compiled the data, coded the data, and established themes in the data related to the research questions. After establishing themes, the researcher virtually met with participants by sending all findings specific to each participant to that participant via email. In this way, member checks were conducted to confirm participant agreement that the themes truly reflected their experience. Member checks further clarified PR understandings in order to best reflect the experience of the participants.

**Data Collection Tools and Procedures**

**Preliminary**

Prior to implementation of the Lesson Study professional development, baseline data regarding teacher experience in teaching, physics content, and teaching physics were established
through survey. Thorough instruction on the entity and process of Lesson Study was given to PLC members in the initial meeting. Research and discussion were used to generate adequate understanding about student misconceptions in physics specific to kinematics. To facilitate this, the researcher provided the participants with literature on student learning and misconceptions relevant to the calendar-determined and participant-selected topic for lesson study focus. At the second meeting, after cohorts had reviewed the literature on their own, a discussion on learning was led by researcher to springboard the lesson creation. At the second meeting’s conclusion, the Research Lesson topic and date were scheduled as delineated in the Lesson Study Protocol below.

**Interviews and Focus Groups**

Protocol, consisting primarily of a survey in the study, was used to obtain background data (Appendix D). Guiding questions served as a foundation for interviewing (Appendix G), yet questioning criteria was open-ended and flexible to best respond to and facilitate participants’ elaborations. Phenomenological interviews needed not be standardized (Vagle, 2014), therefore, flexibility was paramount and easily led to interview questions that were open-ended and in direct response to the participant’s desires and opinions. More directing questions were used as needed when the researcher required clarification of participants’ explanations. The researcher then recorded the interviews, both questions and answers, with a duplicating audio recording system consisting of two independent recording devices. One served as a redundant device to the other to guard against unexpected technical mishaps. The interviews were then transcribed into a double-spaced, two column format to best code and organize codes.

Focus groups function as group interviews throughout the meetings with participants. With the researcher serving as a moderator, participants investigated and collaboratively shared
information with a motivation of generating new ideas (Stringer, 2004). According to Stringer, focus groups are ideally composed of four to six participants and should be acutely focused on an agenda, allowing plenty of time and opportunity to address the topic or questions at hand. Lesson Study planning meetings functioned as focus groups in that they elicited deeper and more detailed explanations and insight into teacher understandings.

**Written Anecdotes**

Vagle (2014) argues that phenomenological case studies are well served when participants are encouraged to write about their experience as a method to make meaning of the experience. Participants were encouraged to use van Manen’s (2007) protocol of Lived Experience Descriptions (LED). Van Manen suggested using LED to reflect on an experience such as a lesson taught or an interaction with a student. This reflection was written in an unrestrained narrative style into journal, chronologically stating the scenario factually and descriptively, using all helpful senses to create the happening (Vagle, 2014). Participants were asked to keep a journal of LED and reflections to the LED. This journal was unanimously chosen as a digital platform on Google Docs and served as a springboard to discussions and modifications of the lesson per the Lesson Study protocol.

**Stimulated Recall (SR)**

In addition to using LED to refresh the memories of experiences and springboard discussion, video clips were originally anticipated to be selected by the researcher to be viewed by participants to focus discussion and problem-solving. Formal lesson instruction of Research Lessons was video-taped. These videos did not adequately portray student learning and were unanimously elected not to be used for this purpose. Instead, teacher participant observation notes served as a recollecting tool.
During SR, participants reflected based on the provision of the extensive retrieval provided by the observation notes (Meade & McMeniman, 1992). Stimulated recall was successful, for it recognized and benefited from the fact that humans store vast amounts of sensory information, as well as the emotional impetus in connection with impressions and ideas in which they have participated (Steeples, 2004). According to Steeples (2004), human interactions occur so rapidly that details of these events are often lost to memory without the video reminder. Moreover, Steeples (2004) noted that SR was ideal for teachers in the context of education and studying their classroom practice. The multiple observer notes proved beneficial in recreating this SR experience with individual students’ learning instead of the overall teaching performed as recorded on video.

**Member Checking**

Member checking was instituted periodically to ensure credibility in the project. This process involved open publication in written form or verbally of the current takeaway understandings of the research. In response, members served to confirm or refine the understandings. Member checking assured that the members' opinions and experiences were truthfully represented at all times and especially at the close of the research study (Stringer, 2004). A final email correspondence with itemized understandings from each participant served to clarify the final member check.

**Recording: Note-taking**

Written accounts from meetings or field notes served as data as needed to substantiate happenings or underscore and define new understandings. In fieldwork, notes were used when they made sense to the phenomenon (Vagle, 2014); therefore, field notes were helpful to
document happenings or emergent meaning. Field notes came in many forms and included descriptions, direct quotations, and observer comments.

**The Treatment: Lesson Study Implementation**

The process of Lesson Study was both well established for the Japanese version and adapted for the much less established U.S. version. The protocol for research was an adaptation of the Japanese version using modifications that were drawn from both U.S. research and sample data particular to the study population. Unlike in the Japanese version of Lesson Study, research began with a defined focus on student misconceptions in physics instead of a county or general science principle goal.

The cycle of Lesson Study took place in six steps as seen in Figure 1. First, participants consulted the curricular calendar and chose a topic for Lesson Study. Second, participants were directed to consult the Common Misconceptions List (Appendix H) to identify physics misconceptions specific for that topic. The researcher then gathered appropriate literature from a list of misconception and best practice to combat the misconception literature (Appendix I) and disseminated it to participants. Participants then read this literature at their leisure and took notes in their journal prior to the following group meeting. Third, a group follow-up meeting was conducted to create the Research Lesson to be taught. During this meeting, the teacher to teach the group lesson was selected, the date of teaching established, and all relevant parties such as administrators and other teachers invited. The subsequent re-teaching teacher and date were established during the third meeting when the original Research Lesson was scheduled. During this timeframe, paperwork was filled out and permission granted to have substitute coverage for all participants to attend their cohort’s Research Lesson.
At the day and time selected, the designated teacher taught the Research Lesson, and the other participants observed. Prior to the start of the Research Lesson, all visitors were informed of protocol for observing students’ learning not the teaching of the teacher. The lesson was taught in one teacher’s classroom. At this time, the lesson was videoed, and numerous educators (i.e. observers) were present, including each research participant. All participants and guests circulated and monitored the learning and thinking of the students.

Immediately following the teaching episode, a half-hour block of time was given to each participant to use for reflection through Lived Experience Descriptions in their journal. Many also used this time as discussion and clarification of what they had observed with fellow participants. Shortly afterwards, all participants met to debrief and restructure the Research Lesson. All participants met together for roughly two hours. One participant was designated as the editor of the Research Lesson in response to the direction of the group. LED in the form of field notes served as support for analysis of student learning to fuel the discussion and debriefing after the Research Lesson was taught. Journals were collected for a journal check at the completion of the cycle in order to provide accountability for journaling. After edits were made and new insights gained, the new version of the Research Lesson was discussed in anticipation of the second teaching. The new understandings gained from this cycle fueled another Lesson Study Cycle. Reflections were further recorded in detail in the journal. Each of the Research Lessons subsequently become a staple lesson anticipated to be used for the school for years to come.
Research Instruments

Qualitative data collection took place through field notes, journals, interviews, and member checks. Interviews were conducted concluding the Lesson Study cycle. Videotapes were made of each teacher teaching the Research Lesson. Videos were subsequently played in a significantly truncated version as a tool for the initial SR and then not used thereafter in response to the lack of value. Instead, field notes served as a recollecting tool, not as a means to quantify data. The researcher obtained frequent member checks from each participating member to clarify teacher understandings and to better interpret the reality of the participants’ experience. Moreover, the researcher used these member checks to discover teacher concerns and perceptions that may have been missed during the coding of the data. Member checks facilitated collaboration to gain insight into the experience of the participants. Field notes in the form of
written conversations and documents from meetings, as well as classroom observations from Research Lessons added to the array of data. Other field sources included lesson plans, lesson revisions, summaries, and student misconception pretest data. Each of these was analyzed to construct better understanding of the experience.

This cycle of Lesson Study occurred in both cohorts as illustrated in Figure 2.

Figure 2. Lesson Study Cycle within cohort. This figure illustrates the detailed implementation of the Lesson Study Cycle within the PLC of physics teacher participants.

Ethical Issues

The principal at each high school, as well as the county science director, approved the project, and the Internal Review Board at both the research university and the school district approved the research project. Next, the principal and the science department chair at each
respective high school agreed to the participation of teacher members in both the Lesson Study process and the research regarding this process.

Due to the participant-researcher involvement in the study and relationships with participants, bias may have emerged in places (Vagle, 2014). Nevertheless, the researcher took all possible precautions to preserve the fidelity of the gathered information and the ethical interpretation of that data, in order to minimize study bias. These efforts included data collection through non-confrontational journal writing, video-taping to help facilitate field notes in a non-pressured atmosphere, and triangulation using member checks to confirm and refine understandings.

In an effort to maintain the confidentiality of the data, all data was stored under two locks and key in the researcher’s classroom. It was then transported in such a manner as to reasonably ensure confidentiality of the data, and the confidentiality and anonymity of the subjects (both adults and children) to the researcher’s home for coding and reporting data. Ethical issues of human treatment during research were adhered to strictly. These included but were not limited to taking all reasonable steps to avoid harming participants and minimizing the possibility that results were misleading.

Data Analysis

Vagle (2014) contended that data collection and analysis were simultaneous processes in qualitative research. Merriam (1998), and Marshall and Rossman (1989) claimed qualitative data analysis involves classifying subjects with the properties that characterize them. A process of classification through codification served to honor emergent design and bring forth understandings. To classify the information and realities obtained from the participants, multiple
levels of coding and organizing were employed. These included three levels of coding. Much detail to this process is delineated in Chapter Four.

Overall, multi-level process insured adequate data analysis to delineate themes, prevalence of themes, and meaning derived from themes through the lens of the research questions. First, several general readings of the data were used to perform holistic coding. Key words and synonyms were color coded throughout the manuscript. These codes were then grouped according to cohesiveness and given an over-arching category title. The process produced numerous general themes that occurred and often reoccurred throughout teacher interviews, group discussions, field notes, and journal entries. All codes that were not featured three or more times were addressed individually to see if they closely corresponded to another working subcategory.

Second, in vivo coding was performed to support emergent themes with specific strong evidence from participants’ experiences in participants’ words. The researcher also used Discourse Analysis approach in order to best communicate dialogue that supported the emergent themes. Third, the themes with their supports were categorized appropriately into clusters or groups with one overarchin g theme category. Lastly, overarching themes were aligned with the research question to which they provided further insight.

After the data was coded and categorized, the researcher obtained new understanding of the study through reflection. Then, in reflection of the new understandings obtained through the data organized using coding methods, the researcher refined categories which fostered themes of the participants’ experience. The researcher then wrote a rich and exhaustive description of the lived experiences of the participants. The essential structure of the phenomena was formulated by logically ordering the themes and then the subcategories. Lastly, description was presented to
participants for comments and redirection in the form of periodic member checks; used to test the validity and to clarify the researcher’s interpretations.

**Summary**

This research study investigated an innovative collaborative professional development model taken from a successful Japanese precedent in professional development. Lesson Study, as professional development, was adapted for implementation into two Professional Learning Communities of high school physics teachers. The overarching question used to frame the research was “What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity?” Explicitly, sub-research questions were “How do teachers engage individually and in groups during the Lesson Study process?” and “What are the teacher-reported responses to Lesson Study as a professional development opportunity?”

The researcher examined the teacher participants’ perceptions about their classroom environment and their self-efficacy toward physics, teaching, and physics teaching. The participants consisted of two PLCs with a total of five secondary physics teachers. These teachers taught in one of two high schools within the same county in the southeastern United States. A qualitative methodology and phenomenological case study method were used. Forms of qualitative data collection were teacher interviews, group discussions, written anecdotes, participants’ journals, document analysis, and field notes. The researcher elected to view the research study through a theoretical lens in which social constructivist theory and Professional Learning Communities were bound.

When educators connect and collaboratively learn together, they synergize their profession and the learning within their community of student and teacher learners (DuFour & Eaker, 1998). By merging research-based understandings of physics misconceptions and
teaching practice, this case study serves as a hypothesis-generating experiment, not a hypothesis-testing one. This research, therefore, aimed to add to the research on professional collaboration, specifically Lesson Study in U.S. schools. Finally, this research served to assist teachers and teacher researchers in understanding the experiences of two groups of secondary physics teachers who engaged in Lesson Study as a collaborative strategy for professional development.

Research proceeded according the schedule of Table 4.

Table 4

*Brief Overview and Schedule of Events*

- In response to teaching schedules being released in March of 2016, teachers will be recruited for the study. In March of 2016, the researcher secured funding for stipends for all teacher participants from county science professional development and teacher professional development school-level funds.
- Proposal will be submitted and defended Spring of 2016
- IRB approval requested Spring of 2016
- IRB approval acquired prior to August of 2016
- Acquire IRB consent forms from participants August 2016
- Acquire permission to video tape from participants August 2016
- Initial introduction to Lesson Study August of 2016
- Calendar made to reflect 2 lesson study meetings per month of 1.5 hours each.
- Initial interviews to provide baseline August 2016
- One lesson on Kinematics drafted and taught via Lesson Study during August and September of 2016
- Follow-up reflection and interviews immediately after lesson is taught
- 5 subsequent lessons with two taught per cohort
- Follow-up reflection and interviews immediately after lesson is taught
- Data Collection ends December 2016
- Data Analysis December-January
- Dissertation finished March 2017
CHAPTER 4

RESULTS

Introduction

This research study investigated the implementation of Lesson Study with a group of five participant physics teachers and a participant researcher. This team of teachers consisted of members of two high school Professional Learning Communities and the participant-researcher from a third high school. All participants were in the same county, in a large suburban school system in the southeastern United States. The Lesson Study professional development was a modification of the Japanese Lesson Study strategy and applied to this team of physics teachers.

This team of six participant physics teachers was selected in response to meeting the criteria of teaching one or more honors level classes of physics and by volunteering to see the Lesson Study through two Lesson Study Cycles. These teachers, two from one high school, three from another, and a participant-researcher from a third, met to plan physics lessons with a focus on students' misconceptions. During this cyclical process, participants collectively wrote two Research Lessons. These lessons were each taught by one of the teachers, and observed by all other participants. Afterward, the team met to discuss and reflect on the learning of the students and the effectiveness of the lesson to promote that learning. In response, the team edited the lesson to make it more ideal for targeting physics misconception transformation and conceptual physics learning. Finally, one teacher retaught the lesson with modifications. Two Lesson Study Cycles were completed, culminating in two finely-tuned physics lessons and much
Findings presented in this chapter reflected what happens to secondary physics teachers engaging in lesson study as a professional development opportunity. Specifically:

a. How do teachers engage individually and in groups during the Lesson Study process?

b. What are the teacher-reported responses to Lesson Study as a professional development opportunity?

**The Process**

As a more communicative method of telling the story of this Lesson Study research, the Participant-Researcher (PR) will hereafter be referred to in the first person. The Lesson Study implementation and subsequent research regarding the implementation and participants’ experience was an involved process. Before the invitation was issued requesting participants for the Lesson Study professional development opportunity, I met with the county science department director. The director agreed to support the professional development opportunity and the research. In turn, he penned a letter to the Internal Review Board (IRB) for the county. He also designated a $405 stipend for full participation in Lesson Study professional development for up to ten physics teachers. I then contacted this IRB and applied for permission to conduct research across multiple schools. The IRB granted the approval.

In preparation for the Lesson Study process, the researcher contacted the principals and department chairs of five high schools to determine interest using the approved email (Appendix E). Two high schools expressed interest. Only three physics teachers from one high school and two from another were able to commit for the semester. A merging of these two Professional
Learning Communities (PLCs) was carried out, and the home high school of the group of three became the location for meetings.

An Introduction Meeting and two Lesson Study Cycles then commenced. Each Lesson Study meeting had the general goal. The Introduction Meeting involved presenting and explaining the idea and process of Lesson Study to the potential participants. Each prospective participant subsequently agreed to participate in both the professional development opportunity posed by the county and the research regarding this professional development. All participants signed Consent Forms (Appendix C). Two cycles of Lesson Study were then initiated. Participants and meeting contents determined the length of time necessary for meeting the goal. Some meetings were roughly an hour long. Others were broken into sections, such as Research Lesson day, and often lasted over two hours each. Table 5 outlined the Lesson Study meetings, the goal, and the details that composed the agendas.
### Outline of Lesson Study Meetings

<table>
<thead>
<tr>
<th>Meeting</th>
<th>Goal(s)</th>
<th>Details</th>
</tr>
</thead>
</table>
| Introduction to Lesson Study | • Participant Researcher (PR) explained the process of Lesson Study (LS).  
• Participants were informed of time and effort obligations.  
• Participants were introduced to the goal of transforming student physics misconceptions.  
• Participants were made aware of stipend obligations from county science department for complete fulfillment of professional development obligation. | • PR gave presentation and handouts on LS process.  
• PR gave out copy of old and new county science standards.  
• PR gave out copy of Common Misconceptions List (Appendix H).  
• PR assessed most convenient meeting data, time, and location.  
• Participants completed Experience Survey (Appendix D)  
• Participants signed consent forms. |
| Meeting 1 | • Select topic and schedule Research Lesson. | • Participants selected and reviewed relevant standards.  
• Participants selected and reviewed relevant misconceptions.  
• Participants finalized topic.  
• PR secured two or three relevant physics teaching research articles specific to selected topic and misconceptions relevant to that topic. These were either handed out at the meeting or sent via currier for review prior to next meeting. |
| Meeting 2 | • Outline the Research Lesson and finalize date. | • Set Research Lesson date  
• Participants decided on focus of topic.  
• Participants discussed research articles and misconceptions.  
• Participants brainstormed past experiences and activities for Research Lesson.  
• Incorporate the dos and don’ts of the topic.  
• Participants decided on activity.  
• Substitute teachers requested and organized. |
| Meeting 3 | • Discuss and debrief the learning of students and the Research Lesson itself. | • Participants used Google Docs to collaboratively and simultaneously write the detailed lesson plan and student activity handout.  
• Participants discussed and added teacher notes to the activity to facilitate all details of lesson being taught.  
• Scheduled follow-up lesson.  
• Took lunch order.  
• Finalized substitute teachers. |
| Research Lesson | • A second teacher at another school would reteach the Research Lesson implementing modifications from the Debriefing. | • Participants used jottings to record events and student comments for later participant discussion.  
• One participant taught.  
• Other participants observed and took notes.  
• Immediately following the Research Lesson.  
• Working lunch, supplied by PR, was convenient.  
• This was an extended meeting. |
| Debriefing | • All participants meet and discuss their observations  
• Teachers use field notes as SR | • A different teacher taught modified lesson.  
• PR and one other teacher observed and took notes.  
• PR summarized the notes and emails to participants.  
• Participants journaled in response to summary of modified Research Lesson teaching. |
| Re-teaching | • One teacher teaches Research Lesson.  
• One other participant and PR observe modified Research Lesson being taught. | |
Lesson Study Participants

At the end of the Introduction Meeting, each participant signed a consent form to participate in the research. Each participant began the research process by completing an Experience Survey (Appendix D). Data obtained from this survey established an understanding of each teacher's educational and teaching experiences. These were itemized in Table 6.

Table 6

<table>
<thead>
<tr>
<th>Participant Pseudonym</th>
<th>Degree</th>
<th>Years Teaching High School</th>
<th>Years Teaching High School Physics</th>
<th>Years Teaching Honors Physics</th>
<th>High School Affiliation</th>
<th>Degree of Research Lesson Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warren</td>
<td>B.S. Geology, M.S. Geology, Ph.D. Geology</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>Taught Research Lesson ½</td>
</tr>
<tr>
<td>Joe</td>
<td>B.S. Physics</td>
<td>&lt;1 year</td>
<td>&lt;1 year</td>
<td>&lt;1 year</td>
<td>1</td>
<td>Taught Research Lesson 2/1</td>
</tr>
<tr>
<td>Rodney</td>
<td>B.S. Geology, M.A. Secondary Science Education, Ed.S. Curriculum and Instruction</td>
<td>21</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>Taught Research Lesson 1/1</td>
</tr>
<tr>
<td>Julia</td>
<td>B.S. Biology, M.A. Science Education, Ed.S. Curriculum and Instruction</td>
<td>12</td>
<td>11</td>
<td>6</td>
<td>2</td>
<td>Taught each Research Lesson Independently</td>
</tr>
<tr>
<td>Participant Researcher</td>
<td>B.A. Middle Grades Math and Science, M.A. Science Education, Ed.S. Science Ed.</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>Leader/researcher Taught Research Lesson 2 Independently</td>
</tr>
</tbody>
</table>

94
The method of data collection as discussed in Chapter Three was applied to Table 7 to schedule collaboratively with participants as the Lesson Study progressed. This schedule, as determined by participants, became a living document, allowing for flexibility for teaching obligations and unexpected events, but providing structure towards the goal of the Research Lesson and the Debriefing that followed. Each meeting, Research Lesson, and ongoing Journal entries, were rich sources of data.

In order to analyze the research, I first transcribed the voice recordings of each meeting, the Research Lesson, and its following Debriefing account. Journals were ongoing during the Lesson Study, and data was added up to one week after the final Lesson Study meeting. After this time, I downloaded the journals from Google Docs and printed for later coding. Video recordings were planned to be used as a Stimulant Response tool. In practice, these videos proved less useful than the teacher notes from the Research Lessons for this purpose. The videos, unexpectedly, were not useful in hearing the individual conversations and verbalization of student thinking. They were only useful in seeing the teacher teach and the possibly the timing of the lesson, neither of which was the focus of the Lesson Study. I still posted each video on Google Drive with access by all participants to review as they desired.
Table 7

Revised Master Lesson Study Scheduler

<table>
<thead>
<tr>
<th>Topic</th>
<th>Week</th>
<th>Cohort 1</th>
<th>Date and Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intro Meeting: What is Lesson Study? Protocol for your PLC</td>
</tr>
<tr>
<td>Kinematics 1D</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>Meeting 1</td>
</tr>
<tr>
<td>Kinematics 2D</td>
<td>4</td>
<td></td>
<td>Meeting 2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td>Meeting 3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>Research Lesson 1</td>
</tr>
<tr>
<td>Newton’s Laws</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td></td>
<td>Meeting 1</td>
</tr>
<tr>
<td>Forces</td>
<td>10</td>
<td></td>
<td>Meeting 2</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td></td>
<td>Meeting 3</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td>Research Lesson 2</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td></td>
<td>Interviews</td>
</tr>
<tr>
<td>Energy/Power/Work</td>
<td>14</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impulse/Momentum</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

I then accessed each participant’s journal as a Google Doc and printed these. I conducted final interviews for each participant and transcribed them.
In order to code this data, I used three types or levels of coding. The process of data analysis began shortly after the first meeting. I transcribed as often as possible while the meetings and conversations were still fresh. The transcription was then immediately read and general summarizing notes of what participants thought, said, or did were added in the margins. Any other reflections, that I, as the participant-researcher, had, were also added to the margins. After 24 to 48 hours, I reread the transcription and coded using holistic coding. This involved looking for key summarizing or overarching words or conceptual tags. Approximately five to eight of these, often repeating, would be written on each page. Once the entire transcription was initially coded, I looked for overlaps. When synonyms or closely related word were used, I chose a code that was broad enough to encompass both and replaced it. In this way thirty or forty codes were reduced to twenty or twenty-five. I then listed all codes and grouped related codes together. In this way, I established the holistic codes and their supporting sub-codes. These became the categories and subcategories that served as an organizational strategy for the data.

After categories and subcategories were established, I performed the next two levels of coding. Again, I read the transcription. This time I was looking for salient quotes and dialogue that portrayed the essence of the Lesson Study experience. I first identified these prime examples through two or more readings of the transcription. Then, using the map of holistic codes, I classified each in vivo code or code sequence into a subcategory. Color coding aided this process.

After holistic coding had revealed categories and subcategories, the researcher attempted in vivo coding. In vivo coding proved to be inappropriate for coding meeting dialogue. The researcher then searched for another level of coding that would be adequate for this data source,
a possible third level of coding as outlined in Chapter Three. In response, the researcher discovered a third appropriate method of coding for qualitative data, an approach modeled after Discourse Analysis. This Discourse Analysis approach proved to honor the context of the discourse, modifying in vivo coding of a singular voice into the in vivo coding of dialogue. I utilized a stream of in vivo conversation through Discourse Analysis approach as supporting dialogue of multiple participants, their words, actions, and often intents as expressed through body language.

After the codes were complete and organized into coherent groupings of categories, subcategories, and supporting data, I wrote an analytical memo for the transcription. This memo was the story form of the data in light of the coding, aligned for learning and further analysis. I performed this coding process and wrote a culminating analytical memo for each transcription. After all transcriptions from the meetings were complete and analytical memos were written, I synthesized each individual analytical memo into one grand story. By keeping the mostly overlapping codes and throwing out any codes that were only mentioned once or twice with no insightful in vivo coding, I synthesized the analytical memos.

I then used the same process separately for the journals and interviews. In much the same way, I transcribed, coded using holistic, in vivo, and Discourse Analysis (Gee, 2011) approach to make individual analytical memos. Each participant had a story and became a category. I first wrote an analytical memo in response to coding of data during the same process for each participant. I then used the sub codes for each participant to provide structure and order for telling the stories of each person. This served to align the aspects of the Lesson Study within as perceived by each participant, portraying five participant experiences with Lesson Study.
Lastly, these five experiences were used to better represent this experience of Lesson Study with secondary physics teachers.

Findings

To determine what happens to secondary physics teachers who undergo Lesson Study, the first sub-question of How do teachers engage individually and in groups during the Lesson Study process? was addressed. After the setting up of the Lesson Study as a professional development opportunity, this question was further addressed in response to the data collected during the Lesson Study process. The Lesson Study meeting transcriptions were coded and analyzed using holistic coding and the Discourse Analysis approach. These coding methods revealed seven codes for overarching categories: logistics, alignment, physics conceptions, experience sharing, Research Lesson development, and the Research Lessons. The researcher then coded with subcategories. Each subcategory was further explained using the Discourse Analysis approach with relevant supporting discourse.

Through this process, a routine of Lesson Study was established. Participants fine-tuned this routine during Lesson Study Cycle One and then embraced this routine during Lesson Study Cycle Two. Logistics provided the routine. Alignment provided a focus and goal. The remaining categories served to highlight the ongoing teacher collaboration, learning, and opportunities for growth. Both the process and the experience of Lesson Study with two PLCs of secondary physics teachers is revealed in this research.

Logistics

The first category of data involved logistics. A portion of each Lesson Study meeting was used to set dates, set goals, and accommodate schedules. These logistic discussions were necessary to ensure that all members of the Lesson Study team were able to participate in all
meetings. I introduced the participants to the texting notification application, REMIND, which was subsequently used to facilitate reminders and logistic clarifications as needed to streamline the Lesson Study implementation. The logistic conversations further served to align Research Lesson scheduling to the learning of the students as well as the functionality of the school. I carefully cross-referenced the Research Lessons and the meetings which facilitated school activities such as holidays, field trips, assemblies, county guests, testing, as well as the stage of learning of the physics concept.

PR: For next week, when do we want to meet? Is Tuesday still the best day for everyone?
Participants: nodding heads in affirmation
Warren: We need about ten more minutes to comfortably get here for the meeting, could we shift the time by about ten minutes?
PR: Will 3 p.m. work better?
Warren and Joe nodded.
PR: Ok, next Tuesday at 3 p.m. it is.

Logistics discussions took place impromptu and in sporadic moments as thoughts struck participants. The logistics were truly one of the more informal portions of the meetings. Some examples included daily obligations such as child care and school club meetings. The nature of being both a teacher and having other obligations such as family and extra-curricular events mandated flexibility and an ever-ready backup plan for scheduling. Participants seemed to readily know and accept this reality. When a spouse texted to come home due to child concerns, which happened more than once, others nodded and smiled in understanding. They then restructured the details of completing the current goal, all took a part, and the process continued seamlessly. Teacher-participants seemed bent on remaining flexible. The initial attempt at using scheduling technology (Doodle) to schedule meeting days and times that best accommodated all needs was unsuccessful. Participants simply did not respond. Personal life, especially during
after school hours, proved to dictate last minute meeting schedule changes as well as participants leaving early or portions of agendas postponed until the next meeting.

Further logistics often included the syncing of planning periods and substitute teachers. These negotiations of time and space seemed to be anticipated within a PLC. Thus shortened discussions regarding the time required for both the Research Lesson and the subsequent Debriefing easily resulted in stress-free solutions. Discussions regarding coverage for classes, driving time, and lunch often interrupted or concluded the meetings, as participants planned their schedules and priorities. Occasionally, the participants had to speak with principals or department chairs to organize their schedule and would report back with finalized plans to the group.

**Curricular Calendar and Teaching Schedule**

The county published a curricular calendar to strictly guide all physics teachers in instruction for the school year. Teachers were required to conform to the designated order of conceptual units as well as the duration of these units. In practice, this meant that the physics teachers from two different high schools should be in the proximity of teaching the concept of the Research Lesson during the same short span of time, usually within a week of the other. All participants acknowledged and honored this calendar with flexibility. Each PLC had their way of doing things, often infusing slight modifications to an order or duration. This calendar did loosely bind the schedules of the two PLCs together, allowing them to focus on relevant and timely topics for each Research Lesson.

Using the curricular calendar to select content, participants discussed and selected a content topic for the Research Lesson. Next participants consulted their school teaching calendar to cross-reference the best timing for a Research Lesson and to choose the portion of the selected
unit (e.g., introduction, application, review, or extension). The slight variation in duration and sequencing resulted in one Research Lesson being taught as application mid-unit while the next day, the same Research Lesson was taught as a review at the end of the unit.

Each Lesson Study member taught different periods of the school day. Each had a different period for planning, as well as various obligations to school duties built into their daily schedule. These details added to the logistic manipulation needed to coordinate meetings. Specifically, Rodney had obligations to coordinate the athletic events after school; this impacted his availability for after school meetings on some days. Julia had children with after school activities to coordinate. Joe was still taking classes to secure his teaching certification as a new physics teacher. Rodney also was in a cohort working towards an additional graduate degree with classes placing more obligations on his availability. Warren had a young child at home, and his wife was pregnant. More than once, I noticed the sacrifice that teachers were making to participate in Lesson Study; yet no one complained or batted an eye. They each were noticeably glad to have this unique opportunity for relevant collaboration.

When specifically narrowing to form the single Research Lesson, members began by brainstorming all strategies that might work and were within the parameters of the chosen topic. They would then eliminate details that should have been addressed before or after the day of teaching in question. In the first Lesson Study, the group did this by creating two days of lessons. They created both the official Research Lesson as the mathematical modeling lab activity, as well as the follow-up application and reflection activity. This process gave the Lesson Study team the goal of preparing their students for this collaborative follow-up to their learning.

Warren: I guess this is one thing that we should agree on. Do we use launch angles like 33 degrees or do we not?

Joe (later readdressing): So it is horizontal motion with something rolling off a surface or projectile motion?
PR: So, it sounds like we should probably split these two ideas.
Warren: It sounds like these are two distinct lessons.

Participants had to carefully consider and schedule according to county calendars, school calendars, as well as the flow of the topics within the unit of content. This process was collaborative and effortless.

**Timing**

Participants discussed the schedule regarding who specifically taught an Honors Physics class during the agreed upon time interval for the Research Lesson. Research Lessons were scheduled when a teacher was teaching an Honors class, at the school and room appropriate to that class, and with a built-in window for debriefing after the Research Lesson was taught. I led, "Let's see where the Research Lesson will fall first and then back in the needed two remaining meeting dates necessary to write that lesson plan." Participants used this procedure for both Lesson Study Cycles, setting the Research Lesson date first and then planning the teaching and other events around that event.

After a steady pace of meeting once, sometimes twice per week, the participants were toying with the idea of taking a week off following the final reflections on the first Research Lesson. They were concerned, however, that the timing of the next selected topic and accompanying lesson would mandate another lesson being added to the count. It seemed as if they were feeling guilty for needing a break, for wanting a reward for finishing the first cycle. I decided, "Since I am hearing that we want to take off, let's just do it, and then we can do two meetings during the Research Lesson week if needed." I took both timing and the mental state of the participants into consideration when making this decision. Everyone was busy, and I did not want Lesson Study to become a burden. The participants seemed relieved and pleased to take the week off.
Accommodating All Obligations

For teachers to miss their classes, often for a full day, administrators and fellow science teachers were on board with the Lesson Study process. Department chairs occasionally showed up for portions of meetings and stayed for half of the Debriefing following Lesson Study One. Other department chairs and fellow teachers covered classes as needed to help facilitate participant availability for meetings. Principals agreed at the beginning of the professional development to pay for substitute teachers during the two scheduled Research Lessons from Professional Development funds. Full day substitutes were most often granted as a way for the principal to endorse the extended collaboration. In some cases, a substitute teacher was shared between colleagues.

PR speaking to Rodney: I emailed your principal, and she is all on board and handling the subs for your classes.
PR speaking to Warren: But then I emailed your principal and didn’t hear back. What would you suggest?
Warren: I can talk to my Department Chair.
PR: That would be awesome. Let me know if I need to follow up further. Sorry for the digression.

Joe's collaborative special education teacher taught his class independently, which allowed Joe to attend a follow-up re-teaching by Warren of Research Lesson One.

The act of going to a new school and entering differing cultures and procedures was one topic of conversation. The act of traveling, parking, and finding the classroom concerned both Julia and me. Julia asked, "When I go to the school, where do I park and where is the classroom?" Obtaining space to meet for the Debriefing meeting was another concern. Joe arranged this ahead of time in preparation for teaching Research Lesson Two. Participants began their meeting in Joe’s room during his lunch and then moved to another teacher's room during that teacher’s lunch period in order to have a space to meet for Debriefing.
For the Debriefing, members decided to have a working lunch. The meeting prior, I asked, "So, what kind of subs? Six inch? Twelve inch? Place your order." Joe brought cupcakes, and the Debriefing Meeting took place during lunch and a couple of hours afterward. Keeping the participants comfortable and fed helped to keep them focused and happy during often longer than expected meetings. During all meetings, I supplied the participants’ favorite drinks and snacks which were identified via impromptu survey during the first meeting.

Logistics were primary to the functionality of Lesson Study. Participants addressed the county curricular calendar and high school teaching schedule. Participants considered the timing of daily activities and bell schedules. Personal obligations, external education obligations, as well as the general duties and obligations of educators both professionally and personally were considered when accommodating the Lesson Study process.

Alignment

Participants had to carefully align the lesson to the needs of the students when writing each Research Lesson. They gave careful attention to the details and limits of the standards. They itemized and addressed misconceptions while referencing research. The participants shared personal experiences with teaching for changes in these misconceptions. All of this served to undergird the alignment of the Research Lesson with the school system, physics classroom, and student culture of the students. Specifically, the participants considered the county science standards, leveling to an honors classroom, relevant physics misconceptions, the chosen topic, and the teacher’s expectations for the students. This process of alignment took place through collaborative discussion as participants read through and pointed out the necessary details from their organizing paperwork and calendars.
The teachers showed concern and focus for coordinating new incoming standards which had been recently aligned with Common Core. Many of the participants reported never seeing the new standards which were officially being rolled out for the following school year. They carefully scrutinized the changes that were coming and discussed with their colleagues how this might impact students.

Rodney: Looking at the standards, they have the first one about analyzing the data in two dimensions…and then resolving into the velocity and acceleration and components and one thing that I don’t see explicitly that I like to emphasize is that these vectors are totally independent of each other and then don’t really point that out.

Warren: They kind of mention it in the last bullet, independent motion, I guess that kind of goes without saying, I don’t think the kids really get that.

Specifically, they were concerned both about what would be difficult for the students, as well as the importance of included or excluded topics. The participants also focused their discussion at the depth of content. They specifically discussed what the student should do to demonstrate this depth. The first meeting of each Lesson Study Cycle involved selecting the relevant standards, dissecting and studying these standards, and then placing them in a location of focus during the lesson writing process. I provided the participants with folders that contained the standards, curricular calendar, and physics misconceptions. These folders were used at each meeting, and additional documents such as research articles were added to them. In this way, the participants consistently referred to the standards as the Research Lesson was designed and edited.

**Leveling**

Each affiliated high school taught four levels of physics. Each participating teacher taught two or more levels of physics during their daily schedule. These levels ranged from collaborative classrooms with subgroups of special education students to Advanced Placement
(AP) Physics C, calculus-based physics. Most teachers taught College Preparatory (CP), which is the lowest level, with classes filled by students that would often be taking Physical Science in another school system. All teachers were bound by the commonality of the honors level of physics, the focus of the Lesson Study. One teacher, Clyde, had only taught Advanced Placement (AP) before this year of teaching honors Level. He was extremely concerned with distinguishing between expectations for each of these levels of physics students. For some participant-teachers, the lines of distinction from one level to another seemed to appear naturally. Both Rodney and Julia confidently detailed points of differentiation between levels. These were the more seasoned honors physics teachers, teaching honors alongside other levels for many years. For instance, Joe clarified the depth of content for projectiles with honors level students.

Joe: So in honors, ya’lл don’t launch at angles? You only do horizontal launches? This [the standard] says horizontally launched angles.
Julia: Oh, as opposed to just rolling it off a table?
Clyde: I thought I would try it, but looking at the standards, I am not sure.
Rodney: In the past, they [students] have had difficulty separating the time it took to roll across the table from the time to drop, for some reason, they want to mix those when they calculate the range.

Warren drew the distinction between College Prep (CP) and honors for projectiles.

Warren: With the CP student, we try to make it more about how the object is moving, instead of what is the horizontal velocity

Julia continued.

Julia: Yes, I think the trig [trigonometry] is often the difference between the two levels. With honors, they need to do the trig.

The math was more important to honors level and the concept was more the focus with the CP level. Warren further explained the difference.

Warren to group: In CP, they get more of a step by step. In honors, they get less direction.
Joe: So do you have them do the throwing it up and then back down?
Rodney: Yes, that’s actually funny, because that is the distinction that I have made between my CP and honors now. CP only drops and honors has to throw it up and come back down.

CP is left with less room to make mistakes, using single processes when the math is necessary. This frank talk of the differentiation between levels of physics classes was most targeted at Clyde and Joe. Clyde, who had never taught as low a level as honors had always been teaching AP; Joe was new to teaching in general and was a first-year physics teacher with other classes of CP and Collab levels.

**Preconceptions and Misconceptions**

Participants used The Common Misconception List (Appendix H) as a primary focus in designing lessons. During this process, the participants addressed each potentially relevant misconception by reading them aloud and discussing them. For each Research Lesson, participants selected particular misconceptions as being relevant to both the topic and specific lesson. Participants began creating the idea for the Research Lesson by first selecting each misconception determined to be pertinent to the topic chosen. From there, participants further refined the misconceptions into those relevant to the lesson itself, throwing out any that ceased to fit the lesson. In Research Lesson One regarding projectiles, the misconception of dependence of velocity components was the primary focus. In Research Lesson Two, the misconception of there is no gravity in a vacuum and there is no gravity in outer space were primary. Impetus force was discussed and chosen to exclude in both lessons. They then discussed in detail how best to address and attempt to change the misconceptions in the minds of the honors students.

The participants discussed common experiences that led to preconceptions of students and which were pertinent to the relevant misconceptions. They reviewed the percentage of their students who adhered to misconceptions, using pre-conception surveys from current or past
teaching experiences. Referencing the provided research articles (Appendix I), they then collaboratively attempted to understand the implications of these misconceptions further, examining their past and anticipated future actions with students that might help students endorse or reject misconceptions.

Warren shared: It seems like we need to identify some misconceptions and then address them directly.
Clyde: I highlighted a couple of things: address the misconceptions and bring them to the forefront; let the students know that they are…where they are going astray. Let them realize that this is something that they need to focus on during their learning, that what they think is going on is not.

They further used these literature articles to better understand how to change the specific stubborn misconceptions in their students.

PR to group: Go over the misconceptions, which will you be addressing?
Joe (reading): *Acceleration and velocity are always in the same direction.*
Rodney: Anyone who can break out of that, it helps them a lot in understanding that horizontal and vertical motion are independent.
Joe (reading): *Heavier objects fall faster than lighter ones.*
Clyde: So maybe we could give them a marble and a shooter and see which they thought would hit first and let them try it.

Through discussion, the participants then narrowed the strategies for combatting the student misconceptions that might work or were suggested in one resource or another to the ones they would implement in the Research Lesson.

The teachers eliminated unconnected misconceptions from discussion in an effort to focus on relevant misconceptions and make the lesson topic cohesive.

PR: If I am changing [the focus of this question] from forces to acceleration, then impetus might just be the beginning of addressing this misconception. Maybe it is not appropriate to have it here at all.
*Julia and Rodney discussed the fit with group.*
PR: Ok, let’s throw that [impetus force misconception] out. Any other preconceptions?
They discussed what common experiences students had in physics class and which parts served as a foundation for the new topic or learning experience. They then decided what elements of the topic should be taught previously.

**Expectations**

The participants often referred to the expectations that they had for their specific group of students. Participants viewed some of their classes as high-achieving and capable of stretching further. They viewed others as having behavioral or motivational shortcomings and not a solid fit for extensions or more challenging problems.

PR: Traditionally in the [standards], off a table was for CP, and then for honors, if the class was up for the challenge, then the angle for launch could be added.

Joe: I guess it is a little premature, but I am wanting to set a high standard. It is a little early, but I actually think that my honors kids would be fine with it.

Rodney exhibited further evidence of adhering to high expectations for his students in that he wanted to make the Research Lesson high stakes.

Warren asking Rodney: …and they only get one shot?

Rodney: One. One.

Joe: That is really great. I like bringing out the competitive nature of a lot of my students.

Additionally, Joe and others were in agreement that competition served to increase the quality of the learning experience.

Warren and Joe also shared an expectation to meet the administrative push for differentiation in lessons. Both mentioned the desire to create a differentiated lesson through the Lesson Study process.

Warren reflected in his journal: The group lesson plan seems like a perfect way to build a differentiated lesson, and I’m kinda bummed we haven’t been hitting on that subject.

Joe reflected in his journal: It (Lesson Study) could be a good opportunity to differentiate the students into separate groups to target their specific misconceptions.
Neither shared this with the group at this early stage of the process.

**Physics Concepts**

**Love of Content**

The participants were noticeably excited to embark on challenging physics conceptions and thought experiments. Occasionally, the group allowed a diversion of physics application that was unrelated to the lesson writing on hand to revel in the joy of solving a problem or answering a query.

Joe: So this would give them different rotational inertias, and they won’t pick up the same speed. Drop time would be the same, but the v leaving the table will be a little different.

Joe had a strong foundation of content. He brought that to the discussions with eagerness to learn the required detail level and the PCK necessary best reach his students.

The two-person PLC were fascinated by the knowledge of and usage of the plumb bob as a lab tool for the Research Lesson. They were most curious as to whether or not the students had used one before and whether or not the teacher had explained how to use it before the lab.

Warren: Did you alert them to that? The plumb bob.
Rodney: All I said was there is a tool that can help you.
Joe: I had never heard that word.
Warren: That is interesting. We had had a conversation about…I imagine it relates back to lead pipes or something.
Clyde: Latin
Rodney: Minutia is interesting…crapper, s-curve in a toilet…. When England started modernizing things…

Clyde told the story of his potato gun for teaching projectiles, usually used exclusively with his AP students. He explained how he uses hairspray and a barbecue lighter. Clyde proudly told the team, "One year it shot straight through plywood.” This contraption of ten feet
of PVC pipe, Mylar, and a ping pong ball had all the Lesson Study participants requesting an invitation to the next demonstration.

In response to a difficult physics question that came up during the discussion but was outside of high school level content, Joe eagerly expressed his need to solve the problem to fruition.

Joe: I’ll have to do that tonight. I have to know.

PR: Those are the ones [time consuming problems] that I really have to discipline myself on…don’t consider that right now…you don’t have time to work it out right now. Focus on task at hand.

When discussing the difficulty of students understanding the path of a projectile launched from an extreme height which then goes into freefall in orbit, Rodney shared:

There is a video that shows a jet fighter pilot flying west towards the setting sun. they show the sun setting and he was matching the rotation of the earth. Then it showed him go faster than the sun’s rotation and sun starts rising….they were all like how does that happen….then in that area, he is going faster…. but from where we are at … They also talked about the earth’s gravity and the rotation and then they talk about typhoons and hurricanes and that this is what starts them spinning. I thought it was interesting-- that guy in that plane. You could see it on their faces, like how is that possible that he could actually fly faster than the earth is rotating. They didn’t think it felt possible.

Although a bit of a tangent, Rodney seemed to feel that relating this opportunity for learning and the telling about the experience of his students was valuable to the other members. They seemed intrigued by the notion, speaking of wanting to see it and wanting to find an opportunity to show their students, as well.

Occasionally, current science events entered the Lesson Study discussion. For instance, when addressing the video clip of the International Space Station (ISS), Rodney shared.

Rodney: If you actually want your kids to see the space station, they can see it Sunday night at about 715…that’s a good time…not too late…usually in this area, it is between sunset and 10pm…. look to the south

Joe: Do you know how long it takes to go around? About 90 min.

Clyde: About a 2.1 magnitude
Rodney: We saw some rocket bodies go overhead, not on this list, so they must be classified.
When discussing the video clip of Felix Baumgartner achieving the record for highest freefall jump, all participants were enamored and speculating.

PR: I wonder when your body adjusts to the freefall. I can’t imagine how long it will take my body to adjust and get away from that roller coaster feeling.
Julia: It is not necessarily the fear of hitting the ground, it is that feeling of [freefall].
Warren: We only feel it during the acceleration portion…so it would feel normal?
PR: That was my question.
Clyde: Yeah? But you are constantly accelerating in an orbit…centripetally, yeah, because you are turning, so hmm.

Joy in Relationship

The participant-teachers often expressed value having others relate to their experience. Teachers valued the comradery of sharing physics-specific challenges and accomplishments in teaching. They further appreciated the opportunity to talk about physics and have others understand or wrestle through the thought experiments regarding the application of physics to their world or daily life.

Warren: I know we are off topic a little, but it is nice to hear this stuff…that other teachers are experiencing the same stuff. That is what happens when we get to talk to teachers from other schools. To see that we are having some of the same things going on…
Joe: So I saw you flip through the [student] lab book, and the kid didn’t draw anything. And I am like, “Thank God! I am not the only one.” Because this is still my first year…what am I not getting across?

Rodney took much joy in confiding in his colleagues that the group they had observed in the first Research Lesson was special in his eyes. He said, "They are the best group I have had in 21 years of teaching. Those are my best." Then he reflected, "It's weird how it ebbs and flows. Last year was the sixth period from hell."

Joe began one meeting by relating an experience with his students. He was beaming as he told a story about students having calculated when to drop a water balloon from the top of the
bleachers to hit his bald head. He explained, "…they had to calculate my average walking velocity, and then they had to calculate the time it takes to hit me with the water balloon. They got a direct hit!"

**Experience Sharing**

The teacher-participants spent much of the discussion time relating personal experiences of teaching and learning to their fellow physics teachers. For example, these shared experiences centered on the misconceptions with which students struggle, learning challenges that students face, powerful experiences in teaching physics, measuring the learning of both students and teachers, and the limitations in teaching physics in high school. The participants seemed quick to share and quick to listen to what was shared. They often seemed impassioned with their experiences and found commonality through discussion. The jovial and casual tone revealed both comfortability with fellow participants and pleasure with the interactions.

**Misconceptions**

Some teachers articulated instances of students' misconceptions blatantly displayed during their interactions in the classroom. They noted the reality of lab experiences that did not change the beliefs in the misconception. They further noted the frustration with retention in the new conception and the students' tendency to regress from physics conceptions to their preconceptions. The teachers agreed with research articles that were shared during the Lesson Study meetings. They agreed with the research that claimed that students often departmentalize physics understandings as only applying inside the physics classroom and not when then go out into their daily lives.

Joe told of a student that swore: "if a train was going forward and someone drops something off then it would go [fall] straight down." Other participants nodded in agreement in
recognition of this misconception in students. On another occasion, when addressing the misconception of *heavier objects fall faster than lighter ones*, Joe suggested:

Joe: Maybe we could give them a marble and a shooter and see which they thought would hit first, and let them try it.
Rodney: I have given them the small ball bearings and the larger ones, and they are pretty good about hitting the same spot.

Participants discussed the misconception of a vacuum meaning no gravity is present:

PR: I could suck all of the air out of this room and create a vacuum in here. What would happen to the gravity in here if this then became a vacuum? They still say that there is no gravity. I explain that there is still gravity pulling on everything in the room, so you couldn’t breathe but you would still be stuck to the ground.
Rodney: We did that today with my class and they did the same thing.
PR: I would say 85% believed there was no gravity.
Joe: That’s weird, I had never actually thought about that one.

Warren explained that his students were struggling with the misconceptions that faster objects stay in the air longer than slower objects and that larger projectiles behave differently than smaller projectiles. He then explained what he had done, prior to the Research Lesson, to try to correct this misconception:

So Monday, I showed the MythBusters video *The Drop* because they were still giving me some weird answers when I drew an object leaving the table faster than the other at the same height. They wanted to say that the faster one was going to be in the air longer. We said we would come back to that one. So what about when one is larger? So still the majority were saying that the larger one was going to hit first or last. So we took a metal ball bearing and a glass marble and released them. We then went back to the video. So then they started understanding that it is the height they fall from, not how fast they travel horizontally.

Clyde inquired as to which participants used the Force Concept Inventory [FCI] to assess student misconceptions as a pretest. He was met with raised hands and qualifiers of other physics assessments used as pretest instruments. I related my experience:

PR: I always have a couple of kids who say, “oh I made a 100 on that.” So, I say let me grade it. Uh, no, you got 25%. That is a good beginning.
Student example: What!
PR: So now you know that you don’t know everything; so we can start learning.

Discussion often centered on the stubbornness of physics misconceptions. The more experienced teachers underscored the reality of student misconceptions not changing in the face of solid instruction. This fact was a significant discouragement for participants.

Warren: Even though they learn it in class, they still come and use their preconceptions as if nothing had happened.
Rodney: I did this one 10 question check…with pairs of masses…which is exerting more force? A on B or B on A? Or equal? And two people put all C in the class…that they were equal between all. Then after I had the class raise their hands, who put all C? The little kid in the back kinda raised his hand. I said, you are the only one right. I said read Newton’s 3rd Law. There you go, that says it all.
Joe: Our forces test that we gave had the question of the bug smashing into the windshield….
Clyde mimicking a student: Is the car moving or is the bug moving.
Rodney in his teacher voice: It doesn’t matter.
Joe: You just see the hope drain out of their eyes.

In the wake of this frustration, Rodney added, "I thought this was an interesting article. I am glad to know that [the misconceptions] are worldwide." He seemed to take solace in the fact that it was not simply his inability to teach, but that other great teachers were burdened by the reality of stubborn physics misconceptions.

Learning Challenges

The participants were quick to share experiences. This sharing was an obvious effort to help colleagues avoid that wasted time and energy which they were burdened by from trying approaches that did not work to change students’ conceptions. Participants further asked other team members for suggestions as to what would work better to communicate concepts. By sharing their challenges with student learning, participants searched for answers and tools to meet these challenges. When planning Research Lesson One, Rodney related his experience.
Rodney: In the past, they [students] have had difficulty separating the time it took to roll across the table from the time of drop, for some reason they want to mix those when they calculate the range.

Rodney: [My colleague] and I found out a few years ago that they [students] have a real hard time working with the angles, and then they are like, “well, now we got to go back to geometry.” So we made it a two-part thing: they calculate the velocity leaving the table, and then they calculate the time [of fall].

Julia: Yeah, use the freefall time after separately calculating the horizontal velocity. And still some of the honors kids will want to blend the times of the horizontal velocity and drop time.

As teachers discussed the disconnect between lab experiences and mathematical computations, Julia told about her week of data analysis and the little progress in thinking and understanding of her students.

Julia: They are good at plugging in and working with the computer, but when we start looking at problems based on this data. They are oblivious.

Warren: That’s always a struggle. They always seem that data that they have been collecting does not connect to the learning.

Julia continued to articulate her frustration, asking her colleagues if she was alone.

Julia: So like we do problems and talk about the x velocity, that it’s not changing. Then we come to lab, and it’s like they never knew this. Do you experience that?

Warren: Oh yeah.

Rodney: It makes a difference they do it though. It does. And then they see it and hear it and see it and hear it again. Then they go “well, maybe”

Warren: I’ve heard them say, “well, I just don’t believe this.”

Julia summed up the frustration over the disconnect between the concept and the math, specifically with kinematics:

I think that when you are going through the laws of mechanics and into forces that you just have to remind yourself that you are not alone in your frustrations. Every time I would see a coworker, “It’s just for a short time; it will be ok when we move on to energy.” It seems that they connect to this better. Maybe when I get to energy, they might be able to conceptualize.

Rodney attempted to comfort Julia and encourage her to persevere. They agreed that the repetition was necessary for a cognitive change in the students. I nodded in agreement and then
added my experience that one of the reasons the lab did not connect with calculations was simply due to human errors and the expectation of exact measurement.

PR: If they collect numbers, I will tell you that one of the issues with changing the misconception is that the numbers are never exact enough. The numbers won’t be perfect because they are not perfect. So if they are timing the drop and it is off by .05 seconds, then they think, “see, I told you.”
Rodney: And you think, “No, you broke physics. This is bad.” That’s when I say, “well, where is the error in this?”
Clyde: So they need equipment that is really quite precise; the slow motion camera is nice on such a thing.
Warren: And they have one on their phone.
Joe: And they love to get it out.

Warren made the point that groups of students were always different. The skills and strengths of students change from year to year. The knee-jerk understandings change as well.

Warren: Last year, I couldn’t make them understand what magnitude means… magnitude is an earthquake…
Clyde: …or a tornado
Warren: But this year, when I say what is the magnitude of this, they know I am talking about a number.

Effective Experiences

The participants seemed eager to share compelling experiences in teaching. They wanted to share the triumph of finding what worked to deepen student learning. They were quick to point out specific instructions that had become successful strategies or tools in their teaching. Often the more experienced teachers shared with those less experienced.

On other occasions, teachers more experienced in content such as Clyde who had always taught AP level, related experiences that worked with another group of students in physics while questioning if other members felt this strategy was universally practical for physics students.

Clyde: Do you guys do the contraption that throws outward at the same time it drops a ball? It is spring-loaded.
Warren: I think I have seen it… where you mount it to a table?
Clyde: Yeah, you can mount it to a ring stand. There are two marbles and then you trigger it, this thing punches the marble in a horizontal motion at the same time that it releases a dropped marble.

Clyde (pauses for input, but then continues): Do you want to see it? There is a video too.

Those new to honors level physics were quick to ask about and clarify techniques which worked specifically with those students. The hole in understanding for these teachers was determining how much autonomy to give students in their learning. Clyde clarified the best use of a pretest determining student misconceptions.

Clyde: So you give them the pretest, do you then let them tinker and figure out the answers or do you spill the beans?

Rodney: When I did it [told them the answers to the pretest], it served as a wakeup call that they didn’t know everything they thought they did. So now you know that your thinking is not right, now let’s see why. With my kids, it made them focus, knowing that they did not know it all.

Julia: I think it’s good to address it [wrong preconceptions] with them, because some might come around, and some others may not come around unless you are pretty clear with remember this, it applies here.

Rodney: I think that what I have done with mine [students] leading up to this is teach them that there are three motions. There is constant motion, changing motion, and freefall.

Participants often focused the conversation on the frustration with students not linking the math equations or calculations with the motion of the object. The participants agreed that some students could do the math and some students could mimic the rules of the concept, but few put the two together with thorough understanding. Joe said it best, "Just because they can do the math doesn't mean they have conquered the misconception."

Participants discussed the dichotomy between having students work individually in contrast to working in a group. Individually, students were responsible for their understanding. They, in turn, got the grade based on their efforts. In a group, although learning could increase with scaffolding from other group members, it often did not in practice. Often in groups, students cheated off of each other or at minimum brushed over things they did not understand,
trusting in the understanding of the strong group member. After discussion, the participants decided to use groups in both Research Lessons. They agreed that the positives outweighed the negatives and that overall, more learning could be accomplished in the group. As Rodney pointed out, "The thing with group versus individual is that in a group there is a safety factor." Thus, even the less able and shyer students had a bigger opportunity to learn.

**Measuring Learning**

Some techniques to evaluate student learning proved better than other techniques in teacher experience. The teachers agreed that traditional testing often failed to show the depth and breadth of student learning. They discussed techniques which allowed students to demonstrate learning in less conventional ways. The teachers were in agreement that measuring learning need not take the form of a formal assessment. The teachers shared some techniques which they used, including a quick sketch and a show of hands. Rodney gave credence to this thought:

> As long as they [the students] know that acceleration is always down and that horizontal motion is constant; we view that as done [meeting the standard]. If they can describe that or draw it or graph it or something like that, we look at is as they are able to do it.

Lesson Study participants were in agreement that teachers are learners too. Specifically, they agreed that some instruments used to monitor student learning could be used to reflect teachers' teaching. The Force Concept Inventory was an example of this.

Joe: Do you give the FCI [Force Concept Inventory]?
PR: That is one of those measurements that I do for myself to see if I am doing what I need to do. I do see growth, and you know that every year that you teach something, you hope that you are feeling a little more confident and getting better at it. You have a couple more tools in your bag that connect with the kids. But I do feel that that [FCI] is a good measure for me and that’s what I keep from year to year.

Finally, participants agreed that summative questions targeted at shared learning experiences were a solid teaching strategy during discussions. I recommended, "I do think you
should write a summative test question relating back to the Baumgartner. What would he do and why…the drop straight down.” Participants agreed and also suggested summative test questions should be added relating to the projectile Research Lesson and the follow-up analysis questions which the participants had written.

**Limitations in Teaching**

Teachers wanted to know that they were not alone in their struggles. Interruptions, administration, and the daily responsibilities of the school functioning tended to create less than optimal circumstances for teaching and learning in each teacher's experience. Often the best-conceived plan for instruction was thwarted by occurrences that were outside the control of the teacher. Participants saw this frustration during the follow-up teaching of the first Research Lesson.

In this reteach of Research Lesson One, approximately 25% of Warren's class greeted him by handing him passes to attend school-wide testing, telling him that they would be leaving halfway through class. About fifteen minutes into the lesson, an office aide entered with a stack of about fifteen more passes for other students. Warren had not been made aware of testing that would pull out over 50% of his students during this class. Students obviously knew that the activity could not count for a grade and many were wholly disengaged during the short portion of the lesson for which they were present. This disengagement set the stage for the few students who stayed for the whole class; they seemed less motivated to try to meet the expectations of the lesson. In turn, no students successfully hit the target. Many calculations were illogical and wholly wrong. Warren resorted to simply giving equations instead of aspiring for understanding to salvage the lesson and the learning.
After participants had selected the topic for each Lesson Study Cycle, I selected research articles for participants aligned to their selection. Participants then received two or three research articles relevant to the physics content topic and misconceptions unique to that topic for review. These were either sent to participants via carrier during the week or given to participants at the onset of the next meeting. The participants claimed to appreciate and learn from the articles. In the reflection of a research article, while developing the first Research Lesson, participants discussed this learning.

Joe: Something else that was brought out to me from that article is that although math and science are supposed to go hand in hand, they don’t always.
PR: I know that I have had some misconceptions that have been spurred by the math class where they do something differently or they use different equations or the English System.
Joe: Yeah, teachers in the math classes were fueling the [misconception] fire.

The participants recognized and agreed that often other content areas worked in opposition to overall learning. Specifically, they referenced math curriculum that ignores the metric usage of constants and teaches their English equivalent. Physics students then plug in the wrong constant, ignoring units. Additionally, math curriculum teaches projectiles with parametric equations. This is contrary and wholly disconnected to the vector and algebraic methods used in physics. The lack of a bridge builds confusion. The combined experience of the participants indicated that often, teachers in other content areas served to undermine the teaching and learning of students in physics.

During one meeting, Clyde shared an article regarding the number of highly qualified physics teachers. He and the other participants were surprised and frustrated by the report.

Clyde referring to an article he shared: Only 7% of physics teachers are highly qualified.

Rodney: I have talked to people at conferences that are teaching physics and they are biology trained.
Julia: They [biology and physics] are very different, and I think that some administrators think that science is like social studies, that if you know how to teach one, you can teach any. It’s [the content] just a different book…that’s just not the case.

PR: Even the strategies used in the classroom are different.

All participants acknowledged the reality of differences in science content. Each agreed that specialization must occur in one field and that a passing score on a Broad Field Science Certification test was not indicative of qualifying someone to teach physics. This intuitive idea was supported by Breslyn and McGinnis’s (2012) research which found that conceptions and inquiry understandings were distinct between science content areas.

**Teaching Techniques**

Throughout the course of the Lesson Study, the participants shared exposure to equipment and strategies. Many ideas or resources came from conferences. Others came from colleagues. Still, others came from ideas they had stumbled upon during much practice with teaching physics. The technology was a source for not only experimental or demonstration equipment, but for on-line resources. Participants shared on-line resources that were meant to enable better collaboration as well as better visualization of physics concepts. The participants seemed to value both some of the old and new technologies shared, taking notes or requesting links.

**Effective Equipment**

Teachers shared equipment and uses of the equipment that had helped them communicated physics concepts to students. Often, one Lesson Study member brought in an apparatus to demonstrate a relevant concept. Other times, one member explained something that they used or ask others how the apparatus could be used to demonstrate a concept better.
Equipment was not limited to mechanical devices, but included software, hardware, and other types of technology.

Warren explained his access to and experience with technology in his classroom. He claimed to appreciate the accessibility that students had to access information, videos, and examples. Warren expressed a fault in the compatibility between the McIntosh technology and Windows technology. Specifically, Warren listed probes that were not compatible and on-line simulation platforms that were not accessible. Warren explained, "Now we have 15 Chromebooks in the classroom. The Chromebooks are great, but they are not great for PhET simulations."

Warren was endorsing the suggestion of using PhET simulations. Warren, “Projectile Motion is one of the best ones [PhET simulations] that they have that we like to use. Julia and PR nodded in agreement. Joe searched for the simulation online to examine it for the first time.

When asked what platform he used or recommended for data analysis, Rodney raved about Logger Pro. He explained the ease with which students can use it and the value of the pre-loaded videos for analysis. This discourse recommended a specific video analysis for kinematics.

Rodney: We have a video analysis on Logger Pro, and they have some video files. They have one, Basketball Toss, where you can graph it and scale it, and show the velocity and the position v. time graphs. And so it takes a nice path and track it and teach them how to do the tracking and they see the data coming up on the right, and they see that right here is the velocity. Some see that it is zero here for just an instant and then the velocity starts increasing again.
Clyde: Where are it?
Rodney: It is in your Logger Pro files—Basketball Toss.
Joe: I want to know if we have Logger Pro for Mac.
Warren: There is a phone app that can be used—a free app. For the Macs, we can’t use Logger Pro.

Participants often opened meetings with stories of experiences they had had recently with student learning. Many times these opening stories related demonstrations. Sometimes the
demonstrations were planned and sometimes they were impromptu. Sometimes the
demonstrations featured purchased equipment and other times participants gave instructions for a
"poor man's" version. One such opener featured Clyde discussing a piece of equipment that he
enjoyed using which portrayed the concept of constant horizontal motion.

Clyde: Do you guys do the contraption that throws outward at the same time it
drops a ball? It’s spring loaded.
Joe: I think I have seen it. Do you mount it to a table?
Clyde: Yes, you can mount it to a ring stand. So when you pull the stick out at the
very same time these occur, and you can hear them hit at exactly the same
time.
Clyde: Do you want to see it? [demonstrates contraption] There’s a video too.
Warren: That is a good one. I show a MythBusters video where they have rigged
up a similar system. So it launches a bullet at the same time that it drops
a bullet and they have a camera at the place where they have calculated
the bullet landing. It’s really good.
Joe: That’s crazy. We have always said that if you fired a bullet and dropped a
bullet at the same time, but now that shows it, that’s cool.
PR: Would you do that as a demo or do you have a class set?
Rodney: You can make a poor man’s version of this with pennies and a notecard.

Participants occasionally spoke of uses for the physics textbook. It never was mentioned as a
source of learning or a reference for concepts. The real usage for the physics textbook was
brought to light when discussing an experimental setup.

Clyde: You could just use different numbers of textbooks. Yea, like you, use two;
you use three.
Warren: You could do that. It would give you some variation.
Rodney: That’s all I use the textbooks for anyway. (laughing)
PR: I’m sorry, no I agree. I hate the book.
Julia: …or we use it for a mass to weigh something down…make a barricade with
them…

Other apparatus for labs or demonstrations included a plumb bob for making sure a vertical
measurement was aligned, and a center of mass apparatus that showed the center of mass by
allowing the user to select different masses for each end and to then rotate them about the center
of mass.
The participants discussed a new piece of technology that was entering their classroom more and more. Students are now bringing and using the slow motion camera. They all agreed that this was a real asset to collecting experimental data. Some students naturally used it. Others needed to be taught or have to practice.

Joe pointed out that there is a learning curve to all technologies, including the slow motion camera found on most modern cell phones. He was concerned about losing the class time necessary for any new apparatus or technique to become part of the student/teacher toolbox. This time must be strategically scheduled and budgeted, notably at the expense of content learning. When considering using the slow motion camera in one of the Research Lessons, Joe objected, “Yea, I don’t know. Now we have to get them familiar with the slo-mo and how to upload it, and so many new things; it is kind of stressing me out just thinking about it.”

On three occasions outside of the Research Lessons themselves, participants made reference to or showed clips of videos for instruction. When creating Research Lesson Two, Rodney recommended a video to demonstrate the progression of projectile motion to orbital motion.

Rodney recalled: Paul Hewitt used to have a video about that where he would draw a cannon and shoot it progressively farther.
Joe: That’s the picture that I used to add the illustration to the Google Doc [for the Research Lesson in progress]

Overall, participants shared experience and wisdom regarding effective equipment to use when teaching honors physics. They retold experiences and shared hands-on demonstrations of equipment. Participants related experiences and judgments of Chromebooks, PhET simulations, Logger Pro, demonstration equipment, and a variety of video clips.

**Effective Strategies**
Lesson Study members discussed strategies that they found effective for teaching specific concepts and then tried to decide, using input from other members, which were optimal. Often an effective strategy used by one teacher evolved through conversation into a modified strategy, refined by other members’ input and suggestion. Participants discussed the specific strategies of using Misconception Probes from Physicsclassroom.com, getting students involved and collaborating in their learning, showing and discussing video clips, doing mini-labs, and a variety of teacher tricks of the trade to engage students.

Throughout the Lesson Study, members focused on misconceptions and how to alter these deep rooted false beliefs. The practice of addressing them head on was prevalent in lesson planning. This practice was also prevalent in daily practice, often shared, by the participants.

Nancy: I did the Freefall Conceptions Probe off of Physics Classroom.
Warren: I wish I had thought of that probe because I recently did that—darn it. I should have done that.

The participants discussed strategies to maximize the engagement of students. Joe believed that students arguing with him regarding their sincere belief in a misconception were the most fun and best opportunity for learning. Other participants seemed to have different opinions and approaches.

All participants seemed to agree on the value of students using collaboration as a learning tool or platform. They discussed grouping strategies as well as technologies and methods to open communication lines for collaboration. Rodney reminded the group that grouping students was the first step to collaboration.

Joe speaking to Rodney: How do you group?
Rodney: If you can get three levels in each group, then you can group like that, but make the one that is good at the math responsible for helping the one that is not as good doing the math.
Julia: Assigning roles or jobs in the group's help, especially in the CP classes. Otherwise, they may go get the materials, or they may not. They may just sit there.

The struggle with group work and the reality that many times there was one member that did not do their share of the work was a discussion.

PR asked Rodney: How do you doc when you have got someone that didn’t do what they were supposed to do?
Rodney: If I have one person that just goofed off for the first ten minutes, I’ll take off ten percent. If they don’t do anything, I’ll give them a 50. The group that I had last year, I would just call them out.

I expressed concern over the dysfunction that sometimes surfaces in groups. Rodney recommended the practice of giving students a deadline to finish before the bell when doing group work. He claimed that this motivated them “to not goof off.”

The participants agreed that students always maximize their effort when a grade was involved. Rodney simply wrote "Assessment 2D" on his board before beginning the lab. It became a test grade in the students' eyes. The students were extremely motivated to get a good score, so much so that the stress level was palpable. In the original teaching of Research Lesson Two, Joe also used an opening assessment; this time it was a quiz. The intent of the quiz was to assess misconceptions before the teaching of content formatively. Students seemed concerned with being unstudied for this quiz, yet this concern caused them to concentrate and engage in the learning.

Warren: Some kids were pretty alarmed by opening with a quiz for the preconceptions.
Warren mimicking students: We haven’t learned this yet!
Joe: I didn’t want to tell them that it doesn’t matter. It is not a grade, but I didn’t know how to handle that.
Clyde: But yeah when they see it that is their first thought. I think you did pretty well, you just told them that you wanted their opinion.
The participants endorsed online platforms of Web Assign and Sapling Learning. While collaborating on Google Docs to create the Research Lesson, I realized that two participants did not know how to use a clipping tool to take screen shots and then add them to documents. Rodney and I demonstrated the use of both the Clipping Tool and Hyper Snap.

Technology was often a source of conversation. The participants discussed both basic and technology-supported platforms for collaboration. Specifically, participants saw whiteboards as remaining valuable for brainstorming and collaborating. These were recommended to use to document answers and to share simultaneously. As a technologically advanced version of this practice, I recommended and demonstrated an online platform, Padlet. I suggested this platform for pooling or comparing lab data as well as for homework assignment contributions. Clyde suggested, "Maybe we could have all the groups collect the drop times and the velocities and show that it doesn’t matter how fast the marble is going, they [the marbles] will all hit the ground at the same time."

A final communicative or collaborative platform discussed was REMIND. This communication platform was already used by the teachers in one of the two PLCs occasionally. The smaller PLC, however, were wholly unfamiliar with it. I explained that REMIND is primarily used by the teacher to issue reminders to students. It also served to open communication lines back to the teacher as it had a user-friendly text function which students used with or without attachments.

Julia pointed out that video clips such as the hammer and the feather being dropped on the moon served to clarify student understandings. Although it did not make it to the final Research Lesson, one strategy that participants selected and refined during the discussion was
the usage of a video clip of bad physics. Julia made reference to a Wile E. Coyote video where he falls off a cliff straight down.

Julia: How about opening with something like that, I mean what is it a 20-second clip?
Joe: Then have a quick discussion?
Rodney: Or you could have it running in the background the whole time. So we ask them to write down all the wrong physics.

Julia also shared her strategy of using mini labs to create common experiences with students. She explained, “I like to incorporate mini labs that help the students view examples of the motion and then go back to those examples when we are addressing concept questions.” The participants avidly presented and discussed numerous recommendations of strategies, relating their experiences, to employ in the honors physics classroom. They further refined or expanded many of these strategies, pooling their knowledge.

**Research Lesson Development**

In writing a Research Lesson, the participants established a routine or somewhat consistent procedure. This procedure resulted from collaborative trial and error. In order to design this fine-tuned lesson intended to be taught by one teacher and observed by the remainder of the team, the participant-teachers had to select the physics content that fit this within the confines of their curricular calendar. I gave a reminder of the purpose and focus when writing the Research Lesson:

We are trying to design the best lesson we can design for their learning. Then the Lesson Study is to study that lesson being taught and focus on the student learning. So that then the lesson can be tweaked and made better. So, it is teacher growth and student growth simultaneously.

The participants discussed and debated the specifics of the lesson in detail. They deliberated cautions of what not to do based on the research base that they shared and the individual experiences that they had in the past. They then planned the logistics of teaching the Research
Lesson. They made arrangements for all to observe the Research Lesson being taught, as well as scheduled and facilitated the Debriefing following.

**Selection and Fit**

For the first Research Lesson, the participants reviewed standards, research, and misconceptions in the light of the curricular and school calendars to plan. For the second Research Lesson, participants had learned from their first experience. As the second Lesson Study Cycle began, the participants discussed the mild frustration with missing the evidence of many of the misconceptions in the first Research Lesson. Joe summarized the first lesson writing experience, "I think that I really like the activity. I also think that identifying the misconceptions is different than doing the calculations that needs to be in a separate part. I think they are two different things." By selecting the lab activity as the Research Lesson, students were spending the majority of their observable time calculating and experimenting. They were not analyzing and verbalizing conceptions. The participants agreed through discussion the that there needed to be a shift in lesson activity to allow observers to focus on the thinking of the students. I summarized for the group, "We do want to see the kids thinking, so maybe the day after the lab this time…so we can create something totally new, or we can revamp."

In response, Research Lesson Two was purposefully structured to be a highly collaborative display of student thinking and conceptions. This lesson included a full assignment to be done the next day of analysis questions. These analysis questions were centered on the misconceptions and served as goals when writing the Research Lesson.

The participants agreed that the short survey of student preconceptions to establish the prevalence of misconceptions in the class was valuable. Joe suggested a “quick and dirty five questions [pertaining] to whatever the lab specific misconceptions are.” In response, the
participants unanimously chose to repeat the preconception quiz process at the beginning of the second Research Lesson.

**Brainstorming**

During the discussion preceding the writing of the Research Lesson, members were careful to notate what must occur the day before, as well as the day after to endorse the Learning Cycle. Clyde asked, “So is this like the very intro part of projectiles? So do they already know the path it [the projectile] is going to take, like the independence between the two [velocities]?” He continued, “So my question is, ‘Is this a test of their [students’] skills or is this an assessment after they have learned?’” Rodney responded based on his experience of doing a similar activity in years past.

Rodney: Usually, we have talked a bit, and then have drawn the motion map on the board.
PR: So in other words, they need to have the conceptual understanding prior to this day?
Rodney: They [the students] just can’t let the ball leave the table. They have to catch it. They stop it. They only get one chance to hit the target.

During the discussion of misconceptions for Lesson Study Two, Warren interjected, “We could make a little pre/posttest out of this stuff [discussed misconceptions].” Warren volunteered to take on that task for homework. The team agreed to pursue the misconceptions in the lesson for the day following the Research Lesson.

Rodney: What if we take each of the misconceptions that we were looking at and each of us write an analysis question like what can you do or what did you do with your apparatus to prove… I don’t know something along those lines.
Joe: Like the gravity thing?
Rodney: I think you could, but these should all be application/analysis level.
Julia: It seems like here has to be some follow-up on the misconceptions at the end. Did they make a change? Did what you try to do convince them to make a change on the specific misconceptions?
Rodney: What if we gave them a chance to change any of their [answers to the] preconception questions that they wanted?
PR: You could even do it as an out the door [question].
Clyde: I don’t think it’s bad to revisit them. I think it’s a good idea to revisit the
preconception questions.
Julia: …or even an in the door question the next day.
Joe: I do like that; I like replicating it.
Joe: I would like to say, “how could your experiment be improved?” Maybe as a
bonus.

Rodney added the details which must be addressed by the teacher or student and itemized
through discussion to the teacher notes for the lesson. Julia asked him to add another note to the
teacher notes. Julia explained her teaching protocol, "Usually I will have time to go by and kind
of interview. Are you sure about this? Go back and look at it again, for the groups that don’t
have the high achiever in the group. And adding why questions.”

When trying to gauge the amount of time needed to complete the experiment, teachers
from the larger PLC shared their experience.

Rodney: From experience, some groups are going to do it in 15 minutes; some
will finish at the bell, because for some reason they are not sure. They
may be doing it right, but one person in the group has convinced them
that they are doing it wrong.
Clyde wondered: Anything wrong with giving some kids the ability to start the
questions in class and the others do it for homework?
Rodney: So, yeah that group that finishes first are usually cleaning up their
numbers and their calculations and the group that just barely get it in that
is homework for them.

Writing the Lesson

After the discussion and brainstorming had begun to draw to a close, participants were
ready to write the lesson itself. Joe initiated, "Would it be helpful for me to start a Google Doc
and then we can start sharing it and working together." Google Docs started off as an impromptu
effort to better collaborate the writing process. The following was an example of the process.

PR: Would anyone object to me putting axes for the graphs?
Julia: I am doing that now.
Julia: I really like using the Google Doc.
PR: So I think maybe the right thing to do is to print it out now and look at the hardcopy. Everyone has access to it and can edit and change what’s needed. So we will all look it over a couple more times, and then we will say Saturday we call it complete.

Google Docs proved extremely successful. The participants agreed that it was representative of all participants and time-efficient. They were excited about using this new tool and sharing it with other colleagues in other contexts.

After the document for the Research Lesson was complete, the participants were questioning certain details, unsure on which way to present material and formulate written questions. Everyone was tired and suddenly nervous about making the presentation perfect, especially with observers coming to watch. Warren reminded everyone that they would be allowed to make changes later if they were warranted. He said, “I think we need to keep in mind that we are going to run this twice, so we can come back and discuss what might make sense to tweak and if we want to add like them dropping it. Are we meeting their learning needs?”

**Observation Planning**

As the written lesson plan began to draw to completion, participants began looking towards the teaching of the Research Lesson. All teachers were considering their role. Rodney asked what he should do to prepare his students for the guests and the Research Lesson.

PR: It will be worth letting your students know that a visitor is coming with a video camera to tape the lesson, not them, but the lesson; that way they know and are expecting it.

Warren: Video is only for discussion?

Julia, Rodney, and PR nod.

Other participants anticipated the observation and subsequent Debriefing.

Clyde: Is it reasonable to ask kids to wear name tags so that we can identify them?

Rodney: In my room, the pods are color coded.

Clyde: Oh yeah, that helps.

Clyde continued his clarification.
Clyde: So are we going to be observing the process of them doing the ball launch? 
PR: You are wanting to hear their thinking…. You really put them under a microscope.

At the closure of each final Lesson Study meeting leading up to the Research Lesson, I prepared the participants for the logistics of the day.

PR: I am going to give you two documents to help for Research Lesson day. One is an observation log, something that you can write on and keep in your hand on clipboards that I will provide. The other is a protocol. I mainly have this for when our guests come. They don't know what is going on yet…I am only going to read "do not help students or otherwise interfere with the natural flow of the lesson." I only say this because we are all physics teachers…it would be very much like us to jump in and say "no no no…a little higher."

Clyde: It wouldn’t be a bad thing to inquire, “Now why did you do that?”
PR: It wouldn’t. But what you don’t want to do is lead them. You are trying to observe them and take notes.
Warren: Can you just sit on the periphery and take notes?
PR: Absolutely, but don’t be afraid to circulate.
PR: I encourage you not to jump in and start teaching. We are here for the learning.

**Research Lessons**

Two Research Lessons were written over the course of the Lesson Study. The first corresponded to projectile motion. It was an application of the math supporting projectile motion. This case of mathematical modeling was Research Lesson One, referred to by the participants as the Target Lab (Appendix J). This Research Lesson was a timed lab experience with extensive follow-up analysis, Post Analysis Questions (Appendix K), applying the previously learned content. The second Research Lesson, Weightlessness and Freefall (Appendix L), served as an introduction to Universal Gravitation. This lesson addressed numerous misconceptions specifically involving gravity, including those linked to falling objects and the notion of weightlessness and utilized a high degree of collaborative inquiry in the students in response to outlandish video clips.
Research Lesson One

This Research Lesson was set up as a lab-based assessment. The students assumed it was a test grade, and the engagement level corresponded. The purpose was to build a track out of rulers to accelerate a ball bearing down a ramp. The second part of the track had to be flat to measure the velocity without acceleration. From here, students realized that the constant horizontal velocity would carry over into the launch of the ball bearing off of the table. Students also measured the height of the table plus the height of the ruler carefully to then calculate the drop time of the ball bearing. Finally, they had to use all of this information to decide where to place a target on the ground and successfully hit the bullseye. Participants also wrote an analysis question handout for students who finished early, for homework, or as a springboard to a follow-up discussion the next day.

Student learning. Obvious to all participants was the readiness of the students for the experience of the Research Lesson. They were unscathed by the extra bodies circulating and taking notes. The students were intent on figuring out the calculations and scoring well on their test. The participants were impressed with the readiness and eagerness of the students.

Joe: One student asked immediately if we could neglect air resistance. This showed he was working with a little more thought.

Students showed finely-tuned laboratory skills and insightful thinking. There were times, however, that some missed important details in exacting the experiment.

Warren: It was so hard for me not to intervene when they were introducing quite a bit of error. One group was measuring very precisely how far out it [the ball bearing] would go, but she [a female group member] was measuring from the leg of the table, not from the lip of the table. Julia nodded in shared recollection.
The students were extremely concerned about being precise and making good grades. Multiple groups were finished with calculations and predictions but were afraid to go first. They just continued checking their answers.

Clyde: Was it the pink group who said that they were double checking their double checking?
Warren: Some groups did a lot of time trials. Many did, without having to ask you…students will often ask me. And finding outliers; they seem to know what to do.

One of the elements of the lesson involved sketching a vector diagram of the velocities of the projectile. Many of the students did not seem to connect the diagram with the calculations. The vectors did not emulate the patterns of the quantitative velocities from the calculations. Warren explained, "I saw some with the horizontal rolls off the table, and the horizontal never changing and then the vertical rolls off the table and never changes. That seems like an indicator that they don’t link acceleration with the motion.”

Joe noted another conceptual disconnect.

Joe: Everyone was using the time of the drop. Everyone had a grasp of the procedure, but the underlying concept was not perfect.
Julia: The time thing was the only misconception that we really saw. We are finding the horizontal range.

After later looking over the lesson handout with calculations and conceptual questions, the participants itemized two misconceptions. First, one misconception was drawing the vectors the same, not reflecting the constant horizontal velocity and the accelerated motion in the vertical. Second, the shape of the path of the projectile on the vector motion map was often incorrect and communicated wrong ideas about motion.

Participants noticed that students did not connect the math to the motion it was meant to predict. The students seemed to have a strong disconnect between physics calculations and physics concepts.
Julia: I think when I was walking around, they were doing the math, they were pretty confident in how to do it, but they were scared to death that the math was not real, that the ball would not really do that.

Rodney: Yea, one student said, "As soon as it falls, I feel like it would go farther out." Then someone said, "No, I just feel like we should trust our calculations." So, I made it very clear that gut feeling is not the way but trust the math.

The last observation regarding student learning was that some students appreciated the opportunity to apply the physics concepts in experimental conditions. Rodney emphasized this, “One student said ‘We need to test like this all the time. I can apply this and really see it now.’”

**Teacher learning.** Participants each noted that the stress level of the students was high. The lab groups were so concerned about their grades that they were scared to release the ball bearing in fear of it missing the target.

   Clyde: One kid said, “the moment it hit the ground, all the stress on my shoulders just lifted; like all of the stress was alleviated.”

   One of the most shocking revelations for the participants was the disconnect between the math and the enactment of that math. Rodney expressed that he needed to help his students with that before this lesson.

   Rodney: So that made me think that I needed to stress to them to trust the math.

Warren: I wonder if the period prior it would help to let them use the simulation with their math so that they could have some repetition to see that the math worked so that they would trust the math. I just wonder if fifteen minutes in the PhET lab might build any confidence there.

   The team noticed that some groups missed the bullseye to the left or right. In other words, their calculations were good, and their measurements were good, but their ruler was slightly misaligned and not perpendicular to the edge of the table. The team did not feel that this should be penalized in scoring. The group discussed redesigning the bullseye to make the task of hitting the bullseye fairer. They discussed changing it to a football field format or possibly elongated ovals to cut down on the penalty of lateral movement.
The group discussed modifying the directions for the analysis questions by adding more details to the directions. Rodney said, “Should we change the directions at all? I have been calling it a motion map, but I had modeled it on the board…every table had the notes out and were using them, but much of the notes were wrong.”

Clyde: I wonder if there is anything that would give them a hint to what the shape of the path should be and what the lengths should be. We can we do to make them focus on length of the vectors?
Warren: Something about carefully draw the path with correct shape and vector size, for those that phased out during instruction.
Joe: Proportional
Rodney: We could just straight up say that size matters.
PR reads the revision: Carefully draw a path of the projectile and use vectors that are proportional to the velocity in each direction at each point.

The participants wanted students to articulate their thinking better.

PR: How could we get them talking about doing the lab more—the conceptual plan? How to do it, not the math so much?
Julia: What if you just added some “why’s” around the calculations? Instead of “which equation do you choose?” maybe “which equation do you choose and why?”
Clyde: Maybe that is not unreasonable.
Joe: We could do a power of why question.
PR: What if we did two columns: calculate the value, then justify?
Rodney: They hate those.
Julia: We could do the columns.

All of the participants agreed to add columns beside the calculations asking for justification. If time became an issue, the justification portion could be completed for homework.

The group was in consensus that participants should select the next Research Lesson using different criteria.

Warren: There was not much of the misconceptions that we were looking for.
This would probably be found on the day after, the lesson after this one.
Joe: This was good and interesting to see, but I kind of felt like it this was about labs and how students set up labs and go through the process, this day would have been good.
**Modifications.** In response to the Debriefing Meeting, the participants decided to change the shape of the bullseye to be fairer in grading the challenge. Specifically, participants agreed to redraw it with elongated ovals instead of the traditional concentric circles. The directions for the vector drawing conceptual problem were restructured to be extremely specific, asking students to draw the vectors with appropriate lengths and directions and to construct the proper shape of the projectile path carefully. Finally, participants agreed to add a second column to the calculations to request that students justify their calculations or tell why they selected the equation which they selected.

**Research Lesson Two**

Research Lesson Two (Appendix L) was composed of a series of video clips chosen to spotlight falling objects as they get farther and farther from earth's surface. This series of video clips was interspersed with the questions: (1) What is the evidence of gravity? (2) What is the evidence of weightlessness? After each clip, students answered the questions on their whiteboards as they discussed them with their tablemates. These whiteboard answers were used to feed the whole-group discussion.

The second Research Lesson was much different from the first. This lesson displayed the numerous misconceptions of students. All participants were in agreement with Warren who said that "Joe really did a good job." This lesson served to get students verbalizing what they believed and why they believed it. As Warren summed, "we heard a lot of thinking and what the kids were wrestling with." Observers noticed that the lesson addressed some misconceptions, aggravated other misconceptions, and participants needed to address others at a future time strategically. Overall, this lesson served as a common experience for students, allowing teachers to refer to this experience as a means of universal clarification and learning.
**Misconceptions.** Research Lesson Two was filled with evidence of student misconceptions and affronts to these misconceptions. Students were verbalizing them, arguing about them, and confused by evidence contrary to them. The long list of witnessed student misconceptions included those about:

1. Newton’s Laws
2. Different masses fall at different rates.
3. Some places have no gravitational force.
4. There is no gravity in/outside of earth’s atmosphere.
5. Weightlessness means no gravitational force.

**Newton’s Laws.** Newton’s Third Law came up twice during the lesson. Specifically, the students eluded to it during the ISS video clip as well as the sun and Jupiter revolution animation. Rodney noticed some application of Newton’s Third Law.

Rodney: Did anyone hear the one group that was talking about the space station and said it had unbalanced forces? They were saying that her curls stayed intact. Even though her hair was up…something about her curls. Her hair didn’t straighten out. It was kind of scattered. Then they said, well the shuttle, isn’t floating away.

The final video clip in the series illustrated the mutual revolution of the sun and Jupiter system. The teacher could have alluded to this generic simulation as the sun and earth system or the earth and moon system. It clearly showed the bodies moving around a center of mass outside of the center of the sun. This motion revealed the fact that the sun is also revolving around Jupiter as Jupiter revolves around the sun. The students were shocked. They made many comments of disbelief.

PR: I think Julia and I realized some misconceptions that we hadn’t even talked about. Julia nods in agreement.

PR: You did the Jupiter/Sun animation, and their deal was they thought that something had to be bigger than the one object in order to exert a gravitational force on it. Nothing to do with having mass present, it is because the mass is bigger than. So the sun can pull on the earth because the sun is bigger. The earth can pull on the moon because the earth is bigger.
And they were serious about that, so I don’t know if you heard that comment, but when we were talking about…what’s moving the sun!

PR mimicking student: What’s moving the sun?
Girl student: There’s nothing bigger than the sun.
Another girl student: Jesus Christ must be moving the sun. It’s Jesus!
PR: I know they weren’t serious, but that was a great response. But they were seriously looking for something bigger.

Continuing with that idea, Joe agreed that many were amazed by that simulation.

Joe: I obviously didn’t take any notes, but I could tell things…the one in the back, some of those were shocked by the sun moving. Yea, I kept hearing “the sun moves, but why does the sun move?
Warren: It’s amazing how they can quote it, but make no association with it, they are looking at it but Newton’s Third Law—eh.

**Different masses fall at different rates.** If asked to quote it, students had often quoted that all objects fall with the same acceleration. They could also tell the story of Galileo and the tower of Pisa, but when asked to apply this to a new situation, they struggled. The video clip which showed Baumgartner jumping out of the capsule for the highest freefall jump world record seemed wholly unexpected for the students. Joe took a survey by a show of hands as to what students anticipated would happen once Baumgartner had made his assent, opened the door, and peered down on the earth below. Joe paused the video and gave the students options.

Joe: What do you think will happen next? Will he step out and float? Will he have to push off to get started falling? Will he fall slowly? Will he drop like a rock, very quickly?

Joe surveyed the whole class, going through each option. One group thought he would float; two groups said he would have to push off. The remaining groups all said he would fall slowly.

The video clip commenced, and the students were shocked, shouting "no way!" and other words of disbelief. One student, yelled, "I told you so!" but clearly had not. During the discussion that ensued, Joe explained how relatively close Baumgartner still was to the earth.

Boy student: What would happen if he dropped his air pack while he was falling?
Joe: It is experiencing the same acceleration rate due to gravity, so it would fall with him.

Joe then proceeded to do a sketch on the board. He drew a stick figure to represent Baumgartner and then a pack beside him. Joe then drew a circle to encompass them both. He explained that it was the same as if they were both falling in the capsule or a plane. It was a matter of focusing on the masses being effected by gravitation.

Julia speaking to Joe: You said, “Like if we do encapsulate the guy…”
Rodney: I thought that was a really good illustration that you made!
Warren: Yea
Rodney: Someone must have done a video somewhere where you are falling with something.
PR: If you put a penny on your leg in the Six Flags ride where you drop…the Freefall?
Joe: Because if you are falling with something, then you have to bring in the point of reference.

The participant-teachers agreed that using point of reference at this point in student learning was ill-advised.

Some places have no gravitational forces. Students seem to have been exposed to the workings of gravity outside of the earth's immediate atmosphere from sources that are often not scientifically sound. They have heard terms such as weightlessness and zero gravity. Then these casual terms were merged with their new physics understandings of weight force and acceleration. The fuzziness of the understanding became evident in this Research Lesson. The lesson began to combat some misconceptions by illuminating and focusing on vocabulary.

Warren: I think it was a really good idea to bring in the idea of zero gravity, I think that is an easy thing to change to no gravity.
Clyde: There is still a perceived difference between zero gravity and weightlessness.
Rodney: Somebody said, some places have gravity, others do not.

One student group showed evidence of emerging scientific thinking.
Joe: This group asked, “Doesn’t gravity get less as you go away, and that is a really hard question to answer. Because yes, the answer is yes,
Joe mimicking response to students: But I know what you are thinking and why you are asking that you are thinking that it disappears, that it goes to zero.
Joe to participants: That was scary, I don’t know how to address that. So I said [to students] “like yes, but don’t think there is no gravity.” It didn’t feel like they were able to understand that gravity is acting.

No gravity in Earth’s atmosphere. The first instance that it became apparent that students believed that some locations would not experience gravitational force was during the Baumgartner video clip. The video clip was paused, and students were given choices of what might happen when he stepped out of the capsule to jump. Joe noted that most of the groups said that Baumgartner was going to drop.

PR clarifying: But when they said drop, they were choosing between 4 choices: you said he would go out and float, he would propel himself to get started, then they all said he would start really slowly, and then he would fall downward, so when you said that he would drop. I don't think there was a single student in there (I could have missed one up front) but I don’t think a single student said that he is going to drop like a rock. It was all slowly.

Thinking in subsequent video clips supported this unified perception of the strength of gravitational force diminishing quickly (presumably until it is extinguished). The next layer of zooming out was the video clip of the ISS orbiting the earth. Students again doubted the presence or strength of gravity.

Rodney: Then for the ISS, I heard, gravity is not in outer space. So someone said no there is, then another, space doesn’t have gravity. There was a debate in that group.
PR: I heard them say, they are in outer space, therefore there is no gravity. It was defined, if you are in space, then there is no gravity.

The misconception became better defined as some students revealed their assumptions.

Joe: My kids kept making reference to a line of gravity.
Joe mimicking students: Is it in the atmosphere or outside of atmosphere? Is it in the line of gravity?
Julia: I heard that too...outside the atmosphere and in the atmosphere...
Rodney: Class-wide, they all said it's a border...what is the gravity border?
PR: One of the published misconceptions is there is no gravity in a vacuum. I wonder if what that means in application is that once we get past the atmosphere and there is no air, that is when gravity turns off?
Clyde continued with more evidence of this misconception.
Clyde: And I heard the one group say that there is no gravity on the moon.
Warren: I think they just put the words "no gravity" in place of "no air." They seem to just put the word "gravity" in when you really wanted to hear them say support force or something....

**Weightlessness means no gravitational force.** The ideal explanation for the layman term weightlessness was the reality of a missing normal force. When the supporting force was missing, the gravitational force was allowed to accelerate the object freely. This reality was something the participants agreed students needed to conclude for themselves. Thus, the video clip about the Vomit Comet consistently asked students for evidence of gravity and evidence of weightlessness. This construct forced students to define both better and to try to understand the conditions necessary for both better. A portion of the lesson was given below.

Clyde: Once when you asked about evidence of gravity in the Vomit Comet, they said the balls were staying on the ground,
Clyde mimicking Joe: well how do you have no gravity?
Clyde: Then this one lady said: "well you manipulate the plane to have weightlessness." She knew the general idea that you had to do something to the plane.
Clyde speaking of Joe: He said if you have a video of outside of the plane, what would it look like? It wouldn’t appear to be weightless; it would be falling. I thought that was a good observation, that without the frame of reference, you would be falling.

The next video clip in sequence zoomed out more and showed the inhabitants of the International Space Station (ISS). Here, the astronauts were flying from place to place and living in what is known as a zero gravity environment.
Rodney: I saw a few that put down that the earth pulls ISS to stay in its orbit and one drew a picture of Baumgartner and that he was 26 miles above, they made a little diagram 26 miles to earth and drew a globe.

The team acknowledged that this perspective helped students to remember the earth and its gravitational force still present. Joe summarized one of the learning from the ISS video. Joe said, “It was a tough sell for this lesson to get them to buy that the ISS is falling. They agree that gravity is acting on it, and that is why it's orbiting, but there is a little bit of a disconnect that gravity is causing them to fall.”

Participants then discussed their plans to continue the learning in subsequent lessons.

Joe: I think this lesson really bubbled up all the misconceptions. I don’t think this lesson did as good of a job addressing them. Yeah, it’s hard for me not to rush and then just say—this is the way it is.

PR: So will you springboard off of this as you introduce Universal Law of Gravitation? Will you go back to Jupiter/Sun? What is your plan to follow up?

Joe: I think I will still start off with the two orbiting each other, where we left off. I would like to kinda put a bow on it. And I won’t be observed in that class, so I should be able to.

Warren: I think the simulation that you had Nancy would be a really good way to pick it back up.

Clyde explained where he would go with a follow-up to the lesson to try and build true conceptions.

Clyde: I usually have them calculate the gravitational attraction between them and the person sitting next to them. If that is true about you and that person, now what about everyone else in the room?

Clyde mimicking the students: You see them kinda look around…

Clyde: I always think they leave that conversation thinking that I am making it up. Julia and PR nod.

Summary of Research Lesson Two. This disconnect between student understanding and the video examples became apparent in response to much of the videos. The video clips served to challenge the students' understandings. The clips made them question their assumptions. The clips did not fully change those assumptions. This lesson successfully
engaged the students, targeted misconceptions, and allowed observers to fully witness the
thinking behind much of the student misconceptions related to gravity and weightlessness.

Joe summarized the student learning and understanding at the conclusion of the lesson
from his perspective as the teacher.

Joe: They feel like it is not possible. That is not like what they have always
known…if you drop something it falls, and then we show them this, and it is
kind of like…
PR: It might be nice to develop a definition instead of the force that pulls down on
any object into the force that pulls between any two objects. …when I am in
the plane, I am looking for things to fall down, but if I am on the edge of the
earth, I am looking for things to fall towards the center of the earth. So I
wonder if changing the perspective of down might help.
Warren: I think the video clips did a great job of doing a zoom in to a zoom out
clip by clip, but I do wonder if there is some culmination or introductory
approach that we could literally hit the zoom button on the camera, and
go from [close to far].
Clyde: You don’t realize there is an orbit until there is the orbit.

The teachers pondered how to maximize the learning in response to this highly effective opener
to gravitation. They discussed follow-up lessons and the best strategies to tackle the many
misconceptions that had surfaced during the Research Lesson.

Modifications. In addition to addressing the needed responses to clarify concepts and
combat the dangling misconceptions, the participants agreed on some modifications that should
be made prior to the second implementation of Research Lesson Two. The participants
implemented all modifications that were feasible to accomplish before the teaching on the
following day. Adjusting video clips in less than one day was not feasible, but was suggested for
other implementations of the lesson in the future.

Clyde: I also think that we need to have something in between from where Felix
jumps straight down to the video where something is moving in a circular
path, because what would happen if he was able to propel himself forward
fast enough. It might be better to bridge the ISS.
PR: I wonder if you could go back to the scene where he stepped out and freeze-
frame it on the board and then ask. What happens if he pushes off and then
draw the path. Now, what happens if he pushed twice as hard….and start
drawing projectile paths…
William: That might work.
Joe: What if on their whiteboards, you asked them to draw what is happening to
Baumgartner. Draw the path. And then we show it and correct the drawing.
Then ask them to draw the path of the ISS… You could have them draw
what happens if they push off a little bit.
PR: Maybe it is sitting there staring at them when they look back down.
Joe: I feel like they need some scaffolding there. Otherwise, I don't think they can
make that jump.

The participants agreed that the teacher strategy of sketching a circle around the falling man with
his gear was powerful when explaining to students the Baumgartner video

PR: Please add that to the teacher notes…that was a really good thing to do…to
encapsulate the free-falling person in a bubble on the board.
Julia and Warren nodded emphatically.

After hearing the misconceptions in group discussions during the Research Lesson, Clyde
considered adding a preconception question to the list of four to articulate the student conception
better. Clyde wondered, “Should I add a fifth question and say there is no gravity in a vacuum
and see if they feel that way?” The participants were in agreement. Clyde added it to the Google
Doc.

The last potential modification had been hovering in conversation throughout the day. I
verbalized:

PR: So I was wondering, I do wish there was a way to show or zoom in on the
person riding the plane, then zoom out and see the plane, then zoom out and
see the plane around the earth. I wish that there was a way to use this
repetition to show the concept.
Participants nodded in agreement.

In response, the participants again went to their laptops to search for another video clip or
inspiration on how to do this. After a few minutes of concerted effort, participants found no
answer. Participants agreed to keep looking and to share if they found the answer in the future.
Teacher-Reported Outcomes of Lesson Study

The next question addressed by this research was the second research sub-question, *What are the teacher-reported responses to Lesson Study as a professional development opportunity?*

The primary sources of data for determining the teacher-reported outcomes of Lesson Study were participant journals and exit interviews. Participants had varying levels of detail in the journal. Some participants used the journals as both a source of documenting happenings from Lesson Study meetings and Research Lessons, as well as a place of reflection. Others predominantly reflected. Each participant was comprehensive in the final interview. The most logical categories for holistic coding were by the name of each participant: Clyde, Joe, Julia, Rodney, Warren. This strategy for coding allowed the reader to understand the overall individual outcome of each teacher-participant better.

Clyde

Clyde's initial goal for professional development was to "tap into students' metacognition, trying to grasp how they think about physics to improve [his] delivery." Also, Clyde was most motivated to participate in Lesson Study as a means of professional development to help him target the level of content for his first honors level physics class. Clyde had been an AP Physics teacher consistently up to this year when he was given one honors level class in his schedule. He explained that the opportunity for, "cross-school teacher collaboration was particularly useful for me since I am teaching honors for the first time after teaching AP for many years. It really helps me to calibrate the level of delivery." Clyde continued, “Additionally, it [Lesson Study collaboration] helps me a great deal to leverage the experience of the more seasoned honors teachers in terms of lessons…that pertain to the standards, contrasted to my habit of meeting college board standards...”
Clyde found that reading the research articles and reflecting on this reminded him of successful strategies that he had used to teach physics in the past. He was reminded of the historical conception of motion, of objects from a “carrier,” reminding him of a demo that he once did. Clyde found that the research articles and the discussion sparked some ideas that he wanted to try in the future, including sample questions from the index of a shared research article. Clyde was eager to embrace the preconcept quizzes. He tallied these in his journal and reflected on strategies to target them. He then carefully “re-worded [the preconcept questions for the Research Lesson] a couple of times” to best assess students. In response, Clyde added a “fifth question about gravity in a vacuum to see how it would correlate with the question about gravity in deep space.” He pondered, “Despite what I thought were clear instructions in the document, none of my students made the connection that they were actually supposed to draw velocity vectors along the path of motion.” In response, he significantly fine-tuned the directions.

Clyde had been particularly pensive in his journal. In one entry titled A Meta-Reflection, Clyde analyzed his subsequent teaching of the first Research Lesson for his students. He writes:

I had mentioned that the motion diagram was universally missed. I think I know the reason for this. The previous day I had students do a worksheet on various horizontal projectiles. Since this was while I was engaged in Rodney’s lesson study observation, I felt compelled to provide a "worked problem" for students to model. These were entirely word problems, so in this sample problem solution, I made the statement that a "picture often helps” in which I drew the ramp, table, and path of a projectile. So the next day, students drew the word diagram, they completely ignored the fact that the quest called for drawing vectors; they simply drew the picture they saw the day before, with no vectors. I follow-up, without telling students what I was up to, I sent students to the board one at a time asking first to draw a vx vector, then vy, then constant vx an increasing vy and finally the path of a horizontal projectile. Then I asked them to re-read the question about the motion diagram, and several said "Ohhh!"

Clyde acknowledged new learning to help him better understand his students' needs. He explained that regarding high school students’ understanding of projectile motion concepts, “a
point that I often overlook is that when my students seem to have learned past their misconceptions, applying the same knowledge in an unfamiliar situation results in reverting back to previously held misconceptions when students knew better.” Clyde concluded, “This perhaps points out the need for more than just repetition, rather repetition from as many angles as possible.” Clyde began keenly looking for misconceptions. Not only did he begin to layer his teaching on the independence of the velocity components in all situations, he anticipated the stubbornness of the misconceptions from his students and implemented Preconception Quizzes to assess the degree of misconceptions prevalent on specific concepts. He then used this process to inform his instruction.

Clyde was quick to share his reflections and ideas. He brought in the demonstration of the horizontal launch of a moving object as well as the two body launcher to show that both a dropped ball and a vertically launched ball will hit the ground at the same time. Clyde sent out a link and initiated a discussion regarding a digital article he encountered which detailed the lack of highly qualified physics teachers. He summarized, "This may be of some interest to our meeting this afternoon: 40% of US schools lack highly qualified physics teachers. And of the 40% that do offer, many [teachers] have been adopted from other disciplines. I have sat in numerous workshops where in passing conversation I hear of a biology teacher attending the workshop because they will be teaching AP Physics next year, for example.” The group appreciated this contribution as well as the video clips with a file categorizing the clips according to physics topics, from an old NSTA conference that he shared. He summarized his spirit of sharing, “It is likely that everyone is familiar with this, but I will bring it to today’s meeting just in case.”
Clyde itemized the benefits that he had experienced in response to Lesson Study. Clyde confirmed, “This [Lesson Study] was particularly helpful in my honors class this year since I have only one honors class. It was useful to observe a lesson, then have a chance to fine tune it before I deliver it to my class.” Clyde continued:

Another benefit [for participating in Lesson Study] that I did not see directly addressed is for the seasoned teacher. The more seasoned I become, the more I am inclined to subconsciously say “been there, done that.” Collaborations such as Lesson Study not only help novice physics teachers with potential misconceptions, it also helps to remind seasoned teacher that while they have “been there and done that”, their students have not. A case in point is the demo I mentioned 4 entries ago to address the misconception of their needing to be a force in order for motion to occur. This also suggests to me that the best collaboration would be with teachers of varying experience levels…it is critical for the non-judgmental aspect of these meeting to be in place. Even so, it is a difficult thing for anyone to bare their misconceptions among their peers or to offer insight without the worry of sounding overly critical. Nevertheless, collaboration with other teachers, especially across institutions always presents new and fresh ideas.

Clyde began listening to his students more in response to the Research Lesson experience in Lesson Study. He found that sometimes, “In the absence of more specific guidance from me, students did not attempt to employ logic, but rather relinquish understanding to a fellow classmate who appeared to be in tune with what to do. He concluded that “the most helpful thing to me was calibrating my teaching with respect to teacher and student interactions that I don’t normally engage in.”

Clyde identified three downsides to the Lesson Study with physics teachers. First, he noted that “there was a bit of a downside in the serial nature of the process. Since it was not originally an integral part of my lesson planning, it felt as if I was losing a couple of days of instruction, at least relative to my initial plan. Of course, the lesson study was not lost instruction, but I felt the serial nature of the lesson study to be a bit disruptive.” Secondly, Clyde was disappointed that his PLC did not incorporate the learning and experiences of the Research Lessons into the summative assessments. Third, he noted that “the days of observation were a bit
disruptive to lesson planning, [even though] in-person observations are the most efficient.” He suggested that the Lesson Study process would be improved through “up front planning around observation days.”

Clyde was complimentary of the Lesson Study Process overall. He noted that he was carefully articulating questions and listening to his students more. Clyde also was intently aware and sensitive to the relevant misconceptions. He was made mindful of the fact that these misconceptions are difficult to reshape to redefine students’ understanding of the topic, requiring scaffolded experiences to push past misconceptions. These foci shifted his teaching, making him more aware of the metacognitions of his students, which was his original professional development goal. Clyde summarized:

Also, all of this was done in a non-threatening, non-judgmental setting in which it seemed there was a free exchange of information and observation. It was a growth experience as are nearly all collaborative activities. But then again being pulled out our element is rarely a bad thing.

Joe

Joe was quick to ask questions and collaborate by nature. He was a brand new teacher and loves his content. Joe's primary goal to participate in Lesson Study with physics teachers was to become a more seasoned teacher. He wanted to learn as many strategies as possible for teaching physics. He also was hungry for physics Pedagogical Content Knowledge.

Joe appreciated the research articles. He claimed that some of them “really helped [him] characterize the misconceptions I deal with in my classroom.” One interpretation of a demonstration by his students had stumped Joe. He explained:

When going over the comparison between a dropped bullet and a fired bullet, most students who have misconceptions about the fired bullet seem to think that the gun gives the ball some impetus force...even when compared to a drop-shooter (the spring loaded mechanism Clyde showed) they still believe there is a difference in the two problems. I've always associated their misconceptions with the distance each one would travel. I
thought they would believe the fired one would hit the ground later because it has to go further, but instead, it’s primarily because of this impetus force.

Joe realized much about student misconceptions and faulty thinking. During the observation of Research Lesson One, Joe noted some faulty thinking:

Despite having the equations explained to them, most students began setting up their apparatus in order to start measuring velocity/rolling their ball. Many groups tried to roll the ball off the table and catch the ball before it hit the ground to see around where it would land. Demonstrating a lack in confidence of the methods/calculations.

Joe was also quick to share ideas or experiences. Regarding the misconception that no gravity acts on the space shuttle, Joe located a strong image and then edited it to make it a powerful illustration for the analysis questions for Research Lesson Two. He further shared in discussion his experiences with this specific video/image of a projectile being launched “that can help address this misconception; it shows the increased projectile speed increases the length of the curved trajectory, and will eventually lead to the projectile constantly falling around the curvature of the earth.” In his journal, Joe had a list of “links for later” which he avidly shared.

Joe developed some strategies to address student physics misconceptions. He reflected, “Having the follow-up day immediately after the lesson is a more ideal way to cover these topics [misconceptions and analysis]. Joe also considered pretesting students to identify their primary misconceptions and then targeting these misconceptions through differentiation. Research introduced Joe to the impetus force misconception through research. He used his journal to hash out the implications of impetus force in his students and their beliefs.

Joe experienced two frustrations with the Lesson Study meetings. First, he noted that:

Staying focused on designing the lesson is difficult. There are several tangents that distract from the overall objective of the lesson study. Sometimes the tangents are good, and they relate an anecdote to some method or idea we can incorporate in the lesson, but often times I feel like we get onto a tangent that never really helps progress the objective of the meeting. This isn't really to say that they aren't fun/interesting topics to talk about,
but rather our meetings could possibly be more productive and focused if we keep our objective in sight.

Second, he expressed concern that “the time it would take to have these meetings and create these quality lessons could be tricky to implement without taking time out of other meetings/activities during the week.” Lesson Study was a time-consuming process.

Joe found value in the Lesson Study with physics teachers:

The lesson study was an excellent way to collaborate with other physics teachers and see how they teach, assess, and plan instruction for their students. In my current situation...we do collaborate when we plan our lessons but not to this extent, and I can clearly see difference in the lesson quality through doing a lesson study. This process becomes more and more effective the longer it’s done because course teams can now build upon their pre-existing lessons from previous years. Without a doubt the lesson study process was helpful. Not only in opening my eyes to very good methodologies to creating lessons but also to help understand how powerful collaboration can be when extended outside your department at your school.

Julia

A seasoned physics teacher, Julia stated that her goal for professional development was to “focus on developing physics lesson plans centered around lab experiences.” She seemed to want to become a better teacher through a collaborative professional development. This quote from Julia’s journal might indicate that her goals were “benefiting from the discussions and learning [and to] to contribute strong points within a meeting, instead of just agreeing with the lead teacher on plans...[and] help[ing] me to expand and re-approach content.”

Julia identified new strategies and resources to help combat her students’ physics misconceptions. She added videos and preconceptions tickets in the door to her tool bag. She also learned that stretching the lesson to the following day for both the observation and discussing misconceptions might be valuable. Specifically, Julia valued:

the video of the sky diver [as] a great way to tackle the misconception there is not gravity in space. Students always seem to think there is a magic line where gravity clicks off.
Viewing this video can allow me to address the ideas of gravity that students already have in their thoughts and help me to gear the way students answer concept questions.

Julia also explained that the “ticket in the door was a great way for me to see that a small percentage of students were hanging on to their misconceptions.” The other item of learning for Julia occurred in reflection of the first Research Lesson. On the day of the projectile lab, “The students did not get to any of the concept questions; We discussed that maybe we should have observed the day after the lab to observe the ideas of the students.”

Julia found profound value in the collaboration process. She explained, “The process helped me to broaden my use of Google for collaboration with other teachers. I enjoyed the process of collaborating with other physics teachers to develop a strong lesson plan.” Julia claimed, “I found the collaboration on the Google documents to be very helpful, and I am hoping to incorporate this into my lesson planning with my PLC groups. We all contributed to the document by using the shared aspect of Google Docs.” She further evaluated the benefit of this simultaneous method of writing and discussing a lesson plan, “This is a very powerful tool for teachers open to using Google docs to develop lesson plans….I do believe that coming together as a team created a very beneficial assignment.”

Julia was thorough in her journals. She embraced the process of Lesson Study as she articulated, “The lesson plan procedure focuses on teacher collaboration and reflection.” She detailed her unspoken comments as well as her comprehensive reflections. Julia underscored, "I am reminded of the power of reflection.”

Julia identified a difficulty with the Lesson Study process. Julia struggled with the time commitment, specifically the amount of time necessary for creating, implementing, and reflecting on a single lesson. She explained, “The time it takes to collaborate with 4 to 5 other teachers is limiting at best…and then reflect instead of plan ahead. I just do not know if there is
time within the day.” Julia struggled with the large amount of time that was used to develop two lessons over the course of the Lesson Study, “Time, Time, and more Time…I cannot imagine spending this much time on one lesson. I usually spend 1-2 hours per unit co-planning with other physics teachers and then just touch base on content as we move through the unit.”

Julia found the Lesson Study process to be helpful. She explained that Lesson Study “helped [her] to go back and refocus on the common misconceptions for students, …to reevaluate [her] time with students in the classroom, and to step back sometimes just to observe their behavior.” She also came to believe that:

Revisiting of the lesson with a focus on what did the lesson accomplish can be very beneficial. I have throughout the process learned to observe my class more during a lesson; are they discussing the topics I have given them; are they engaged in the lesson; and most importantly are they benefiting from the class time?

Julia summarized by identifying the following benefits of Lesson Study in her journal:

- Teachers collaborate to develop a meaningful and comprehensive lesson.
- Teaching techniques are shared between teachers with the shared subject.
- Lessons are shared between teachers.
- Teachers are given time to reflect on the lesson design and see if changes need to be made.
- Teachers are given the opportunity to try new types of lessons.
- Teachers are supported for collaboration and given time to create and reflect on the process.

Julia, a more seasoned teacher, seemed refreshed by the Lesson Study process. She admitted to becoming more cognizant of her students, their thinking, and their struggles with specific misconceptions. She reported re-focusing on her students’ learning in contrast to simply what to teach.

**Rodney**

Rodney was a seasoned physics teacher of honors and other levels of physics. He was an avid contributor to the process, hosting the meetings in his classroom and avidly involved in
discussion. Rodney’s personal goal for Lesson Study was never delineated. Rodney predicted that Lesson Study “can be useful to those teachers that like to collaborate and plan with others.” He continued, “I enjoy that aspect of teaching and feel this would be very beneficial to beginning or inexperienced teachers [as well].” His motivation towards the collaboration indicated that growth in professional knowledge and skill was a closely aligned goal.

In addition to Rodney endorsing the Lesson Study process as a valuable and viable learning opportunity for all levels of physics teachers, Rodney found value in the research articles on misconceptions. He commented, “Interesting reading about projectile motion misconceptions.” He further validated his teaching through the published experiences of others, for when he addressed the dependence of velocity components misconception, he was “glad to read that this misconception is worldwide.” Admittedly, Rodney voiced, “The research literature provided was very helpful to me.”

The new understandings and the statistics showing the degree of student misconception belief motivated Rodney. He embraced the new strategies. Rodney appreciated the collaboration and the general sharing that transpired. Rodney was meticulous in giving preconception quizzes to every student and tallying them. Rodney gained new insight into student misconceptions, their details, and their invasiveness. During the observed Research Lesson, he journaled, “I was surprised by some of the misconceptions voiced by the students.

Rodney enjoyed the learning from the Research Lessons specifically. He valued the critique of his teaching, lesson, and students. Specifically, he valued the additional ears in the classroom to hear his students learning and misconceptions. Rodney was the first teacher for Research Lesson One. He valued the opportunity to teach in front of colleagues for feedback. He explained, “I found the feedback from the lesson study at CH to be very helpful. It was good
Rodney was eager to learn from watching other physics teachers teach. He wanted to see a new perspective and pick up new strategies. For example, he claimed, “I am interested in hearing the explanations for weightlessness.”

Rodney had few complaints about the Lesson Study process. He stated, “I would likely have kept my original timeline for teaching projectiles and focused on 2-D motion.” Rodney found benefit to the Lesson Study process. He claimed to have “Enjoyed the discussion of what we found as valuable to us and our students. The planning sessions were beneficial to me as a way to see other viewpoints on approaching these lessons.” Rodney summarized his thoughts on Lesson Study:

I enjoyed working with other professionals in my area of emphasis. The ability to share and discuss different viewpoints that were combined to develop an effective lesson was very gratifying to me. The review of the lesson with other physics teachers before teaching the lesson, the after action discussion post lesson was very helpful in planning future lessons. The outcomes of participating in Lesson Study for physics teachers for me would be a more confident opinion that I am working to improve my approach to teaching physics and am an effective teacher. This type of process is something that can help me improve that effectiveness.

Rodney expressed that Lesson Study served to build his teacher self-efficacy, his confidence for teaching physics. He also believed that it helped him fine-tune his teaching strategies and lessons, making him a more effective teacher.

Warren

Warren was a relatively new physics teacher. He had recently finished teacher certification classes which helped him to focus on a shift in content from geology to physics. Warren’s goal modeled Joe’s. He too wanted to become a more seasoned physics teacher. Warren had had a short opportunity to experience Lesson Study in a pre-service teacher training
program and found much value in it. Warren wanted to now work with more experienced teachers to build more lessons.

Warren was avidly thinking and problem-solving behind the scenes. His journal reflected detailed ideas for lessons. He was slow to begin collaborating but became a strong voice in the discussions fairly soon into the process. His journal revealed:

I did not bring up the differentiation issue as thoroughly as I would have liked, but I plan on supplying some scaffolding questions to help students in need. I also have a couple of ideas for extension questions, though these could use some fleshing out.”

Warren was often seen checking his watch or anticipating a call from his pregnant wife. He seemed afraid to speak much as this would increase the length of the meetings. Once he began contributing whole-heartedly, as if he simply could hold back no more, he implemented a strategy to balance his time. Warren would occasionally leave a little early, always volunteering to write something up or research something as a closeout for his participation that day. In this way, Warren was able to actively participate and become a valuable member of the Lesson Study team while still meeting his family obligations.

Warren was the primary author of the second Research Lesson. He presented a lesson that he had utilized in the past as a foundation.

Warren discovered some strategies to help deal with his students’ misconceptions. In retrospect of observing the first Research Lesson, he echoed other participants’ revelations, “A perfect lesson to observe would be one given the following day addressing those misconceptions directly.” In evaluation of Research Lesson Two, he concluded:

These videos and discussions did wonders for drawing out student misconceptions. To truly accomplish the stated goal of tackling misconceptions, it seems like a multi-day approach may be the best method: one day to draw them out (which this lesson was great at), another to tackle them (preferably a lab or other hands-on activity).
Warren further identified some struggles with confronting misconceptions, especially with abstract physics principles. He summarized:

> It was difficult to directly address some students' misconceptions; in general, hands-on activities would be better (though impossible with this unit). The only tactic available was to discuss their misconceptions. This worked with some students, but others remained skeptical or confused.

Warren concluded regarding misconceptions, “The main thing I took home from this lesson study, and its focus on misconceptions, was that it is very difficult to adequately address misconceptions in a single lesson.”

Warren expressed his frustration with not focusing tightly enough on the goal of producing the Research Lesson expeditiously:

> The meeting went well, as they all have, but I felt like the discussion(s) on student misconceptions was/were a bit too broad. Our goal for this lesson is to address the content and associated misconceptions of a lesson that will last a bit under an hour. I felt like too much conversation was devoted to broad-scale misconceptions, spanning out to the rest of the unit and branching out to others. We seem to be spending more time talking about interesting things rather than focusing on our task.

Warren was further frustrated when something paused the lesson-creating to relate events or ask advice of other participants about current occurrences of teaching and learning. He explained:

> Unfortunately, our actions during the meetings are not quite so focused. We spend a lot of time with anecdotes about our students, discussing interesting tidbits that are tangentially (if at all) related to the task or concepts being covered…Sometimes the tangents are good, and they relate an anecdote to some method or idea we can incorporate in the lesson, but often times I feel like we get onto a tangent that never really helps progress the objective of the meeting. This isn't really to say that they aren't fun/interesting topics to talk about, but rather our meetings could possibly be more productive and focused if we keep our objective in sight.

Warren valued the collaboration. He elaborated:

> Working with other physics teachers was a great experience, especially because we got to work with teachers from a different school. It was refreshing to be exposed to new materials and, most importantly, new ways of looking at the content. Working with similar-minded teachers was great. Seeing other teachers in action is always helpful:
when they struggle, you feel validated that you’re not the only one with such issues, and when they are successful you acquire new insights on how to run your class.

Warren found practical application in the Lesson Study process. He was pleased to be able to create, witness, and implement new lessons. Warren elaborated:

Seeing other teachers do the same lesson you will do makes your insights all the more relevant. I’ve seen other teachers do wonderful things in their class, but wonder how I can implement their tactics. By seeing teachers working on a lesson that you will do (or have already done, depending on the situation), you can implement changes with great efficiency.

Warren felt the Lesson Study with physics teachers’ professional development was a success. Specifically, when asked what he would change about the Lesson Study process, Warren exclaimed, “Very little! I really enjoyed it!” He elaborated:

The only thing I would comment on is the lack of focus that was sometimes present in the meetings. I mentioned the camaraderie of our group earlier, which was of tremendous benefit to this process, but the touch of gray from our excellent chemistry was a sometimes rambling and off-topic meeting.

When asked if he would see a benefit in doing it again, Warren said, "I absolutely do. I hope to do it again soon.”

Warren summarized Lesson Study and his learning as follows:

It is a lot of work, but it is worth the effort. If I were to design a Lesson Study program for my course team, I would try to work on a lesson (or lessons) that could use a significant boost. I personally would probably try to create a lesson that is differentiated, as our administration has very high expectations for us to do differentiated lessons. If I were to stay on the path to address misconceptions, I would try to focus on a single misconception for the lesson study.

**Summary of Teacher-Reported Outcomes**

Each of the secondary physics teachers claimed that they found the Lesson Study process valuable. Each of the participants further met their participation goal to some extent.

Specifically, Clyde began tapping into the metacognition of students; Joe became more seasoned and learned new teaching strategies; Julia had an opportunity to focus on lesson plans centered
on labs; Rodney had the chance to collaborate and grow in professional knowledge, and Warren learned new strategies through collaboration with other physics teachers.

The team of physics teachers valued the research articles, exposure to new teaching strategies, deepened understanding of misconceptions and strategies to combat these misconceptions, sharing in a safe and collaborative setting, and opinions from other physics teachers. Clyde, Joe, and Rodney all found the research articles helpful and insightful. Clyde, Joe, and Julia listed specific strategies that they would continue to employ in their classroom. Clyde, Joe, Rodney, and Warren all felt stronger in their understanding of student misconceptions as well as their ability to use strategies to target their extinction. Clyde, Joe, Julia, and Warren each purposefully shared with the group from their experiences and problem solving regarding physics teaching and lesson enrichment.

Through Lesson Study, participants used their journals to brainstorm and reflect. Clyde, Joe, and Warren all problem-solved dilemmas for the lesson that the team was creating. They further recorded resources in their journals for following activities, often to share with the team. Clyde and Julia were deliberate and detailed in their reflection. They pondered student understanding. They looked for ways to fight misconceptions and maximize the learning. All of the participants used the journal as a way to improve themselves as teachers.

Participants reached much consensus in their benefits from Lesson Study. Clyde and Joe were pleased to better establish a definition or differentiation in the level of students in the honors classroom. Clyde, Julia, Rodney, and Warren noted Lesson Study caused them to have a fresh outlook on their teaching and the content. Clyde and Warren both commented on the non-judgmental nature of this collaborative professional development. Clyde and Warren both specifically appreciated the opportunity to cross institutional boundaries and to meet with a
second Professional Learning Community. Clyde and Julia both revealed that they were consciously listening to their students more, for insight into their thinking and level of understanding.

Participants also shared views regarding the struggles with the Lesson Study process. Overall, all participants were concerned in some way about the time spent on Lesson Study. Clyde was concerned with the time it took away from his other teaching obligations, as he only taught one section of honors. The time involved in Research Lesson observations during a regular school day impacted his teaching and pace for the other classes. Clyde also was frustrated that the new lessons did not mandate an adaptation of the old common assessments, to incorporate these new elements of learning. Joe and Julia both were concerned that it took many hours of planning and observing to write a single lesson. Both Joe and Julia reported that the Lesson Study method was not practical for writing all lessons or a high volume of lessons. Lastly, Joe and Warren both expressed concern for occasional tangents in discussion. They viewed this occasional lapse of focus as an undisciplined occurrence in the lesson writing process.

Each team member expressed a desire to participate again in Lesson Study, logistics allowing. Each participant reported value in the process. Specifically, each participant seemed to appreciate the choice and relevance of the Lesson Study process which resulted in an appreciated collaboration of professional high school physics teachers. Warren best summarized the synergy of the participants in the Lesson Study:

The camaraderie of our lesson study group was fantastic. It really made all the hard work worthwhile because you knew your colleagues were working hard along with you. I'm sure the fact that we all volunteered made a difference. If lesson study is to become a standard method of professional development, it would be good to try to strike that balance between comfortability between fellow teachers and being introduced to new ideas.
Summary

Using data sources of meeting transcripts, journals, and interviews, the researcher has gathered data to explain the research question and sub-questions:

What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity?

a. How do teachers engage individually and in groups during the Lesson Study process?

b. What are the teacher-reported responses to Lesson Study as a professional development opportunity?

The researcher used three levels of coding: holistic, in vivo, and Discourse Analysis approach to answer these questions. The researcher found the process of Lesson Study with secondary physics teachers coded into seven categories and several subcategories for each. These overarching categories were: logistics, alignment, physics conceptions, experience sharing, teaching techniques, Research Lesson development, and the Research Lessons completed the holistic coding for sub-question a. Sub-question b was coded into categories that aligned with the participants. To best understand the teacher-reported outcomes of the Lesson Study, Clyde, Joe, Julia, Rodney, and Warren were the categories used. The researcher used data provided by the team of six participant physics teachers, focusing on student misconceptions, to better understand the process of Lesson Study with two PLC's of secondary physics teachers.
CHAPTER 5
DISCUSSION

Introduction

This study was an attempt to better align the professional development offered to physics teachers with teacher needs. The study sought to structure professional development in such a way that secondary physics teachers would find personal and professional value catered to their individual needs. This value, in theory, translated into learning and fresh insight towards meeting the learning needs of physics students.

The aim of this phenomenological case study was to understand the implementation of the teacher-initiated, collaborative professional development of Lesson Study within two high school Professional Learning Communities (PLCs) of physics teachers within a large suburban school system in the southeast. Specifically, the researcher intended to determine what is the process and what are the teacher-reported outcomes of Lesson Study with secondary physics teachers. Qualitative data was coded at three levels to determine findings to generate hypotheses for future study.

Summary of Findings

To determine What happens to secondary physics teachers engaging in Lesson Study as a professional development opportunity, the first sub-question of How do teachers engage individually and in groups during the Lesson Study process? was addressed. After the setting up as mentioned earlier of the Lesson Study as a professional development opportunity, the
researcher further addressed this question in response to the data collected during the Lesson Study process. The Lesson Study meeting transcriptions were coded and analyzed using holistic coding and the Discourse Analysis approach. The researcher then coded each of the categories with subcategories. Each subcategory was further explained using in vivo coding to provide supporting qualitative data for individuals and Discourse Analysis approach was used to provide supporting discourse.

Findings painted a picture response to the second research sub-question, *What are the teacher-reported responses to Lesson Study as a professional development opportunity?* In this study, the process of Lesson Study served to promote growth in physics teachers. This research further itemized this growth in participants. Self-reported growth of teacher-participants included focusing more on student thinking, utilizing new teaching equipment and strategies, establishing a deeper research base on physics learning, deepening understanding of misconceptions and strategies to combat these misconceptions, strengthening teacher self-efficacy, and renewed a fresh outlook on both physics teaching and the content. Overall, participants sited growth in all types of teacher knowledge with special emphasis on physics teacher PCK. Finally, the research subsequently portrayed a potential model of professional development for secondary physics teachers.

**What Happens to Secondary Physics Teachers**

The research determined that changes to physics teachers through the professional development of Lesson Study are dependent on seven features. These seven features were logistics, alignment, physics conceptions, experience sharing, teaching techniques, Research Lesson development, and the Research Lessons. Together, these portrayed the Lesson Study
experience. Each of these features emerged from coding and analysis of these codes into categories.

The first category of data involved was logistics. In practice, a portion of each Lesson Study meeting was used to set dates, set goals, and accommodate schedules. The researcher carefully cross-referenced the Research Lessons and the meetings, which facilitated these Research Lessons with school activities such as holidays, field trips, assemblies, county guests, testing, as well as the stage of learning of the physics concept. The second category was alignment with the county-published curricular calendar and the participants’ personal teaching schedule. As a county alignment practice, the units composing each content course were scheduled on a calendar to ensure consistency across high schools. Teachers were required to conform to the designated order of conceptual units as well as the duration of these units. The researcher and participants then coordinated this curricular calendar with each high school calendar, as well as the teaching schedule of each participant. Lesson Study participants then had to consider the timing of personal scheduling obligations, professional obligations, as well as the teaching schedule for the honors class for each person. Participants had to be careful to accommodate all other obligations to include arranging substitute teachers, classrooms for meetings and Debriefings, co-teacher instructions, logistics of independent work for students on substitute days, details of working lunch, as well as driving time for one PLC to travel to the other high school when necessary. Participants had to align lessons with the new county science standards which reflected Common Core, leveled for honors, targeted at relevant misconceptions, aligned with research, and written by teacher expectations.

The final five categories of what happens to physics teachers who undergo Lesson Study were born out of the interactions of the first two categories. Through these, the meetings, the
Research Lesson teachings and observations, and the subsequent Debriefings, participants focused on physics concepts in ways that only a group of physics teachers could. In these contexts, participants showed signs of their love of content and joy in the relationships with other participant physics teachers. Here they shared experiences in comradery. They pooled happenings and advice regarding misconceptions, learning challenges, compelling experiences, as well as new and innovative ways to measure student learning. They shared the frustrations of limitations brought on by school administration and other impromptu distractions to teaching and learning. Participants showed concern regarding the lack of longevity of the Lesson Study as targeting one lesson instead of one Learning Cycle.

Through these discussions, participants formulated new teaching techniques centered on effective strategies for student inquiry and student collaboration. They participated in rich collaboration and formulated new lessons that emerged as Research Lessons. One was lab-based and centered on projectile motion. The second was a series of riveting video clips with thought-provoking questions for collaboration regarding weightlessness and gravity. Two Research Lessons focused on student misconceptions, were created, observed, and edited through thoughtful reflection and collaboration.

**Teacher-Reported Outcomes of Lesson Study**

The teacher-reported outcomes of Lesson Study with secondary physics teachers were exhibited by the five participants Clyde, Joe, Julia, Rodney, and William, primarily in journals and interviews. Other sources included notes and insight from the participant-researcher. Each of the participants claimed to have found value in the Lesson Study professional development. Each participant met their personal goal for the professional development and obtained a better understanding of student misconceptions and how to combat these. The first hypotheses
subsequently generated is *Lesson Study can be used as a means of professional development to meet the diverse and distinct needs of secondary physics teachers.* In this study, Lesson Study was used to professionally develop secondary physics teachers with a variety of teaching experiences and lack of experiences. Lesson Study further served to help teachers specifically target physics misconceptions in physics students, while exposing them to strategies best-aligned to teach proper conceptions in their students. In this study, goals of better understanding student needs (Clyde), acquiring new teaching strategies (Joe), developing inquiry labs (Julia), better aligning the level of instruction (Clyde and Joe), and growth in teacher knowledge (Warren).

Participants further derived two new lessons that they were confident to teach again and achieved new strategies and tools to teach physics. Members reported growth in self-efficacy for physics teaching of their honors class (Clyde, Joe, Warren) as well as physics in general (Joe, Rodney, Warren), especially for their honors physics class. This data pointed to a second hypothesis to be tested: *Lesson Study can be used to build teacher self-efficacy for teaching secondary physics.*

Although participant goals reflected personal purposes for participating in Lesson Study, each member reported meeting those goals. Research articles and in-depth discussions, coupled with observations of misconception-targeted Research Lessons, served to define, build, and expand participant understanding of student physics misconceptions. Teacher-participants added new tools to their teaching tool bag of new lessons and strategies, culminating in more confident teachers (Clyde, Joe). Journal reflections and shared revelations underscored the nature of collaboration in an atmosphere of trust that endorsed this learning. Clyde, Julia, Rodney, and Warren all reported Lesson Study causing them to have a fresh outlook on their students and their content. A third hypothesis is *Lesson Study can be used by teachers new to physics or a*
level of physics in order to better align their depth of content and delivery strategies with student needs.

Participants not only added to their teaching tool bag, but they changed their actions in response to the Lesson Study experience. Clyde and Julia both revealed that they were consciously listening to their students more, for insight into their thinking and level of understanding. Most participants specifically acknowledged having a renewed outlook on their teaching and the content. Some members admitted to stepping out of their comfort zone of teacher-led lecture and into student-centered practice, allowing more open-ended collaboration in students.

Participants expressed some negatives regarding Lesson Study. Participants were all concerned in some way about the time spent on Lesson Study. The process took away from other teaching obligations. Each lesson created took many hours of collaboration. Teacher-participants often got off on tangents regarding their classes or physics concepts outside of the scope of lesson writing. All participants were driven to produce lessons and seemed to bear guilt when this process waivered.

Teacher-participants reported that they appreciated the choice and relevance of Lesson Study to their roles as physics teachers. They each indicated that they actively enjoyed the collaboration of professional high school physics teachers. Warren and Clyde both extolled the non-judgmental nature of this collaborative professional development. Julia was a prime example of the ease of collaboration. Google Docs seemed to give Julia power to collaborate. She expressed value in collaboration and various appreciated experiences and ideas in her journal, but it was with the Google Docs that she presented herself as more than an occasional
contributor. The fourth generated hypothesis is *Lesson Study serves as a bridge, giving physics teachers the opportunity to collaboratively use inquiry to more effectively teach their students.*

Each team member expressed a desire to participate again in Lesson Study, logistics allowing. As Warren emphatically claimed, “The camaraderie of our Lesson Study group was fantastic. This made the hard work worthwhile because you knew your colleagues were working hard along with you.”

**Relation to Previous Research**

**Constructivism**

Cognitive constructivist theory and social constructivist theory together established a theoretical framework for this research. Cognitive constructivist theory claimed that knowledge is not an accumulation of transmissions, rather it is constructed by individuals (Abdal-Haqq, 1998; Good & Brophy, 2008; Iran-Nejad, 1995; Richardson, 1997; Young & Collin, 2004). Constructivists emphasized the importance of relating new content to the individuals’ prior knowledge (Good & Brophy, 2003; Iran-Nejad, 1995; Richardson, 1997). Abdal-Haqq (1998) explained that in constructivism, learning is characterized by "active engagement, inquiry, problem-solving, and collaboration with others" (para. 2). In this research, Lesson Study was shown to use active inquiry regarding student learning as a viable means to improve teaching, supporting both cognitive and social constructivist theories.

Through continuous collaboration, participants pooled and related prior knowledge as they built lessons. Constructivists, such as Bruner (1990) and Vygotsky (1978), recognized that influences on individual knowledge construction were derived from and preceded by social relationships. This social facet of Lesson Study was used to knit two PLC’s into one collaborative unit. This research further supported constructivist theories of learning as
participants learned through and in response to their collaboration with other participants. The journal writing continued to uphold the learning theory of constructivism. Constructivist theory focused on metacognition as an essential aspect of constructing knowledge as learners reflect on the ways they construct knowledge (Kaufman, 1996). Participants embodied this process in the journal writing act and collaborative discussions.

**Means of Professional Development**

This research stood in contrast to research by Kennedy (1991), who found that regardless of the approach to teacher development studied, most professional development programs were unable to change the ideas of teachers substantially. Kennedy's (1991) findings showed teacher ideas were limiting and persistent. In this Lesson Study Research, teacher-participants were open to changing strategies and the eyes through which they viewed their students.

These findings were (to some extent) at odds with those of Gerard, Varma, Corliss, and Linn (2011) and Sopovitz and Turner (2000) who claimed that an implementation of one year of professional development was necessary to make a change in teacher knowledge and practice. Early implications of this professional development of Lesson Study with physics teachers indicated change happened in only half of that time. Each of the participants acknowledged meeting their learning goals and other collateral teacher growth (Chapter 4; Teacher-Reported Outcomes of Lesson Study). Findings corroborated Mutch-Jones, Puttick, and Minner (2012) who found after conducting three cycles of Lesson Study that by determining the focus of the Lesson Study at the onset, participants might not take the one year plus mandatory duration to obtain significant results.

For the current research, participants experienced changes in their teaching to include fresh eyes to see their students, a focus and improved aptitude to target physics misconceptions,
improved listening to their students, and a more student-centered environment with increased inquiry learning. Further study is needed to determine whether or not these improvements in teachers and their teaching can be expected in response to Lesson Study in a shorter period of time. Specifically, the fifth hypothesis to be tested is *Physics teachers have a unique ability to establish teacher change in a shortened, less than one year, period of time*. Additionally, a sixth study hypothesis should be conducted to establish if *Teacher change after a short duration of Lesson Study is linked to teachers already established in the group as a PLC*. A seventh hypothesis is *Student Physics Misconceptions is an ideal goal for Lesson Study in secondary physics teachers*.

**Out of Isolation**

Other researchers established that teaching is one of the few occupations whose practitioners are isolated from one another (Huberman, 1993; Puchner & Taylor, 2006; Sato & McLaughlin, 1992). The Lesson Study research with physics teachers provided counter evidence. The findings from the Lesson Study further run counter to Flinders (1988) who found that isolation is a shared condition of teaching, that teachers both accepted this situation and embraced it. In contrast, possibly due to the pre-established relationship of the PLC, participants were open to collaboration and embraced it. Findings supported Puchner and Taylor’s (2002) research which recognized the importance of building collaboration to overcome isolation while safeguarding the teacher’s sense of control of her classroom and her teaching.

**PLC**

The experience of this Lesson Study Research supported other researchers who found that PLC claims to build community among teachers while increasing the quality of teaching and learning (Easton, 2012; Rismark, 2011; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006).
The two PLC’s of physics teachers established a foundation for Lesson Study which endorsed Stoll et al.’s (2006) research showing that PLC supported the experiment of educational practices, using subject matter and curriculum to gather the data that formed the problems of inquiry. Professional Learning Communities gathered the data that formed the problems, and Lesson Study provided the inquiry opportunity to learn from and attempt to solve these problems. An eighth hypothesis generated is *PLC is necessary for teacher buy-in into the Lesson Study process.*

**Improved Teaching/ Improved Teachers**

These findings were consistent with previous research by Stigler and Hiebert (1999) who made the point that Lesson Study provided benchmarks against which teachers could measure their practice, compare it with colleagues, and grow towards a newly conceived image of teaching. Rodney verbalized his personal experience in response to Lesson Study, upholding this idea as he appreciated the opportunity to hear the voices of his students from observers and fine-tune his teaching in response to feedback.

Findings supported teachers building knowledge of all sorts. Findings supported research by MacIsaac and Falconer (2002) who claimed that physics PCK developed through professional development teaching experiences that are content-specific such as Lesson Study. During the Lesson Study process, participants gave credence to Shulman (1987) and Cochran (1991) who propound that teachers critically reflecting on and interpreting content knowledge can lead to the development of pedagogical content knowledge (PCK). These findings further supported research by Fernandez (2002), Rock and Wilson (2005), and Wagner (2003) which showed that Lesson Study contributed to the growth of teachers’ PCK. This research further seemed to support Van Manens's (1995) research findings that both practical knowledge and reflective
practice vigorously implemented in the arena of teacher learning provided the necessary
transformative learning linking practical knowledge, practical reflection, and action in teaching,
serving to develop teacher knowledge (Van Manen, 1995). These findings mildly supported the
research by Lewis (2002) which found that Lesson Study was a means of increasing teacher
development of content knowledge. Hypotheses regarding different types of teacher knowledge
development in response to Lesson Study seem supported and could be further tested. Most
relevant to this study, however, is the strong implication and ninth hypothesis, Lesson Study is an
effective means of building physics teacher PCK.

Findings were in harmony with those of researchers such as Rock and Wilson (2005) who
found that teacher self-confidence for teaching was shown to improve as a result of Lesson
Study. Findings supported numerous other studies that confirmed the positive correlation
between teacher self-efficacy and Lesson Study (Chong & Kong, 2012; Lewis, Perry, & Hurd,
2004; Puchner & Taylor, 2006). This research partially supported Sibbald (2009) who found that
Lesson Study contributed to both student achievement and teacher self-efficacy. In the present
study, student achievement was not determined.

Saito and Atencio (2013) found that Lesson Study served as a tool for challenging
pedagogical practices and was most valuable when balanced with peer lesson observations.
Clyde explicitly supported this research in response to his experience with the Lesson Study.
Lesson Study proved to be instrumental in prodding teachers (such as Clyde) away from lecture
and a teacher-centered style of teaching and toward teaching that incorporated a Social
Constructivist approach, requiring the establishment of dialogue in the classroom. Findings
supported research by Gerard, Varma, Corliss, and Linn (2011) which found that comprehensive,
constructivist-oriented professional development enhanced teachers' support for student inquiry.
science learning. Participants used the Research Lesson as a laboratory to improve their abilities to cultivate inquiry in students. A 10th hypothesis is *Lesson Study is a means to cultivate an environment of inquiry in the physics classroom.*

**Lesson Study in the U.S.**

Japanese teachers, in contrast to U.S. teachers, welcomed critique. Chokshi and Fernandez (2004), Lewis (2002), and Perry and Lewis (2009) prescribed this change for all Lesson Study participants. In Lesson Study, educators had to shift their critique to follow the rules of Lesson Study, shifting their focus to critique the lesson and not the one presenting the lesson. Notably, findings indicated that participants’ focus was on the lesson and its impact on student learning, not on the talents of the teacher presenting the Research Lesson.

In contrast to Fernandez’s (2002) recommendation that a systematic approach might be needed to create the necessary learning environment for teachers to develop the skills required to conduct Lesson Study, this research supports the alternative. High school physics teachers were able without external systemization to function effectively in Lesson Study. Without a mandate from administration or a school-wide restructuring of professional development, this group of participants, with a participant-researcher who served as a Lesson Study expert, were able to successfully implement a Lesson Study. Participants learned the procedures and contributed to Lesson Study with ease. A 11th proposed hypothesis counter to Fernandez (2002) emerges: *A systematic approach is not needed for a PLC of physics teachers to implement Lesson Study.*

Few full implementations of Lesson Study have been studied, and even fewer implementations have been sustained. Perry and Lewis (2009) in Bay Area School District in California, found that Practitioners were overwhelmingly positive and transformed their view of the nature of Lesson Study from one of instructional product to one of a process for instructional
improvement (Perry & Lewis, 2009). Findings with the physics teacher participants of Lesson Study contrasted with Perry and Lewis (2009) in that these participants were still focused on the instructional product after two cycles of Lesson Study, with only a secondary focus on instructional improvement. Other distinctions between this U.S. implementation of Lesson Study and the traditional Lesson Study as structured in Japan include the goal of the Lesson Study and the teacher time dedicated to the Lesson Study. In contrast to character-driven goals in Japan (Cerbin and Kopp; 2006), this U.S. Lesson Study focused on physics students’ misconceptions as character development is not generally accepted as the teacher responsibility in the U.S. Teachers in the U.S. view their obligation to teaching consisting of a forty-hour work week in sharp contrast to their Japanese counterpart (Lewis, 2000; Sato & McLaughlin, 1992). Although they often grade or plan outside of this time, professional development outside of these hours is viewed as an extra job requiring an extra monetary compensation. Thus the time dedicated to Lesson Study in this study was considerably less in hours than might be in Japan. As a stipend professional development, however, Lesson Study participants were driven to function and learn at a high level.

**Lesson Study Experience**

This study is broadly in line with the literature showing that in other contexts, Lesson Study met the needs of groups of teachers as a viable and valuable means of professional development (Lewis, 2000; Rock & Wilson, 2005; Saito & Atencio, 2013; Sato & McLaughlin, 1992). The pairing of Lesson Study with PLC’s seemed to be instrumental in expediting and deepening this learning process. In spite of the traditional competition in the science arena, Professional Learning Communities (PLC’s) served to remove this competition and fostered a rich collaborative environment. Borko (2009) found that PLC cultivated an atmosphere of trust.
This trust was pre-established before the implementation of Lesson Study. Participants showed characteristics of highly functioning PLC when Lesson Study initiated.

The PLC had already established conditions that were ripe for committing to Lesson Study as a means of deeper professional development. Findings supported Little's (2002) research that strong PLCs contribute to instructional improvement. Lesson Study facilitated the development of instructional knowledge, builds capacity for colleague collaboration, and helps develop "the eyes to see students" (Lewis, 2002, p. 13). Participants showed corroboration with research by Cerbin and Kopp (2006) who reported teacher benefit through collaborative analysis of teaching practices and student learning.

All participants reported strong affinity for Lesson Study and a perception of significant professional growth. Participants strongly agreed with findings by Rock and Wilson (2005) which underscored the appreciation for exposure to and sharing of professional literature, resulting in increased confidence in teaching. Their words were in close alignment with participants in Rock and Wilson's (2005) research who felt Lesson Study was more demanding than other means of professional development but was also more rewarding by substantially increasing professional understandings and competencies. In response, numerous hypotheses have been generated which will need to be tested with other studies to best understand both the process and value of Lesson Study for secondary physics teachers.

**Limitations**

Limitations to this research included sample size, specificity to pre-formed Professional Learning Communities, and duration of the study. The sample size of this study was that of only 5 participants and one Participant-Researcher. Notably, more implementations in other high schools were sought but were not possible. The study involved two PLC’s meeting as one group.
This served to provide fresh ideas from a neighboring PLC while also providing a foundation of established rapport and trust from functioning PLC units. The duration of the study was one semester or two Lesson Study Cycles. Due to logistic conflicts, this study could not continue into another semester, nor was it originally intended to do so. Finally, this study did not attempt to follow the teacher-participants back into their classrooms to establish a degree of long-term change in teacher practice.

**Problems**

Problems arose during the research process on Lesson Study. Lesson Study would have been an easier fit with like-classed, like-scheduled teachers. This fit occurred often in elementary and middle school settings. As the model in Japan suggested, Lesson Study is a best-fit for elementary schools; therefore, the majority of implementations in the U.S. were in the elementary school setting (Dudley, 2013; Lewis, 2002; Rock & Wilson, 2005). In a high school setting, teachers work askew to one another. Planning periods often occur at varying times of the day. School–related obligations are unique to the individual, depending on administrative assignment, athletic schedules, and club schedules. Personal commitments add another factor to logistic maneuvering for scheduling Lesson Study meetings. One evidence of this was the lack of response from multiple schools and their teachers. Two department chairs responded that this opportunity was not a good fit for them at this time. Of the two schools that did commit administratively, many teachers were unable to make the time commitment.

Another problem surfaced regarding anticipated methods of data collection. Originally, field notes were to serve as data sources for the researcher. These became more valuable as stimulated response (SR) tools for the participants to use during Debriefing. Most of the information translated into the discussion which was comprehensively included on the audio
recordings for transcription. Participants found that the tool designated for SR, video recordings of Research Lessons, proved to be unhelpful for that purpose. Participants were only able to view teacher and the lesson to some extent. Student conversations were lost on the recordings; therefore, these were recorded and posted on Google Drive, but not a primary source of SR or data.

**Discussion**

The autonomy given teachers throughout this bottom-up professional development opportunity serves to establish teacher buy-in while amplifying the degree of teacher learning. Participants acknowledge their comfort with the format of this professional development medium. The researcher contends that the act of allowing members to volunteer and then set their scheduled endorsed autonomy. Making this professional development a choice, not an administrative mandate, evokes not only buy-in, but enthusiastic involvement. The participants' self-reported high levels of buy-in in spite of the large workload. They choose to do the professional development of this type; schedule times that would work for their individual schedules and collaborate fully through discussion and Google Doc lesson writing to find a voice in the process. A 12th hypothesis generated is *The autonomy afforded to secondary physics teachers in the professional development process of Lesson Study served to amplify teacher buy-in and subsequent learning.*

This autonomy was coupled with relevance by positioning professional development within the comradery of like-minded, like-goal teachers. This seemed to endorse a positive outcome of Lesson Study, the researcher maintains that the specificity of targeting only physics teachers, in contrast to all science teachers or all high school teachers, undergirds Lesson Study with relevance, allowing commonality to set the stage for collaboration. The 13th hypothesis is
Grouping teachers by specific content area and level provides relevance and value in the eyes of teachers for the professional development.

This research applies to two functioning and mature PLC’s. The trust and nonjudgmental atmosphere already prepared by the PLCs fosters ideal conditions for the implementation of Lesson Study as a means of professional development. Physics teachers report having been avidly searching for in-context, content specific learning. The specific chemistry of the PLC’s quickly merges in the appreciation of other voices and experiences of like-minded physics teachers. As applied to the Lesson Study, the heterogeneous groupings of new teachers, as well as highly experienced teachers, provide resources of fresh insight as well as well-developed teaching strategies. Participants who are new to teaching experienced impromptu mentoring.

This study offers suggestive evidence that Lesson Study in functioning PLCs of physics teachers is a viable means of professional development. Riveros, Newton, and Burgess (2012) explain that PLCs seek continuous improvement in student learning through ongoing collaboration of teachers and administrators who concentrate their actions on improving practice and students’ achievement. Lesson Study is a natural next-step for a robust PLC. Lesson Study takes this established collaboration and focuses it on an inquiry into student thinking and learning through the medium of lesson creation.

According to the purpose as conceived in Japan, Lesson Study is about teacher development and learning, not about fashioning lessons. The purpose of Lesson Study is teacher growth through the inquiry process of collaboratively writing a Research Lesson. The purpose is to grow in teacher knowledges, skills, and strategies to maximize student learning. Research Lessons are secondary to the process. Findings with the physics teacher participants of Lesson Study contrast with Perry and Lewis (2009) in that these participants are still focused on an
instructional product after two cycles of Lesson Study, with only a secondary focus on instructional improvement. This dichotomy seems to show immaturity in the Lesson Study professional development, suggesting a continuation through more cycles to obtain this shift.

To reveal this focus on product, each Research Lesson participant feels that the time during the lesson study could have been used more effectively to produce more product. Each member has some negative comment regarding the usage of time. Most also have a negative comment regarding the scarcity of lessons achieved with many hours of input. Possibly the teacher participants have been conditioned to believe that the purpose of professional development is a product. Each participant wanted more lessons and less time to create those lessons.

Warren had an opportunity to be exposed to a version of Lesson Study as a teacher education student. In this certification program, he was partnered with two other potential physics teachers to participate in Lesson Study. Here, he learned that Lesson Study serves the purpose of writing an effective lesson. This experience certainly could carry over into his PLC with Joe and then into the Lesson Study (as evidenced in his journal).

Each participant offers suggestions to better focus the time on building lessons more efficiently. Clyde suggests a narrated presentation of a video lesson and then reneged on that, acknowledging that in-person observation was too valuable. Joe suggests changing the meeting times/structure. In his words, “Having several meetings that span several weeks to plan one lesson is nice but also not time efficient.” He suggests setting aside large blocks of time to plan weekly for a lesson the following week or doing longer, more focused meetings that occur less frequently. Julia possibly struggles most with the time issue. She suggests, “I would have liked to meet less often. Maybe if we could collaborate about the misconceptions and the lesson focus
beforehand through Google, email, or surveys. Then at the first face to face [meeting] develop the lesson plan.” Ironically, Julia sees value in the quantity of time spent on collaborative professional development as seen in her journal regarding her prior experiences during teacher training for physics.

Warren alludes to the lack of focus occasionally present during Lesson Study meetings:

We seem to be spending more time talking about interesting things rather than focusing on our task. I believe this was the main problem with our last lesson study: as physics teachers we enjoy labs, but our focus should have been on misconceptions. I believe we are getting closer to the goal of tackling misconceptions with this lesson. Unfortunately, our actions during the meetings are not quite so focused. We spend a lot of time with anecdotes about our students, discussing interesting tidbits that are tangentially (if at all) related to the task or concepts being covered.

It seems to the researcher that participants are so focused on producing the product of lessons, they overlook, or are afraid to mention, the collateral learning that occurs during the process of Lesson Study.

Some suggestions on formatting the Lesson Study should be considered. Clyde suggests the lesson planning happen at an earlier stage so that observations were less disruptive to course planning. Clyde also suggests that the summative assessments better incorporate the Research Lesson experiences. Participants show concern regarding the lack of longevity of the Lesson Study as targeting one lesson instead of one Learning Cycle, giving credence to restructuring the product goal of future Lesson Study Cycles.

Confirmed by all participants, the value of Lesson Study is foremost in the process. One participant, Rodney, summarizes the Lesson Study experience with two PLC’s of physics teachers. He says:

I kind of like this because you get feedback about what the kids are saying because you can't hear everything. Plus, we can tweak it based on what we come to as a group, finding what to change to be more effective.
The insight obtained through Research Lesson observation and the subsequent debriefing is another rich source of learning. It appears that the learning of students is rich in the well-designed Research Lessons produced through the lesson studies. The students are highly engaged and intently thinking to find understanding. For instance, in Research Lesson Two, when students are discussing the simulation of the sun orbiting Jupiter, one group battles with the duality of rotation:

Girl 1: What's moving the sun! What's moving the sun?
Girl 2: There’s nothing bigger than the sun.
Girl 3: It has to be bigger than the sun! Jesus Christ must be moving the sun. It’s Jesus!...
PR: I know they weren’t serious, but that was a great response. But they were seriously looking for something bigger.

Conversations like this immediately reveal the misconceptions of the students. Specifically, in this example, students believe that all objects are attracted toward the bigger object, in contrast to all objects are attracted to each other.

A focus on misconception transformation is powerful for all participants. By placing this pitfall in learning at the forefront, the foundation of lessons and the focus of teaching changes. Teachers tally and examine the heart of student misconceptions. Teachers deliberate on what strategies will result in a transformation of conceptions. Julia verbalizes her learning, "Sometimes it is so hard for them to leave that gut instinct that they already have, even when they have seen it, it’s hard." In another instance, Julia shows the disconnection between student conceptual learning and equation solving. She says, “I think when I was walking around, they were doing the math, they were pretty confident in how to do it, but they were scared to death that the math was not real, that the ball would not really do that.”

Participants obtain a deeper understanding of what common physics misconceptions are, what that looks like in student thinking, and how to battle these misconceptions. Research
exposes Joe to the impetus misconception. New evidence of new applications in student thinking reminds Clyde of this misconception with new evidence of new applications in student thinking. As a group, the participants conclude that the published misconceptions *there is not gravity in a vacuum* may have stemmed from an unsuspected origin. Participant-Researcher ponders, “I wonder if what that means in application is that once we get past the atmosphere and there is no air, that is when gravity turns off?” Julia confirms that students always seem to think there is an invisible line where gravity ends. Observations of students during Lesson Study Two gives credence to a deeper understanding of this misconception.

Inquiry is another focus of Research Lessons. Students have to problem solve and think about the how and why of their learning. This deeper learning results in strong engagement levels in each of the Research Lessons. To underscore, Rodney claims, “Out of all the activities that they will do, this is the one they remember.” This focus on inquiry could further be used to develop the specific inquiry skills needed by physics teachers for the participants in the Lesson Study (Breslyn & McGinnis, 2012). In Lesson Study One, mathematical modeling was used, one skill specific to physics inquiry conceptions. In Lesson Study Two, inquiry was used to better understand principles of gravitation and freefall by examining many examples in order to construct a conceptual model that can predict the behavior of falling objects.

Despite the value of the Lesson Study process, logistics prevents the present continuation of this valuable professional development. Participants agree that for the spring semester, scheduling and obligations would not allow for an extension. For instance, Warren is having a new baby. Rodney is concerned about his athletic obligations after school hours. Participants make suggestions.

Rodney: Maybe a more relaxed schedule, but I think something maybe less rigorous
Joe: Like only one Research Lesson.
Julia: Yea like one in the beginning and then like a longer break.
PR: I think some of that is determined by topics and when they are taught.

Participants seem saddened by the loss of this opportunity. Clyde interjects, “It’s helpful to see how other people do it.”

Julia suggests: If you could condense it into a say 3-hour block instead of dragging it out. Like nail down what you were going to teach and outline it all in one session. Maybe on a teacher work day or something. So that you are not starting over in a way each time and then have the Research Lesson Day.

As a final word to the group, I agree to “send out a feeler as to what you are teaching and if you can find the time and want to do it [Lesson Study] … I will send out a feeler.”

Clyde suggests: What about doing it by video?
Joe: I think the Research Lesson is ok, but it is not the interaction. I know personally, it is the conversation that I get so much out of. Yeah and it is hard to hear on the video when you are not in the classroom.
Rodney: You can’t get the different conversations, you can’t move around the room and all.

All participants agree that they want the opportunity to participate in another Lesson Study if the future logistics would allow.

All participants find much value in the Lesson Study process. As final evidence, Rodney mentions to the group a concern that he has. In response to the earlier administrative comment of possibly of having common departmental planning next year, Rodney is unhappy. He explains, “but if we have common planning, we couldn’t [have Lesson Study] because we would never be able to watch each other.” He believes that the value in Lesson Study supersedes the value of a daily opportunity to meet in unstructured ways with his colleagues.

The study appears to support the argument for a change in administrative mandates for professional development for physics teachers. Lesson Study as applied to this study is significant to cause teacher change in both reported self-efficacy and improved understanding of
student misconceptions. Participants report obtaining new ideas regarding equipment and strategies for physics students’ learning. Each teacher participant notes that they have grown in some way, most in many ways. In response to the positive results and hypotheses generated in this study, future research is recommended in order to test each hypothesis.

**Hypotheses Generated**

In response to this study, thirteen hypotheses have been generated:

- *Lesson Study can be used as a means of professional development to meet the diverse and distinct needs of secondary physics teachers.*
- *Lesson Study can be used to build teacher self-efficacy for teaching secondary physics.*
- *Lesson Study can be used by teachers new to physics or a level of physics in order to better align their depth of content and delivery strategies with student needs.*
- *Lesson Study serves as a bridge, giving physics teachers the opportunity to collaboratively use inquiry to more effectively teach their students.*
- *Physics teachers have a unique ability to establish teacher change in a shortened, less than one year, period of time.*
- *Teacher change after a short duration of Lesson Study is linked to teachers already established in the group as a PLC.*
- *Student Physics Misconceptions is an ideal goal for Lesson Study in secondary physics teachers.*
- *PLC is necessary for teacher buy-in into the Lesson Study process.*
- *Lesson Study is an effective means of building physics teacher PCK.*
- *Lesson Study is a means to cultivate an environment of inquiry in the physics classroom.*
- *A systematic approach is not needed for a PLC of physics teachers to implement Lesson Study.*
- *The autonomy afforded to secondary physics teachers in the professional development process of Lesson Study serves to amplify teacher buy-in and subsequent learning.*
- *Grouping teachers by specific content area and level provides relevance and value in the eyes of teachers for the professional development.*

Each of these hypotheses were supported by this research study, indicating a need for further research to better understand the process of Lesson Study with secondary physics teachers.

**Recommended Research Questions**

Further suggested research takes the form of questions to be answered. Some ideas were presented during the Lesson Study which did not imply hypotheses, but did imply a need to do further research in order to generate hypotheses. These five questions regarding Lesson Study
with secondary physics teachers beg answers or clarification. First, *Does the process of Lesson Study help secondary physics teachers to better understand students’ misconceptions?* Second, *Does the process of Lesson Study help secondary physics teachers to develop strategies to combat these common physics misconceptions?* Third, *How long and under what conditions can the process of Lesson Study move teachers from a focus on the product of fashioning a lesson into a focus on the process of learning from the experience?* Fourth, *Is Lesson Study useful to improve student achievement?* Fifth, *How long will the changes in teachers endure both during an extended Lesson Study and beyond?* Future research is needed to explore these questions and generate further hypotheses.

**Conclusion**

This study may serve a purpose in the field of science education in that it provides a rare opportunity for the education community to experience Lesson Study as a collaborative means of professional development as applied to two groups of secondary physics teachers. This research helps explain the process of Lesson Study. This study should further provide a better understanding of the value of both the collaborative and PLC models for professional development specific to Lesson Study. It may provide new insight into the process of developing secondary physics teacher PCK. Undergirded by both cognitive and social constructivist theories, Lesson Study may give physics teachers the opportunity to maximize their conceptual change through collaborative inquiry. This research could help administrators and stakeholders in judging the value of Lesson Study as a possible form for future professional development, providing insight to guide the spending of professional development funds.
Recommendations

For future implementations of Lesson Study, the researcher recommends earlier initial commitment and introductory meetings. Selection of topic and timeframe before the semester in which the Research Lesson is taught may prove valuable in writing summative assessment questions for common exams. Earlier initial meetings may also facilitate better planning for other content classes taught by the teacher so as to maximize the learning of students left with substitutes. This change in introductory timing should be explored through testing.

The researcher recommends a change from the writing of one lesson to the writing of a complete Learning Cycle. The Research Lesson is then chosen to be the one with the most display of student thinking and learning. Options of subsequent observations during the created Learning Cycle are optional. Daily reflections by teachers throughout the Learning Cycle should be written and shared with all. A Learner Cycle Debriefing meeting should be scheduled in addition to the Research Lesson Debriefing.

The researcher recommends some aspects remain the same and others change in response to the teacher-reported outcomes of Lesson Study. The goal or focus of physics students’ misconceptions is valuable and recommended to be retained. Another aspect of Lesson Study that should remain is the original foundation of the PLC. If a PLC of physics teachers has not been established, then combining this group with other PLCs could prove disadvantageous. Instead, an unestablished PLC should simply be established with other potential members before implementation of Lesson Study. The merging of multiple PLCs into one Lesson Study group proves a favorable circumstance that should be repeated. The group size of five participants and one participant-researcher is optimal. Group size should be modeled closely to this.
Hypotheses to be Tested

In response to the twelve hypotheses which are generated. Each deserves testing, many in unique ways. Studies examining teacher goals, self-efficacy, alignment with course objectives, collaboration, needed time to enact teacher change, Lesson Study goals, teacher buy-in, teacher knowledge growth, Lesson Study goal and Lesson Study implementation approach are all warranted within the context of secondary physics teachers. In order to best embody the spirit of the hypothesis as generated, the researcher itemizes some recommended structural details for the specific hypotheses to be tested.

First, in order to address the hypothesis, Lesson Study can be used as a means of professional development to meet the diverse and distinct needs of secondary physics teachers, participants in the study should each be secondary physics teachers. They each should state their goal for participating in the professional development before the Lesson Study begins. Over the course of the Lesson Study, each participant should review their goals to evaluate if any have been added or modified. At the end of the Lesson Study Cycle or series of cycles, participants should be interviewed regarding the degree to which they feel they have met their goal. Research should be targeted on what goals are represented, which were met to what degree, and which were not met. Participants should further be surveyed to determine if they feel that this goal could be met or more fully met if aspects of the Lesson Study were changed. These itemized proposed changes should be recorded and implemented in subsequent Lesson Study Cycle if possible. From the study regarding the hypothesis, Lesson Study can be used as a means of professional development to meet the diverse and distinct needs of secondary physics teachers, more knowledge regarding relevancy of Lesson Study to which physics teachers could be determined.
Regarding the next hypothesis generated, *Lesson Study can be used to build teacher self-efficacy for teaching secondary physics*, an instrument to measure teacher self-efficacy relevant to secondary science teachers should be selected. This instrument should be used to measure teacher self-efficacy towards teaching physics as well as teacher self-efficacy towards the content of physics itself should be measured. This should occur as both a baseline and a final measure of potential growth after a series of Lesson Study Cycles. Interviews to better undergird the rationale to these potential findings could prove valuable in increasing understanding of any needed aspects of Lesson Study essential or helpful to achieve the measured results.

For the hypothesis generated, *Lesson Study can be used by teachers new to physics or a level of physics in order to better align their depth of content and delivery strategies with student needs*, qualitative research is suggested. To obtain participants for this study, a cut-off for the definition of *new* must be established. This researcher recommends three years, as this is the standard in her county for new teacher mentoring programs. After physics teacher participants are selected, survey data regarding their experiences and duration of experiences should be gathered. For this hypothesis, interview data would be needed to assess teacher-perceived growth towards the specific student needs at the level of physics in question. Surveys using a Likert scale could be used to quantify physics teacher perceptions of alignment with the content and content level. Findings should focus on both the degree of newness to physics or the level of physics correlated to the degree of perceived teacher growth in alignment of both depth of content and usefulness of strategies learned.

The next hypothesis generated, *Lesson Study serves as a bridge, giving physics teachers the opportunity to collaboratively use inquiry to better teach their students*, should be tested. This research would involve selecting and administering a tool which measured teachers’ degree
of use of inquiry during a meeting situation. A baseline could optionally be established by implementing the same instrument at a different type of meeting with the participant. After a level of inquiry is established, teacher interviews and surveys with Likert scales could be used to establish the teacher-perceived degree of growth in response to the inquiry. This study would presuppose that Lesson Study is both a constructivist and inquiry process in action.

The next proposed research to test hypotheses would focus on measuring the outcomes of the Lesson Study process with secondary physics teachers. Baselines would need to be taken for each and then a final measurement to show growth would need to be administered after approximately two cycles of Lesson Study. For the hypothesis, Lesson Study is an effective means of building physics teacher PCK, an instrument to measure PCK must be selected and administered. For the hypothesis, Lesson Study is a means to cultivate an environment of inquiry in the physics classroom, another instrument which measures the degree of the inquiry environment in a physics, or alternatively science, classroom would need to be selected and administered. Interview data could add a mixed methods layer to the research, revealing a more complete picture regarding the growth of teacher PCK and the improvement to the student inquiry environment, respectively.

Some research opportunities could group the hypotheses generated and be tested in a single study. Specifically, research conducted with PLCs of secondary physics teachers could target the three hypotheses specific to PLC:

- **Teacher change after a short duration of Lesson Study is linked to teachers already established in the group as a PLC.**
- **PLC is necessary for teacher buy-in into the Lesson Study process.**
- **A systematic approach is not needed for a PLC of physics teachers to implement Lesson Study.**
In this proposed research, teacher change would need to be selected and measured by both an instrument targeted at physics teacher, or possibly science teacher, conceptual change. An alternative instrument might be one that measures aptitude for different types of teacher knowledge. Additionally, survey and interview data should be obtained to qualify the types of changes and impetus for the changes. For the next hypothesis, confidential and free-of-repercussion surveys, using a Likert scale, could measure a before and after degree of buy-in of the teacher-participants. Additional surveys or interviews could solicit responses regarding the teacher-perceived effectiveness with strangers within like or differing content areas. The last PLC-related hypothesis to be tested could be supported or refuted with the aftermath summary of any Lesson Study implementation with PLCs of physics teachers. Success could be measured by self-reporting in interview or any relevant growth measure. Also, stifling or significant functionality problems should be considered if they were to occur.

A research study with secondary physics teachers which gathered data through an interview process could assess hypotheses *The autonomy afforded to secondary physics teachers in the professional development process of Lesson Study served to amplify teacher buy-in and subsequent learning* and *Grouping teachers by specific content area and level provides relevance and value in the eyes of teachers for the professional development*. Interview questions should be targeted at the participants’ perceptions of choice, their feelings regarding that choice, and their motivation in response to that choice. These interview questions should be asked both prior to any significant participation in Lesson Study meetings and at the conclusion of all Lesson Study Cycles. Additional interview questions to accompany the same data gathering episode should address the second hypothesis regarding the value in grouping
participants by content area. Surveys with Likert scores could be used to further assess the degree to which teachers value both autonomy and working with like-content teachers.

Throughout any of the earlier mentioned proposed testing of the hypotheses generated, the hypotheses *Student Physics Misconceptions is an ideal goal for Lesson Study in secondary physics teachers* and *Physics teachers have a unique ability to establish teacher change in a shortened, less than one year, period of time* could be tested. Research to test these hypotheses would involve adding a survey question or interview question to other studies. Qualitative data would reveal the teacher-perceptions of using physics students’ misconceptions as the Lesson Study goal. Other facets of this hypothesis would suggest other questions to further determine proposed alternatives to this goal. Still other interview questions could serve to determine growth in understanding of student misconceptions and increased aptitude in both identifying and changing the misconceptions in students. Regarding the other hypothesis, teacher change should be monitored via self-reporting in either interview or survey. Additionally, an instrument which measured teacher cognitive change could be selected and administered. This instrument should be administered as a baseline and then either each semester or after every two Lesson Study Cycles are completed, showing when a significant amount of teacher cognitive change had occurred.

**Recommended Research**

In an effort to completely address the understandings and questions that were revealed during this study, the researcher makes suggestions for further research outside of hypothesis-testing. Some notions did not imply hypotheses rather implied a need to do further research in order to generate hypotheses. The five questions regarding Lesson Study with secondary physics teachers reflect an ongoing need to understand the process of Lesson Study. Specifically, the
researcher reported growth and regarding all aspects of physics misconceptions. Not only did teachers learn to better identify and recognize classic physics misconceptions in their students, but teachers began to sort through strategies of what worked and did not work in altering student conceptions. Research purports that inquiry and hands-on learning is valuable in obtaining conceptual change (Abdal-Haqq, 1998; McDermott, 1993).

In their experience, however, the mathematic modeling lab failed to affect student conceptions. This was observed in both responses to the lab-based questions and the follow-up student misconception surveys. In Research Lesson Two, collaborative inquiry with teacher-guided video and questioning served to begin to change students’ conceptions. All participants agreed that more discussion and more misconception-targeted lessons were needed for a single misconception. This was the scenario that sparked the desire to complete an entire Learning Cycle during the course of each Lesson Study Cycle.

Supovitz & Turner (2000) acknowledge that the science education reform movement emphasizes the importance of professional development as a venue to elevate student science achievement. In response, further research should add the facet of student achievement to research questions. One beginning option might be to use the Force Concept Inventory scores both before Lesson Study and in response to Lesson Study to examine conceptual change on targeted misconception during the Lesson Study process. This instrument could be used for both teachers and students to target standard physics misconceptions.

One question surfaced in the mind of the researcher regarding the long-term effects of Lesson Study with secondary physics teachers. The duration of the motivation and teacher change have not been measured. Research should be conducted to determine if the peer pressure of colleagues trying to teach better is the sole motivation to drive others to better their teaching.
Moreover, research should be implemented to measure the growth on many levels at the end of the Lesson Study with follow-up measurements over the course of a semester, year, three years, and five years.

Finally, in response to both aspects of teacher growth and learning as well as lack of appreciation for collateral learning, the researcher questions, at what point and under what circumstances does Lesson Study reach maturity with PLCs of secondary physics teachers? This question, birthed out of a researcher frustration, is How long and under what conditions can the process of Lesson Study move teachers from a focus on the product of fashioning a lesson into a focus on the process of learning from the experience? The participants all voiced frustration at not producing more lessons in less time. They further were frustrated by the seemed wasted time talking shop with their colleagues. As conceived in Japan, the collateral learning is the true value of Lesson Study. This is the professional development in action. The researcher wonders if teachers could grow towards this understanding and appreciation, possibly by itemizing their collateral learning and then drawing their attention to it.

Future research should be considered for a longer duration, possibly four cycles of Lesson Study. The process of Lesson Study must be taught to participants and learned by those participants before consistent successful implementation can occur. Once this consistency is obtained, other research questions could be posed that are more quantitative in nature. For instance, longitudinal studies are greatly needed to achieve measurable gains in student achievement in response to Lesson Study with physics teachers. These longitudinal studies would allow triangulation with other qualitative studies. Although narrative type data is useful for judging practitioner perceptions, administration and district managers demand quantitative data in student achievement to sustain funding (Perry & Lewis, 2009).
Contributions to the Literature

The professional development method of Lesson Study is composed of layers of experiment and data. Teacher learning is a primary focus that is shrouded by student learning. This duality in itself makes data collection and analysis difficult. Additionally, the process of Lesson Study is an inquiry, a research of sort within itself. The extra layer of documenting, summarizing, and organizing data for writing up research is not a natural course of action. This layering of learning and inquiry places the majority of functioning Lesson Studies outside of the arena of research. This layering serves to hide the effectiveness of this professional development model.

In contrast, this Lesson Study Research specific to secondary physics teachers paints a vivid picture of a functioning and valuable model of professional development. This research itemizes the levels of increased learning and the synergy of focused, like-minded teachers in the act of Lesson Study. This study can be used as evidence to defend the implementation of other Lesson Studies in similar schools and teacher groups.

In addition to the provision of some directions for future research, this study makes three major contributions to areas where research is still limited. Firstly, this research undergirds the effectiveness of giving teachers autonomy in their professional development. This autonomy is shown to promote teacher buy-in. Secondly, this research endorses the need and value for science content specific professional development. Physics teachers find much value working with other physics teachers for relevance in their learning. Thirdly, Lesson Study is shown to be a viable means of professional development in the high school classroom. Where much research in the past centered on elementary or middle school teachers, this research indicates that Lesson Study is also viable with secondary teachers in content areas.
Final Words

The professionalism of the teaching occupation has been an elusive aspiration for those in the vocation. Professionalism is characterized by learning and continued growth within the occupation, an act that runs parallel to the practice of Lesson Study. It is my hope that Lesson Study might prove to act as a vehicle, as it has in its birth country, to perpetuate the transformation in the public’s view of teachers from those who can’t to professionals who can do it better than anyone else. Through Lesson Study, the pools of teacher knowledge no longer puddle in isolated classrooms but are free to flow to other classes in other schools reviving and nourishing both teaching and learning.
REFERENCES


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APPENDIX A

IRB Approval University of Alabama

May 18, 2016

Nicki Collins
Department of Curriculum & Instruction
College of Education
The University of Alabama
Box 870232

Re: IRB # EX-16-CM-050 “Lesson Study as a Means of Professional Development within Two Professional Learning Communities of High School Physics Teachers”

Dear Ms. Collins:

The University of Alabama Institutional Review Board has granted approval for your proposed research. Your protocol has been given exempt approval according to 45 CFR part 46.101(b)(2) as outlined below:

(i) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Your application will expire on May 17, 2017. If your research will continue beyond this date, complete the relevant portions of Continuing Review and Closure Form. If you wish to modify the application, complete the Modification of an Approved Protocol Form. When the study closes, complete the appropriate portions of FORM: Continuing Review and Closure.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number.

Good luck with your research.

Sincerely,
APPENDIX B

IRB Approval GCPS

August 3, 2016

Tonya M. "Nicki" Collins
241 Durham Drive
Hoschton, GA 30548

Re: File ID 2017-04

Dear Ms. Collins:

This is to advise you that your research application, "Lesson Study as a means of Professional Development Within Two Professional Learning Communities of High School Physics Teachers," ID Number 2017-04, has satisfactorily met GCPS Research Standards and was approved by the Institutional Review Board. This approval is valid beginning August 1, 2016 through May 1, 2017. Please note the following comments regarding your study:

- Given the researcher’s status as department chair at Mountain View HS, consider selecting another school so that the responses of participants to the Lesson Study program are independent of day-to-day working relationships with the researcher.
- The first research question "1. What happens to secondary physics teachers who undergo Lesson Study?" requires rewording to limit the range of actual anticipated participation effects; "happens" is too broad a term.
- Science Director Dr. Wetherington’s approval of this research and a teacher stipend of $400 payment from the GCPS Science Department budget is a strong endorsement of the study’s value to the district.

Please note the following requirements of you as a researcher in GCPS:

- A copy of this approval letter must be attached to any initial communication with a Gwinnett school or office.
- The above File ID number must be included in the subject line of any communication with a Gwinnett school or district office concerning this research study.
- If circumstances prevent you and every member of your research team from following these requirements, please let me know so that we can make alternative arrangements.

Note that schools and teachers may elect not to participate in your research study, even though the district has granted permission.

Please forward a copy of your results to me when they are completed.

Best wishes for a successful research project. Please call me at (878) 301-7000 if I may be of further assistance.

Sincerely,
APPENDIX C

Informed Consent for a Non-Medical Study

Informed Consent for a Non-Medical Study

Study title: Lesson Study as a Means of Professional Development within Two PLCs of High School Physics Teachers

Investigator’s Name, Position, Faculty or Student Status: Nicki Collins, Physics Teacher, Mountain View High School; and Ed.D. degree candidate for University of Alabama

You are being asked to give your consent to take part in a research study.

This study is called Lesson Study as a Means of Professional Development within Two PLCs of High School Physics Teachers. The study is being done by Nicki Collins, who is a graduate student at the University of Alabama. Mrs. Collins is being supervised by Dr. Dennis Sunal who is a professor of Mrs. Collins at the University of Alabama.

Is the researcher being paid for this study? No

What is this study about? What is the investigator trying to learn?
This study is being done to find out what is the process of Lesson Study in two groups of Professional Learning Communities (PLCs) of physics teachers in two high schools. In Lesson Study, teachers collaborate to create a powerful lesson using research and best teaching practices. One teacher is then selected to teach this lesson while all others observe and take notes. This research is on the learning experience of the teachers as they participate in this process, as they learn more about student learning and their own practice.

What data will be gathered?
This research will gather data in the form of interviews, journal entries, fieldnotes, and other narrative.

Why is this study important or useful?
This study will be used to better understand how Lesson Study is both implemented and impacts physics teachers. This will be useful in better establishing a fit for the professional development of physics teachers. It will further help stakeholders best invest professional development funds.

Why have I been asked to be in this study?
You are a physics teacher in a functioning PLC of other physics teachers.

How many people will be in this study?
Approximately 10 teachers will be in this study.

What will I be asked to do in this study?
You will be asked to spend time discussing Lesson Study and your experiences with this professional development. You will be asked to keep a journal, allow interviews of yourself, and discuss your experience with the researcher and other participants.
How much time will I spend being this study?
This study will involve approximately 18 hours (8 of which are contracted professional
development hours). Thus approximately 10 extra hours will be devoted to the process of Lesson
Study and the research will come from the data revealed and recorded during this learning
process. This will span a one semester period of time and finish prior to the Christmas holidays.

Will being in this study cost me anything?
The only cost to you is your time.

Will I be compensated for being in this study?
You will not be compensated for being in this study. You will be compensated for participating
in Lesson Study as a means of professional development with a $405 stipend, provided all
meetings are attended and activities are completed. If you fail to fully participate in the
professional development by attending all meetings, then the stipend will be forfeited. This
choice of professional development for physics teachers is one of several options, many of which
have varying levels of stipend associated.

What are the risks (dangers or harms) to me if I am in this study?
Little or no risk is foreseen.

What are the benefits (good things) that may happen if I am in this study?
This study should result in ongoing improvement in teaching skills or understanding through
Lesson Study.

What are the benefits to science or society?
The study should help researchers to achieve a better fit for the professional development of high
school physics teachers. It should also provide insight as to how Lesson Study functions in a
PLC of high school physics teachers.

How will my privacy be protected?
No names will be used at any time in either data gathering or data reporting. Furthermore, all
answers are optional.

How will my confidentiality be protected?
All data will be kept confidential by separating signed consent forms from data collected,
locking all data by either lock and key or by password-protected computer file. Videos will be
recorded and used to facilitate discussions during Lesson Study. Videos of lessons being taught
will also be recorded. Video tapes of meetings and collaboration will be kept under two locks
and keys during Lesson Study professional development and the research study. All video tapes
recorded during the course of Lesson Study professional development will become the property
of Gwinnett County Science Department and used for future teacher professional development.

What are the alternatives to being in this study? Do I have other choices?
Gwinnett County Science Department offers several other opportunities for professional
development; many of these have varying levels of stipends associated with them.
What are my rights as a participant in this study?
Taking part in this study is voluntary. It is your free choice. You can refuse to be in it at all. If you start the study, you can stop at any time. There will be no effect on your professional position or evaluation as a teacher.

The University of Alabama Institutional Review Board ("the IRB") is the committee that protects the rights of people in research studies. The IRB may review study records from time to time to be sure that people in research studies are being treated fairly and that the study is being carried out as planned.

Who do I call if I have questions or problems?
If you have questions about the study right now, please ask them. If you have questions about the study later on, please email Nicki Collins at Nicki_Collins@gwinnett.k12.ga.us or the faculty advisor, Dr. Dennis Sunal at 205-348-7010.

If you have questions, concerns, or complaints about your rights as a person in a research study, call Ms. Tanta Myles, the Research Compliance Officer of the University of Alabama, at 205-348-8461 or toll-free at 1-877-820-3066.

You may also ask questions, make suggestions, or file complaints and concerns through the IRB Outreach website at http://osp.ua.edu/site/PRCO_Welcome.html or email the Research Compliance Office at participantoutreach@bama.ua.edu.

After you participate, you are encouraged to complete the survey for research participants that is online at the outreach website or you may ask the investigator for a copy of it and mail it to the University Office for Research Compliance, Box 870127, 358 Rose Administration Building, Tuscaloosa, AL 35487-0127.

I have read this consent form. I have had a chance to ask questions. I agree to take part in it. I will receive a copy of this consent form to keep.

_________________________________________  _________________________
Signature of Research Participant                Date

_________________________________________  _________________________
Signature of Investigator                        Date
APPENDIX D

Background Data Survey

Background Questions

1. What is your educational background? What degrees do you hold?

2. What teaching experiences do you have?

3. What are your favorite teaching experiences and why?

4. What are your least favorite teaching experiences and why?

5. What do you see as your teaching strengths?

6. What areas do you feel are relatively weak in your teaching?

7. What types of professional development have you been involved with?

8. What characteristics of professional development are most valuable to you?

9. What characteristics of professional development do you think stifle its effectiveness?

10. What do you usually consider when you plan a lesson?

11. Do you ever consult others when you plan a lesson?

12. If yes, who do you consult and in what ways?
APPENDIX E

Advertising Email

For the Fall 2016 semester, two Professional Learning Communities (PLCs) of physics teachers will have the opportunity to participate in the teacher-driven collaborative professional development opportunity of Lesson Study. Lesson Study is a 50-plus-year old form of teacher professional development that began in Japan. It was incredibly successful and valued by teachers there. In the past decade or two, groups of teachers have begun the process here in the U.S. with impressive results in teacher learning, student learning, and teacher satisfaction.

In Lesson Study, teachers collaborate to create a research-based and best-practice driven lesson. This lesson is then taught by one teacher and observed by all. Teachers circulate to interview and investigate students in their learning and take field notes. This hands-on inquiry lab for teachers provides new insight and understanding of how students learn, what specifically impedes their learning, and how to best meet the needs of these student learners. After the lesson is taught, the participating teachers record their reactions and understandings in a journal. At the end of that day, teachers meet to debrief and fine-tune the lesson in response. Substitute teachers are provided to facilitate this time.

Teachers who agree to participate in this Lesson Study opportunity are encouraged to also participate in the doctoral research that is being conducted by the Lesson Study director, Nicki Collins, a physics teacher at Mountain View High School and student at the University of Alabama. This research is entitled Lesson Study as a Means of Professional Development within Two PLCs of High School Physics Teachers. Participation in this study involves minor time spent undergoing short interviews and sharing journals, field notes, and feedback to contribute to this phenomenological case study. Completion of the Lesson Study professional development and research participation for the semester will result in a stipend of $405 being paid from Gwinnett County Department of Science.

Please advise your department chair and myself if this opportunity is of interest to you.

Thank you.
Sincerely,
Nicki Collins
AP Physics, Mountain View High School
Lesson Study Director, Gwinnett County Public Schools
## APPENDIX F

Budget for Lesson Study as Professional Development: One Semester: FALL 2016

<table>
<thead>
<tr>
<th>PRODUCTION HOURS</th>
<th>HOURS</th>
<th>TOTALS</th>
</tr>
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<tbody>
<tr>
<td>LS PLC meetings (one hour each)</td>
<td>3</td>
<td>0 (Occurs during contract hours)</td>
</tr>
<tr>
<td>1 Lesson Study Research Lesson Taught</td>
<td>1</td>
<td>0 (Occurs during contract hours)</td>
</tr>
<tr>
<td>Outside of PLC Reading and Planning</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1 Lesson Study Journal Hour</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1 Lesson Study Debrief Meeting</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2 Lesson Study Cycles</td>
<td>X2</td>
<td>10</td>
</tr>
<tr>
<td>2 High Schools</td>
<td>X2</td>
<td>20</td>
</tr>
<tr>
<td>5 Physics Teachers Each</td>
<td>X5</td>
<td>100</td>
</tr>
</tbody>
</table>

**TOTAL PRODUCTION HOURS**

100

**TOTAL PRODUCTION COST**

@ $33/hr

$ 3300

<table>
<thead>
<tr>
<th>ONE TIME NON-PRODUCTION HOURS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>April Meeting (Introduction)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Preplanning Meeting (Protocol per HS LS)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Interview to improve LS PD</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2 High Schools</td>
<td>X3</td>
<td>10</td>
</tr>
<tr>
<td>5 Physics Teachers Each</td>
<td>X5</td>
<td>50</td>
</tr>
<tr>
<td><strong>TOTAL ONE TIME NON-PRODUCTION HOURS</strong></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>TOTAL ONE TIME NON-PRODUCTION COST</strong></td>
<td>X $15</td>
<td>$ 750</td>
</tr>
</tbody>
</table>

**TOTAL COST**

$ 4050 ($405/teacher x 10 teachers)
APPENDIX G

Interview Guiding Questions

1. Tell me about your experience with Lesson Study.

2. What was helpful to you?

3. What would you have changed about the process?

4. Do you see benefit in doing this again?

5. What would you assess the outcomes of Lesson Study to be for you personally?
APPENDIX H

Common Misconceptions List

Students’ Alternate Conceptions in Introductory Physics
The following is a list of misconceptions and preconceptions that high school physics teachers and college professors have recognized in their students.

0. OVERALL/ KINEMATICS
History has no place in science. Two objects side by side must have the same speed. Acceleration and velocity are always in the same direction. Velocity is a force. If velocity is zero, then acceleration must be zero too.

1. FALLING BODIES
Heavier objects fall faster than light ones. The acceleration of a falling object depends upon its mass. Freely falling bodies can only move downward. There is no gravity in a vacuum. Gravity only acts on things when they are falling.

2. INERTIA
Forces are required for motion with constant velocity. Inertia deals with the state of motion (at rest or in motion). All objects can be moved with equal ease in the absence of gravity. All objects eventually stop moving when the force is removed. Inertia is the force that keeps objects in motion. If two objects are both at rest, they have the same amount of inertia. Velocity is absolute and not dependent on the frame of reference.

3. NEWTON’S LAWS
Action-reaction forces act on the same body. There is no connection between Newton’s Laws and kinematics. The product of mass and acceleration, ma, is a force. Friction can’t act in the direction of motion. The normal force on an object is equal to the weight of the object by the 3rd law. The normal force on an object always equals the weight of the object. Equilibrium means that all the forces on an object are equal. Equilibrium is a consequence of the 3rd law. Only animate things (people, animals) exert forces; passive ones (tables, floors) do not exert forces. Once an object is moving, heavier objects push more than lighter ones. Newton’s 3rd law can be overcome by motion (such as by a jerking motion). A force applied by, say a hand, still acts on an object after the object leaves the hand.

4. GRAVITATION
The Moon is not falling. The Moon is not in free fall. The force that acts on apple is not the same as the force that acts on the Moon. The gravitational force is the same on all falling bodies. There are no gravitational forces in space. The gravitational force acting on the Space Shuttle is nearly zero. The gravitational force acts on one mass at a time. Moon stays in orbit because the gravitational force on it is balanced by the centrifugal force acting on it. Weightlessness means there is no gravity. The Earth’s spinning motion causes gravity.

5. CONSERVATION OF ENERGY
Energy gets used up or runs out. Something not moving can’t have any energy. A force acting on an object does work even if the objects does not move. Energy is destroyed in transformations from one type to another. Energy can be recycled. Gravitational potential energy is the only type of potential energy. When an object is released to fall, the gravitational potential energy immediately becomes all kinetic energy. Energy is not related to Newton’s laws. Energy is a force.

6. CONSERVATION OF MOMENTUM
Momentum is not a vector. Conservation of momentum applies only to collisions. Momentum is the same as force. Moving masses in the absence of gravity do not have momentum. The center of mass of an object must be inside the object.

*This document was obtained as a portion of a common document distributed by the Plano ISD and edited by Terri McMurray as an agent of College Board for AP Physics training.
APPENDIX I

Bibliography for Physics Misconception Research for Lesson Study Participants’ Knowledge Base


APPENDIX J

Target Lab

**Projectile Target Test**

Names _________________________________________     Group _______

Date ____________       Period 1 2 3 4 5 6

Materials: meter sticks, metric rulers, 1 steel ball bearing, tape, 1 stopwatch (optional), and plumb bob.

*Use a separate sheet of paper for your calculations. Put your answers on this page only. Use correct units.*

1. Calculate the time it will take for the projectile to hit the floor. _______

2. Calculate the horizontal velocity of the projectile as it is about to leave the table. ______.

3. Calculate the distance the projectile will travel horizontally (range). _______

   Notify me when you have done this. I will bring a target to you.

4. Place the center of your target at this distance from the table. Notify me when you are ready to make your attempt. I will bring the carbon paper to you and observe your projectile hitting the target.

5. **Target score ______**

*Reminder: Measure everything multiple times. Check your work with your partners. Staple your work to this sheet along with your target after I have checked it.*

*The ball bearing shall not leave the table during the calculation steps.*

---

**Projectile Target Test**

Names _________________________________________

Date ____________       Period 1 2 3
Materials: 2 meter sticks  1 metric ruler  1 steel ball bearing  tape
1 stopwatch

1. Measure the height of the table from the floor. ___________
2. Calculate the time it will take for the projectile to hit the floor. _______
3. Calculate the horizontal velocity of the projectile as it leaves the table. _______
4. Calculate the distance the projectile will travel horizontally. ______
   Notify me when you have done this. I will bring a target to you.
5. Place the center of your target at this distance from the table edge. Notify me when you are ready to make your attempt. I will bring the carbon paper to you and observe your projectile hitting the target.

NOTE: Measure everything multiple times. Check your work with your partners.

Staple your work to this sheet along with your target after I
APPENDIX K

Post Analysis Questions for Target Lab

Post Analysis Questions

When we launched our ball off the side of our tables we calculated how long it would take before the ball struck the ground. We used this time to figure out how far away the ball would land.

*How would the time and distance compare to our original launch if we:*

<table>
<thead>
<tr>
<th></th>
<th>Faster Launch</th>
<th>Slower Launch</th>
<th>Dropped Straight Down</th>
<th>Taller Table Launch</th>
<th>Shorter Table Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance</strong></td>
<td>Further Shorter Same</td>
<td>Further Shorter Same</td>
<td>Further Shorter Same</td>
<td>Further Shorter Same</td>
<td>Further Shorter Same</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>Longer Shorter Same</td>
<td>Longer Shorter Same</td>
<td>Longer Shorter Same</td>
<td>Longer Shorter Same</td>
<td>Longer Shorter Same</td>
</tr>
</tbody>
</table>

Consider rolling a marble down a ramp (region I), it rolls horizontally across the table (region II) and then off the end of the table (region III), as show below. Answer the following question for each of the three regions: Does gravity act on the marble in this region? In each case, provide evidence to support your answer. Be precise in your answer using terms you have learned so far regarding displacement, velocity and acceleration vectors, in the x and y directions.
Answers -
Region I:
Region II:
Region III:

Use the diagram from the front to answer the following questions.

1. What is causing the ball to roll down the ramp in Region 1? How does this affect the ball?

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

2. Why does the ball continue to move in Region II?

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

3. In Region III describe what is happening to the ball and why.

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

Provide a sketch of the following graphs for the horizontal component of the movement and the vertical component of the movement.

**Horizontal Component**

Position vs. Time
Velocity vs. Time
Acceleration vs. Time

**Vertical Component**

Position vs. Time
Velocity vs. Time
Acceleration vs. Time
**BONUS QUESTION**: If the end of the table had a ramp angled up and we kept your original initial velocity, how would that change your experiment? Think about how the following would be affected: initial and final vertical velocities, height the ball bearing will fall, time in air, horizontal distance, and horizontal velocity.

**Before You Begin**: (T/F)

1. In order for something to move, it must have an acceleration.
2. When a book is sitting on a table, gravity is not acting on it.
3. If two cannons are launched horizontally, the faster cannonball will hit the ground first.
4. If a cannonball is fired horizontally, the horizontal velocity will remain the same.
5. If a cannonball is fired horizontally, the vertical velocity will remain the same.
APPENDIX L

EXPLORING SPACE

NAME: _______________________________________

Preconceptions:
1. If an object experiences weightlessness, it means there is no gravity acting on it. True / False
2. Gravity exists for objects in Earth’s orbit (e.g., the International Space Station, Sputnik, satellites, etc.) True / False
3. The Earth feels a gravitational force from the Moon. True / False
4. There is no gravity in deep space. True / False
5. There is no gravity in a vacuum. True / False

After each film clip, the students will discuss with their group (approximately 4) to answer the questions. Each group will answer on whiteboards. After 5 minutes, timer will sound and teacher will ask groups for answers. After whole group discussion, the process will continue with next movie clip.

CLIP 1: VOMIT COMET: https://safeshare.tv/x/ss580f48cb75d5d#v
1. What evidence is there of weightlessness?
2. What evidence is there of gravity?

CLIP 2: FREEFALL: http://safeshare.tv/w/KmaiKOodYa
Pause clip prior to Baumgartner exiting the capsule.
1. What will happen when the astronaut steps outside?
2. How could you fall straight down?
Resume clip.
3) What evidence is there of weightlessness?
4) What evidence is there of gravity?

CLIP 3: ISS: http://safeshare.tv/w/ouFfktloMB
1. What evidence is there of weightlessness?
2. What evidence is there of gravity?

CLIP 4: JUPITER AND SUN:
https://upload.wikimedia.org/wikipedia/commons/5/59/Orbit3.gif
1. What evidence is there of gravity?
2. If gravity is acting, then is the force on the sun greater than, equal to, or less than the force acting on Jupiter? How can you tell?
Using the picture above, answer the following questions:

1. Label the path of a ball thrown off the tower.

2. Label the path of the ISS launched off the tower.

3. Draw the ISS on the path.

4. Draw vectors to indicate all forces on the Earth and on the ISS.
5. What factors contribute to these forces? (Name 2)

Write a short statement (2-3 sentences) describing the relationship between falling and the feeling of weightlessness, using examples from our videos to back up your statement.
APPENDIX N
Lesson Study 2 Teacher Notes

EXPLORING SPACE  Teacher Notes:

Preconceptions:
1. If an object experiences weightlessness, it means there is no gravity acting on it.  
   True / False
2. Gravity exists for objects in Earth’s orbit (e.g., the International Space Station, Sputnik, satellites, etc.)  True / False
3. The Earth feels a gravitational force from the Moon. True / False
4. There is no gravity in deep space. True / False
5. There is no gravity in a vacuum. True / False

CLIP 1: VOMIT COMET: https://youtu.be/LWGJA9i18Co
1. What evidence is there of weightlessness?  
   (Notes: Pre-discussion about what is the meaning of weightlessness - what will you be looking for in the video. The objects and people in the plane appear to be levitating and floating around the plane. Is there any point when the objects lose their sense of weightlessness?)
2. What evidence is there of gravity?  
   How did they achieve the feeling of weightlessness on the Vomit Comet?  
   (Notes: The plane was descending at a steep angle, making the plane and the passengers fall together. Falling gives you the “feeling” of weightlessness by removing the Normal Force while the Weight Force continues to pull you down)
   a. Was gravity affecting the Vomit Comet? What would have happened if they had stepped out of the airplane?  
       (Notes: Yes! Gravity was affecting the Vomit Comet, that’s why it was descending. If anyone had stepped out of the VC, they would have continued falling to Earth.)

CLIP 2: FREEFALL: http://safeshare.tv/w/KmaiK0odYa
Pause clip prior to Baumgartner exiting the capsule.
1. What will happen when the astronaut steps outside?  
   (Notes: I like to give the students three options: 1. He will float outside the capsule, 2. He will fall slowly, perhaps have to push off the capsule to really get going, and 3. He will sink like a rock.)
   Resume clip.
   2) What evidence is there of weightlessness?  
   3) What evidence is there of gravity?  
       (Notes: No evidence of weightlessness, ample evidence of gravity: he sank like a rock. This might be a good time to ask the students about how the falling VC and the Baumgartner freefall are different: why did the VC people appear weightless while Baumgartner did not? It’s all about frame of reference: the VC was falling with the people...
and they could bounce off of it and “fly” around in the airplane. Baumgartner just fell, with nothing to push off of.)

CLIP 3: ISS: [http://safeshare.tv/w/ouFktIoMB](http://safeshare.tv/w/ouFktIoMB)
This is the Space Station that orbits the earth between 205 and 270 mi from the surface of the Earth
1. What evidence is there of weightlessness?
   (Notes: ample evidence of the astronaut feeling weightless: wild & crazy hair, she has to push off of the handles in order to move through the station, flies through the station with the greatest of ease, etc.)
2. What evidence is there of gravity?
3. If you answered “none” to Question 2 for Clip 3 (ISS), how does the ISS stay in Earth’s orbit? (Notes: even though the video provides no direct evidence of a force of gravity acting on the ISS, the fact that the ISS is in orbit requires gravity to hold it in Earth’s orbit.)

CLIP 4: JUPITER AND SUN:
1. What evidence is there of gravity?
   There’s evidence that the smaller mass is being pulled around the bigger mass. There’s also evidence that the bigger mass is being pulled around the smaller mass.
2. If gravity is acting, then is the force on the sun greater than, equal to, or less than the force acting on Jupiter? How can you tell?
   The forces are equal. The larger mass moves around the center of mass as well. Both objects experience gravitational attraction.

[http://astro.unl.edu/naap/ebs/animations/ebs.html](http://astro.unl.edu/naap/ebs/animations/ebs.html)

Write a short statement (2-3 sentences) describing the relationship between falling and the feeling of weightlessness, using examples from our videos to back up your statement.
(Notes: Falling gives you the “feeling” of weightlessness by removing the Normal Force while the Weight Force continues to pull you down. The Vomit Comet video shows this at relatively low elevations; the ISS video shows the same thing in Earth’s orbit. The ISS is essentially falling “around” the Earth instead of falling towards the Earth because a significant lateral force was applied, sending the ISS into orbit around the Earth.)
APPENDIX 0

Definition of Terms

Definition of Terms

The following definitions are provided to ensure uniformity and understandability of the terms used throughout this study. The PR developed all definitions not accompanied by a citation.

Broad-field. A certification for secondary science teachers which authorizes them to teach any type of science. This broad test of general science knowledge has little detail to any specialized science content such as biology, chemistry, physics, or earth and space science.

Collab. Collaborative class for mainstreaming special education students, characteristic of two teachers (one general education and one special education) and two rosters of students.

College Preparatory physics (CP). This is the beginning level of physics for high school. All students are required to take one physics class, and this is the lowest level taught. It is less difficult than the honors or advanced placement level of physics.

Discourse Analysis approach. Method of qualitative data coding and reporting for discourse that uses dialogue from multiple sources while in conversation.

Field notes. Written conversations and documents from meetings as well as classroom observations from Research Lessons are considered field notes. Other field sources include lesson plans, lesson revisions, summaries, student work samples, and the investigator’s reflection journal (handwritten or digital).
**Force Concept Inventory.** A test given to physics students to measure their degree of understanding regarding targeted Newtonian physics misconceptions. This thirty question multiple choice test was written and validated by D. Hestenes and L. Halloun in 1992.

**Learning Cycle.** A popular strategy of structuring science learning often labeled with the “5 E’s” of engage, explore, explain, elaborate, and evaluate.

**Lesson Study.** A fifty-year plus old method of professional development, that originated in Japan, which collaboratively groups teachers together to write model lessons and then to teach these lessons in an effort to uncover student learning idiosyncrasies and establish best practice in reflective collaboration.

**Lived Experience Descriptions (LED).** Van Manen suggests using LED to reflect on an experience such as a lesson taught or an interaction with a student. This reflection should be poured out onto paper chronologically stating the scenario factually and descriptively, using all helpful senses to create the happening (Vagle, 2014).

**Member check.** Periodic discussions and exposure to analyzed data as collaboration and others’ understandings to clarify teacher understandings and to better emulate the reality of the experience of the participants.

**Misconception.** A preconception or common sense understanding that students and the general population holds that explains natural phenomenon. These preconceptions are often not scientifically sound and work against scientific understanding. More plainly, “the phenomenology of patterns in the learners’ responses…that are not consistent with experts’ understanding” (Lee, 2010)

**Participant-Researcher (PR).** Name of a researcher who has a role in the community or group of whom she studies.
**Pedagogical content knowledge (PCK).** A type of teacher knowledge which synergizes content knowledge and pedagogical knowledge as applied specifically to the teaching and learning of a special population in context to a specialized content.

**PhET.** A platform for physics simulations produced by the University of Colorado Boulder.

**Posttest.** Test given at the end of learning to determine to what degree learning occurred.

**Practical Knowledge.** A “term designed to capture the idea of experience in a way that allows us to talk about teachers as knowledgeable and knowing persons. Personal practical knowledge is in the teacher's past experience, in the teacher's present mind and body, and in the future plans and actions. Personal practical knowledge is found in the teacher's practice. It is, for any one teacher, a particular way of reconstructing the past and the intentions of the future to deal with the exigencies of a present situation” (Connelly & Clandinin, 1988, p. 25)

**Pretest.** Test given prior to learning a concept in order to establish a baseline of knowledge.

**Professional Development.** A type of teacher learning takes place after a teacher is working in a classroom. To increase the effectiveness of the teacher, additional learning and growth are supported through carefully constructed means, often from an administrative initiative.

**Professional Learning Community (PLC).** A Professional Learning Community is a group of teachers who collaborate on teaching or curriculum as the binding purpose of their scheduled time spent together.
**Research Lesson.** In the practice of Lesson Study, the Research Lesson is the culminating collaborative work of the participants. This is the lesson that is then taught for participants and invitees alike to better understand student learning.

**Stimulated Recall (SR).** In addition to using LED to refresh the memories of experiences and springboard discussion, video clips will be viewed as selected by the researcher to focus discussion and problem-solving. Thus, formal lesson instruction of the group-designed lessons will be video-taped. These videos will serve as a recollecting tool, not as a means to quantify any data.

**Teacher buy-in.** Teachers believe in the value of a certain initiative to an extent that motives them to support and work towards the initiative’s success.

**Teacher certification test.** Teacher certification to teach any content area is received by taking and passing specific content area tests to prove content knowledge or pedagogical proficiency as scored in comparison to a standard of performance. Once a passing score is achieved and other mandatory coursework specific to the certification field is complete, a teaching certificate in the tested field will be granted.

**Teachers’ perceptions of their classroom environment.** When asked about one’s classroom environment, teachers may perceive or imagine something that does not align with an unbiased observer. They may project their desires instead of the reality of their classroom. This potential bias should be noted when teachers self-report their descriptions of their classroom environment.

**Teacher self-efficacy.** This is a belief and general confidence of a teacher in her or his ability to provoke and facilitate learning in her students, and is a measure of a teacher’s perceived ability or capacity in her or his teaching.
TIMSS. The Third International Mathematics and Science Study in 1995 was the largest and most ambitious international study of student achievement conducted up to that time. Data was gathered at five grade levels in more than 40 countries (the third, fourth, seventh, and eighth grades, and the final year of secondary school). ("TIMSS 1995 Home")