Exploring Pedagogical Content Knowledge of Biology Graduate Teaching Assistants Through Their Participation in Lesson Study

by

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With much love, I dedicate this dissertation to my mom and dad.

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ABSTRACT

Graduate teaching assistants (GTAs) are responsible for teaching the majority of biology undergraduate laboratory sections, although many have not received training in the aspects of effective teaching. One type of professional development, called lesson study, has played a key role in improving student achievement in secondary education in both Japan and the United States. Key features of lesson study, including research, collaboration, observation, and reflection, are believed to create changes in teachers' knowledge and beliefs, which can inform the development of pedagogical content knowledge (PCK). PCK is an integration of both content knowledge and pedagogical knowledge and involves teachers' understanding of the best ways to help students comprehend the specific subject matter using multiple instructional strategies, examples, and explanations. The present study examined the potential that lesson study holds for advancing GTAs' PCK while teaching an introductory biology laboratory course.

The participants in the study included four GTAs who taught the laboratory sections of a general biology course for students majoring in Biology. The participants had diverse backgrounds, both in terms of their teaching experience and their teacher training. Collectively, the group met for 10 weeks during the fall 2014 semester in order to complete two cycles of lesson study. Using a qualitative methodology, this study found that two aspects of PCK emerged during the lesson study process. The researcher also noticed a disconnect between the participants' intent and practice. This disconnect could be attributed to the awkwardness of implementation of new strategies, the duration of the lesson study, and the inexperience of the participants in the study.

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CHAPTER I: INTRODUCTION

Introduction

This study investigated the development of biology graduate teaching assistants' (GTAs') pedagogical content knowledge (PCK) through their participation in a collaborative teacher professional development opportunity known as lesson study. This chapter presents an overview of the background of the study, the purpose of the study, and the overall rationale for and significance of this research. Key terms and a chapter summary are also included.

Background

Despite decades of education reform efforts, there has been little change in mathematics and science proficiency in our nation's students (Business-Higher Education Forum, 2011). Indication of this lack of student proficiency has been highlighted in several sources. First, at the K-12 level, the National Assessment of Educational Progress (NAEP) indicated that only 21% of 12th grade students scored at or above a level of *proficient* in science, with only 2% of students scoring at the *advanced* level (National Science Board, 2012). Second, when transitioning from K-12 to college, results from the American College Testing (ACT, 2013) found that fewer than half of 12th grade students who took the assessment met the college readiness benchmarks in mathematics and science, with only one in three students meeting the science benchmark. Finally, students who took the Scholastic Aptitude Test (SAT), a test designed to assess college readiness, showed a six point gradual drop in their scores over the past seven years (Snyder & Dillow, 2013). Taken collectively, these scores indicate that American students are not adequately prepared in mathematics and science education.

Poor student preparation in science, technology, engineering, and mathematics (STEM) fields in K-12 education can lead to students' lack of interest in majoring in these fields in higher education, with only 30% of students who enter college in the United States choosing a major in science or engineering (Institute of Medicine, National Academy of Sciences, & National Academy of Engineering, 2007). Additionally, many universities are experiencing attrition rates of up to 40% of intended undergraduate science majors (Strenta, Elliot, Adair, Matier, & Scott, 1994). Atkinson and Mayo (2011) claimed that less than half of students who intend to graduate in a STEM field actually do so, with more than a third of students majoring in STEM fields leaving their program between their freshman and sophomore year. Lack of STEM graduates is particularly concerning in that STEM-related employment opportunities will grow nearly 17% over the next decade, with more than 90% of those jobs requiring a college degree or higher (Carnevale, Smith, & Strohl, 2010).

Much of this attrition at the university level could be due to the learning experiences of students in STEM classes. Seymour and Hewitt (1997) reported that the effects of inadequate high school preparation were the most common contributor to early decisions to change majors in science, engineering, and mathematics (SEM) fields. Additionally, poor teaching in SEM fields was the most common complaint (90.2%) of all students who changed from a major in SEM fields to non-SEM fields (Seymour & Hewitt, 1997). In the same study, students reported that they perceived the faculty in SEM fields "do not like to teach, do not value teaching as a professional activity, and lack, therefore, any incentive to learn to teach effectively" (Seymour & Hewitt, 1997, p. 146). As a result, one could argue that increasing the quality of teaching can better prepare our students for STEM fields in secondary and post-secondary education, resulting in increased persistence and meeting the demand of jobs in the STEM fields in the United States. The next section will focus on the role of the teacher in improving STEM education.

The Teacher's Role in Improving STEM Education

Stigler and Hiebert (1997) suggested that teachers are integral for making improvements in our educational system because they are in a unique position to both understand and propose solutions to problems that students face. Since the teachers are the driving force for student learning, there is a wide range of information they must possess in order for their students to be successful. A deep understanding of the subject matter, also called content knowledge, is necessary in order to help students create useful cognitive maps, relate ideas to one another, and address common misconceptions (Darling-Hammond, 1998). Possession of effective teaching skills, known as pedagogical knowledge, is also needed (Kind, 2009). Shulman (1986) claimed that in order to teach content such as science in a way that truly promotes student understanding, teachers need an integration of both content and pedagogical knowledge that he termed pedagogical content knowledge (PCK). According to Shulman, PCK is a combination that involves teachers' understanding of the best ways to help students comprehend the specific subject matter using multiple instructional strategies, examples, and explanations.

The Role of the GTA in Postsecondary Instruction

Although the role of a teacher can greatly affect student learning, many GTAs are not adequately prepared for this task (Rushin, Saix, Lumsden, Streubel, Summers, & Bernson, 1997). A qualitative study by Muzaka (2009) found that undergraduates viewed

GTAs as lacking overall content knowledge, teaching experience, confidence, control, and authority. Muzaka also reported that both GTAs and faculty perceived GTAs as lacking overall content knowledge and possessing limited teaching skills. Despite these limitations of their training, many GTAs are frequently expected to make instructional, curricular, and assessment decisions in the courses they teach (Luft, Kurdziel, Roehrig, & Turner, 2004).

GTAs are responsible for a significant amount of undergraduate instruction in the United States mainly in introductory courses in which student attrition in STEM is particularly high (Gardner & Jones, 2001; Kendall & Schussler, 2012; Rushin et al., 1997). According to Sundberg, Armstrong, and Wischusen (2005), GTAs in the discipline of biological sciences were responsible for teaching 71% of undergraduate laboratory sections at comprehensive institutions and 91% at research institutions. Seymour and Hewitt (1997) found that faculty often delegate a high degree of responsibility to their GTAs for teaching the “fundamentals of their disciplines, and for responding to undergraduates’ questions and problems” (p. 158). This reliance on GTAs to teach many of the introductory undergraduate courses can be problematic to efforts in decreasing attrition rates in STEM fields if instructional preparation is assumed to be a strong predictor of student success (Seymour & Hewitt, 1997).

Given the reliance on GTAs for a majority of science laboratory teaching at universities in the United States and their lack of pedagogical training, there is a need for effective professional development for this group to impact the interests and proficiency of undergraduates in STEM-related courses (Park, 2004; Prieto & Scheel, 2008; Rushin et al., 1997). Recognizing this need, researchers have examined a variety of professional development opportunities (Biology Teaching Assistant Project [BioTAP], 2013; DeChenne et al., 2012; Gardner & Jones, 2011; Rushin et al., 1997). In the College Faculty Preparation Committee of the National Association of Biology Teachers, a nation-wide survey was conducted to determine the extent of formal opportunities that were available for graduate students in order to develop teaching skills (Rushin et al., 1997). Surprisingly, the most common perception was that no formal training was required. On the rare incidences when GTAs received professional development opportunities, the types vary and included: a pre-academic year workshop, a semester-long college teaching seminar, a formal college teaching course, and/or training by a professor (Rushin et al., 1997). A more recent look into professional development of biology GTAs from several institutions found that most of the biology departments required a pre-semester orientation followed by either a voluntary or required one semester of discipline-specific professional development (BioTAP, 2013). These findings suggest that some opportunities exist for professional development for GTAs but these opportunities are highly variable.

Although professional development for GTAs exists, the belief of some university faculty that there is not a need for professional development (Prieto & Scheel, 2008; Rushin et al., 1997) indicates that more research is needed that addresses what aspects of training are most beneficial to GTAs and how to support changing ideas for the need of GTA professional development (BioTAP, 2013). In order to address what type of professional development opportunities might be appropriate for GTAs, a broader approach is taken in the discussion below to examine a type of professional development model that has demonstrated positive results in K-12 education and how it might be applied to GTAs.

Teacher Professional Development Model: Lesson Study

The solution to effective professional development at the GTA level may possibly be found in the K-12 setting. However, professional development opportunities that are available to teachers in the United States traditionally have had little long-term influence on actual teaching practices (Nilsson, 2014; Stigler & Hiebert, 2009) and have been criticized for the inability to produce effective change in teaching and student achievement (Loucks-Horsley, Love, Stiles, Mundry, & Hewsom, 2003). This is in contrast to other nations around the world. For example, particularly effective professional development models are seen in Japan where teachers spend a great deal of time each month (Takemura & Shimizu, 1993) participating in ongoing professional development groups called *Konaikenshuu*, which literally translates to *in school training* (Fernandez & Yoshida, 2004). One common component of *Kounaikenshuu* is *jugyoukenkyuu* (Stigler & Hiebert, 1999), which translates to *lesson study. Jugyoukenkyuu* has been the centerpiece of Japanese teachers' professional development since the early 1990's (Chong & Kong, 2012; Puchner & Taylor, 2006) and has played a key role in improving student achievement nationwide (Fernandez & Yoshida, 2004). In a survey taken by 125 lesson study practitioners in Japan, 98% reported that lesson study helped them improve their teaching, and 91% claimed lesson study as the most helpful form of professional development (Murata & Takahashi, 2002).

Lesson study was introduced in the United States in the late 1990's by Stigler and Hiebert (1999) in their publication *The Teaching Gap,* which looked at the Trends in

International Math and Science Study (TIMMS) 1995 video study of mathematics teaching practices in Japan, the United States, and Germany. The authors noted that Japan was the highest achieving country in mathematics, and subsequently traditional forms of teacher development in the United States came into question. This resulted in focused attention toward finding alternative professional development for teachers (Stigler & Hiebert, 2009).

A lesson study is a collaborative approach to professional development that focuses on learning from a constructivist perspective (Fosnot, 1996) while helping teachers carefully examine their practice (Dotger, 2011). Constructivist methods in teaching are centered on the learner and reflect the belief that information is constructed by the learner rather than directly transmitted (Lefrancois, 2006). In a lesson study, three to six teachers of the same grade level and/or content area work collaboratively to design, teach, observe, analyze, and revise a single lesson called the research lesson (Cerbin & Kopp, 2006; Lewis & Hurd, 2011). Participants are asked to view the process as research by posing questions, designing experiments that will answer the questions, collecting evidence, and interpreting the results (Fernandez, 2002). One team member teaches the research lesson to a class of students, while the other participants of the group record notes about the teacher's behaviors, students' behaviors, and interactions in the classroom. Afterwards, the team meets again to discuss and improve upon the research lesson. Another member of the team then teaches the revised lesson to another class of students, and the cycle is repeated (Chong & Kong, 2012). The lesson study group is usually supported by a specialist in either content or pedagogy (Lewis & Hurd, 2011).

The primary purpose of a lesson study is to determine if and how the lesson fosters “intended forms of thinking and behavior” (Demir, Czerniak, & Hart, 2013, p. 23) in students while increasing student learning. Because lesson study focuses on student learning, it provides an opportunity for the participants to evaluate the learning process (Becker, Ghenciu, Horak, & Schroeder, 2008). The result of this process includes a plan for a highly successful lesson that could be used by anyone wanting to teach the topic (Becker et al., 2007). An indirect benefit to the instructors who participate in a lesson study includes learning from both colleagues and students, improving pedagogical knowledge, and developing a deeper understanding of the curriculum (Demir et al., 2013).

There is a growing body of evidence that teacher participation in lesson study can improve student learning by increasing teacher knowledge of content and pedagogy while focusing on student thinking and learning (Lewis, Perry, & Hurd, 2009; Perry & Lewis, 2009; Saunders, Goldenberg, & Gallimore, 2009). In lesson study, teachers work together in a professional learning community in order to share their professional knowledge base on teaching which can include instructional strategies, content knowledge, or knowledge of student learning (Lewis & Hurd, 2011).

Statement of Purpose

The purpose of this study was to examine the potential that lesson study, a form of professional development, holds for advancing GTAs’ PCK while teaching an introductory biology laboratory course. Several studies have documented K-12 teachers’ participation in a lesson study (Lewis et al., 2009; Perry and Lewis, 2009; Saunders et al., 2009), but few have examined the impacts of this form of professional development at the post-secondary level (e.g. Cerbin & Kopp, 2006; Dotger, 2011). The design of undergraduate science laboratories, which offer multiple sections in one week, provide many opportunities for GTAs to implement iterative lessons and to study students' thinking in this way (Dotger, 2011). This study addressed the following research questions: What components of PCK emerge as Biology GTAs participate in lesson study? What are GTAs' perceptions of lesson study as a form of professional development?

Significance of the Study

Examining PCK of GTAs during their participation in a lesson study contributes to the limited amount of research available for professional development models for GTAs. Investigating what components of PCK emerge as Biology GTAs participate in lesson study provides information for these novice teachers' knowledge development while finding an effective way to support their learning to teach. Since PCK is an important aspect of effective teaching, it is believed that improving GTAs' PCK can lead to improved teaching while subsequently decreasing attrition rates in STEM fields.

Definition of Terms

GTA is an acronym for Graduate Teaching Assistant and is a recognized position within the higher education system. The GTA position provides funding for postgraduate research while additionally providing teaching support for the university (Park, 2004). In this study, a GTA can be either a masters or doctoral student and, unless otherwise indicated, is supporting instruction in biology.

Lesson study is an approach to professional development that originated in Japan and has spread rapidly in North America in the last 15 years (Lewis & Hurd, 2011). A lesson study is a collaborative approach to professional development that focuses on learning from a constructivist perspective (Fosnot, 1996) while helping teachers carefully examine their practice (Dotger, 2011). Constructivist methods in teaching are centered on the learner and reflect the belief that information is constructed by the learner rather than directly transmitted (Lefrancois, 2006).

NOS is an acronym for Nature of Science. NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman et al., 2002). NOS includes the following aspects: scientific knowledge is tentative, empirical, theory-laden, partly the product of human inference, imaginative, creative, and socially and culturally embedded (Lederman et al., 2002).

PCK is an acronym for Pedagogical Content Knowledge that is a recognized characteristic necessary for effective teaching (Kind, 2009; Shulman, 1986). PCK is an integration of both content knowledge and pedagogical knowledge and involves teachers' understanding of the best ways to help students comprehend the specific subject matter using multiple instructional strategies, examples, and explanations.

Research Based Instructional Strategies are instructional strategies extracted from the research base on effective instruction (Marzano, Pickering, & Polluck, 2001). Teachers can use these strategies to guide classroom practice in order to maximize the possibility of enhancing student achievement.

SMK is an acronym for Subject Matter Knowledge, which includes the knowledge and understanding of facts and principles and the ways in which they are organized, as well as knowledge about the discipline (Shulman, 1986).

Vision and Change in Undergraduate Biology Education: A Call to Action (American Association for the Advancement of Science [AAAS], 2011) is the framework that guides undergraduate instruction in the biological sciences. This document offers a series of recommendations aimed at ensuring that all students gain a better understanding of the nature of science and the living natural world.

Chapter Summary

Many students majoring in STEM are leaving their field of study in higher education (Atkinson & Mayo, 2011; Seymour & Hewitt, 1997; Strenta et al., 1994). Of the students who have changed majors to a non-STEM field, many point out the role of the instructor as a reason for their departure (Seymour & Hewitt, 1997). STEM faculty, including GTAs, need to provide better quality instruction in order to keep students interested and motivated to learn and increase student learning (Seymour & Hewitt, 1997). Many GTAs do not have the necessary training in order to improve student learning and student motivation while decreasing student attrition rates (Golde & Dore, 2001; Park, 2004). The professional development opportunities of universities, if available, are not meeting the needs of GTAs (Gardner & Jones, 2011; Prieto & Scheel, 2008; Rushin et al., 1997). One type of Japanese professional development, called lesson study, may be a way to increase GTAs' professional learning. This study will explore the effects of lesson study on GTAs' PCK.

CHAPTER II: LITERATURE REVIEW

Introduction

In universities throughout the United States, GTAs are responsible for a significant proportion of undergraduate instruction in STEM disciplines, particularly in introductory laboratory courses (Gardner & Jones, 2011; Miller, Brickman, & Oliver, 2014; Rushin et al., 1997). Sundberg et al. (2005) found that GTAs provide 91% of biology laboratory instruction at research universities. In this role, GTAs are expected to be content experts and knowledgeable of the appropriate pedagogical strategies for undergraduate instruction (Luft et al., 2004) though many have not received any training in educational theories or strategies (Luo, Bellows, & Grady, 2000). Because of this lack of prior training, many GTAs do not have an adequate foundation to carry out their assigned instructional responsibilities effectively, yet still are expected to (Golde & Dore, 2001). This is disconcerting given that many GTAs will become the next generation of faculty members who also have instructional responsibilities with limited preparation (DeChenne et al., 2012). Since most GTAs are still poorly or completely unprepared to teach (DeChenne et al., 2012), there is a need for GTA professional development that can enhance the learning experience for the GTA as well as the undergraduate STEM students they teach (Park, 2004).

This literature review will include a description of professional development opportunities currently available to all GTAs regardless of discipline. It will then discuss the knowledge base that is necessary in order for GTAs to promote scientific understanding and provide evidence for the efficacy of a professional development program called lesson study that could potentially enhance the professional knowledge in GTAs.

Professional Development Opportunities for GTAs

There have been numerous studies that have examined the need for better GTA professional development and training (DeChenne et al., 2012; Gardner & Jones, 2011; Miller et al., 2014). Despite this body of research, there appears to be little overall improvement in the amount of GTA preparation in the last 15 years (DeChenne et al., 2012). The literature suggests that professional development programs vary greatly among institutions both within and among disciplines (Gardner & Jones, 2011).

A common format for GTA professional development is a short program that happens before the semester begins and focuses on administrative details and university policies and procedures, with little to no time focused on instructional practices (Prieto & Scheel, 2008; Rushin et al., 1997). Many university professional development programs go a step above the short program by offering non-discipline specific training that emphasizes course management and logistics and is oriented toward generic teaching skills. This minimal preparation is in contrast with current learning theories that include pedagogical instruction (Gardner & Jones, 2011). If any pedagogical instruction is included in these one-shot sessions, the GTAs are usually told the effectiveness of the techniques and are expected to implement these techniques into their classrooms without further guidance (Gardner & Jones, 2011). However, research has shown that effective transmission and application of this new knowledge into practice is no guarantee (Michael, 2006). These unguided training sessions are also in contrast with theories of adult learners that suggest that the best instruction occurs when the learner interacts with the material and others in order to build conceptual understanding (Taylor, Marienau, & Fiddler, 2000).

Professional Development for Biology GTAs

The Biology Teaching Assistant Project (BioTAP, 2013) is an NSF-funded research coordination network incubator designed to share resources and create model practices that can develop GTAs as researchers while also developing their teaching practices. BioTAP created a survey that included a mixture of multiple-choice and open-ended questions in order to gain an understanding of what institutions' professional development programs offered, how much time GTAs spend in such programs, and how the institution assessed the effectiveness of the program. The survey was sent to all the research-active universities in the United States and Canada, and yielded 91 respondents from 81 different institutions. From the BioTAP survey, it was found that many biology GTAs were required to attend a pre-semester orientation program. However, professional development offerings during the semester were less common and often optional, leaving GTAs with little incentive to attend. The BioTAP survey also revealed that some universities provided professional development during laboratory preparation meetings for a specific course (~30%), some offered professional development by department or institution (~20%), and a few offered formal peer-mentoring (18%) or faculty-mentoring programs (~10%) for biology GTAs. The topics covered in professional development meetings, workshops, and programs were relatively consistent including classroom management, course content, learning theories, lesson planning, teaching policies, and teaching techniques (BioTAP, 2013). However, many respondents of the BioTAP survey felt their professional development programs were insufficient in the areas of pedagogical theory.

Elements of Successful Professional Development Programs for GTAs

Of the GTAs who receive basic professional development, many find that it does not adequately prepare them to teach (Duchenne et al., 2012; Luft et al., 2004; Prieto & Scheel, 2008). In a national survey on doctoral education, 45% of graduate students felt they were not prepared to teach (Fagen & Wells, 2004). Many graduate students are interested in pursuing a career in academia in which professional development should prepare them for instructional responsibilities of their future faculty positions (Park, 2004). In fact, successful professional development programs have shown a positive impact on GTA self-efficacy in teaching (Komarraju, 2008), which is a central component in social cognitive theory (Bandura, 1977) and positively correlated with teaching performance (Bandura, 1997).

A common belief of many GTAs is that only content knowledge is required in order to be an effective teacher and the role of instructors is to transmit their tangible knowledge to their students (Gardner & Jones, 2011). However, successful professional development programs emphasize the importance of pedagogy and stress that content knowledge alone is not sufficient in promoting student learning (Hammrich, 2001). Useful components of effective instructional programs include the best practices of active learning, constructivist learning strategies, peer interaction, formative and summative assessment, reflection, and generic and discipline-specific teaching information (Park, 2004). However, GTA training should also involve ongoing activities and opportunities to actually teach, not just formal training programs explaining instructional strategies and learning theories (Park, 2004).

As indicated, content knowledge is not the only factor necessary in order to become an effective teacher. Shulman (1986) stated that teachers need an understanding of subject matter, curricular, and pedagogical content knowledge in order to be effective instructors. His comments were initially made in regard to kindergarten through 12^{th} grade education, but the same knowledge is essential for GTAs (Luft et al., 2004) because GTAs are often required to teach the fundamentals of their disciplines (Seymour & Hewitt, 1997). The next section will focus on the types of knowledge that are required for effective teachers in general.

Professional Knowledge of Teachers

Researchers and policy makers have argued that an increase in a teacher's professional learning leads to high quality teaching and gains in student achievement (Gess-Newsome, Carlson, Gardner, & Taylor, 2011). A teacher's professional knowledge has been conceptualized in multiple ways throughout the years (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Shulman, 1986) but a current review of the literature suggests four main areas of teacher knowledge critical for effective instruction: subject matter knowledge, pedagogical knowledge, pedagogical content knowledge (PCK), and knowledge of context (Grossman, 1990; Park & Oliver, 2008). Of the four knowledge areas, PCK is believed to have the greatest impact on teachers' classroom actions (Gess-Newsome, 1999; Grossman, 1990) and the promotion of student learning (Shulman, 1986).

Pedagogical Content Knowledge

PCK is commonly defined as the knowledge base that is necessary in order to transform subject matter knowledge in ways that are comprehensible to students (Grossman, 1990; Shulman, 1986) and involves a teacher's "understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment" (Park & Oliver, 2008, p. 264). The development of PCK involves a shift in teachers' understanding "from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students" (Shulman, 1987, p. 13). Furthermore, Park and Oliver (2007) stated that PCK distinguishes novice from expert teachers.

Policy makers in many countries are working to improve teacher education by focusing on teachers' PCK (Gess-Newsome, 1999), which can provide a theoretical framework for understanding and examining teachers' skills (Abell, 2007). PCK has also been identified in many reform documents as a knowledge base that teachers should possess (e.g., American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). However, there are many discrepancies that persist in the literature regarding what the components of PCK are and how researchers can use this knowledge to develop effective practices in teacher education (Kind, 2009).

The next section will describe the various models in the literature that are used to describe PCK.

Models of PCK. Shulman's (1986) original PCK model proposed that there were two components of PCK. These components included the knowledge he referred to as *representations*, which is commonly known today as *instructional strategies* (Kind, 2009), and knowledge of students' subject matter referred to as *learning difficulties*. Most scholars agree on Shulman's original components of PCK, but also note that Shulman's model is too simplistic (Kind, 2009; Park & Oliver, 2008).

In an extensive review of the literature, Kind (2009) described nine different models that attempted to further explain PCK. A majority of these models, labeled *integrative models*, combined Subject Matter Knowledge (SMK) within the construct of PCK and suggested they are not separate components. Three of the models (i.e., Grossman, 1990; Magnusson et al., 1999; Shulman, 1986, 1987) used the concept that PCK transforms SMK and were labeled *transformative models*. Gess-Newsome (1999) used an analogy from chemistry to describe the difference between an integrative model and a transformative model. In this analogy, the integrative model was compared to a mixture, in which the individual components, (i.e., SMK, Pedagogical Knowledge, and Contextual Knowledge) when mixed together form PCK and can be separated through physical means. In contrast, the transformative model was compared to a compound in which the original components can no longer be detected, but have formed a new substance (i.e., PCK).

The literature in science education indicates a preference of integrative models over the transformative models because integrative models "tend to offer a wide-ranging general picture of teachers' skills and knowledge" (Kind, 2009, p. 30). Kind further argued that this preference may exist because integrative models reflect current practice in teacher education. Despite attempts to integrate subject matter and pedagogical knowledge in preservice preparation programs, teachers often state that they maintain separate knowledge bases for the two, which is a potential danger of the integrative model (Gess-Newsome, 1999). When teachers do not see the importance of knowledge integration, they will continue to "emphasize the importance of content over pedagogy, resulting in transmission modes of teaching with little regard for content structure, classroom audience, or contextual factors" (Gess-Newsome, 1999, p. 12). An additional criticism for the integrative model is that it is lacking in explanatory power and does not offer a mechanism that demonstrates how the interaction of SMK, pedagogical knowledge, and contextual knowledge results in PCK (Abd El-Khalick, 2006). For the purposes of this study, the researcher will use a transformative model to provide a theoretical background because transformative models "home in on subject-specific issues, including how to teach difficult and abstract ideas that are common in science" (Kind, 2009, p. 31). The next section will describe the specific model chosen for this study.

A transformative model for PCK in science education. Magnusson and colleagues' (1999) transformative model in science education was developed from the work by Grossman (1990) and Tamir (1988) and consisted of five components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. The following sections will describe each component in detail

Orientations toward science teaching. Orientations toward science teaching consists of the teachers' knowledge and the beliefs about the purposes for teaching a subject at a particular grade level (Magnusson et al., 1999). It is the viewpoint of many researchers that the knowledge and beliefs of a teacher can serve as a conceptual map that directs instructional decisions such as determination of learning objectives, use of curricular materials, decisions on content of student assignments, and evaluation of student learning (Borko & Putmam, 1996; Magnusson et al., 1999). In this regard, orientations toward science teaching is considered to be the *lens* through which the other four components of PCK are filtered when enacted (Abell, 2007). Magnusson et al. (1999) proposed nine different orientations to science teaching and defined each by providing the goal of teaching science and the characteristics of instruction for that orientation. The nine orientations proposed by Magnusson and colleagues (1999) included: process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry. A comparison of the characteristics of instruction from each orientation reveals that some teaching strategies are a characteristic of more than one orientation. Therefore, Magnusson and colleagues believed that it is not the use of a particular strategy, but the purpose for utilizing that strategy that distinguishes a teacher's orientation for teaching science.

After examining published studies using the Magnusson et al. (1999) PCK model, Friedrichsen, Driel, and Abell (2010) recommended reexamining the nine categories that were proposed. The authors identified a variety of methodological issues of the nine categories including authors using the categories in different or unclear ways, assigning teachers to only one category, and ignoring the overarching orientations component. Friedrichsen et al. (2010) believed that in order to move the field forward, the construct of science teaching orientations needed a better theoretical basis. As such, the authors identified three important aspects that shape science teaching orientations: conceptions of science teaching and learning, conceptions about the nature of science, and conceptions about the goals of science education in general. Conceptions of science teaching and learning include the beliefs about the role of the teacher, the role of the student, and how students learn science (2010). Conceptions about NOS include the epistemological beliefs about science itself (Phillips, 1997), while conceptions about the goals of science education include beliefs about how students learn science, learn to do science, and learn about science (Hodson, 1992).

Knowledge of science curriculum. Knowledge of science curriculum can be divided into two components: knowledge of goals and objectives and knowledge of specific curricular programs. In order to have well-developed PCK, a teacher should have knowledge of the goals and objectives for students in the subjects and grade levels "as well as the articulation of those guidelines across topics addressed during the school year" (Magnusson et al., 1999, p. 103). Additionally, a teacher should know what students have already learned in previous years as well as what they are expected to learn in later years (Grossman, 1990). Knowledge of specific curricular programs includes a teacher's knowledge of the programs and materials that are relevant to teaching a particular topic (Magnusson et al., 1999). Park and Oliver (2008) claimed that this type of knowledge enables a teacher to identify core concepts and modify activities in order to eliminate aspects believed to be “peripheral to the targeted conceptual understandings” (p. 266).

Knowledge of students’ understanding of science. In order to utilize PCK effectively, teachers should have knowledge of the abilities and skills their students would need in order to learn the specific concepts, as well as knowledge of the science concepts that students find difficult (Magnusson et al., 1999). The authors listed three reasons why students find learning difficult in science: the concepts are abstract and/or lack any connection to students’ common experiences; the instruction centers on problem solving, and students do not know how to think effectively about problems and plan strategies to find solutions; and students’ prior knowledge is contrary to the targeted scientific concepts. This final type of knowledge is referred to as misconceptions, which is a common feature in science learning. Similar to Magnusson et al.(1999), Park and Oliver (2008) also stated that teachers should know students’ common errors, conceptions, misconceptions, motivation, diversity in ability, learning style, interest, developmental level, and need.

Knowledge of assessment in science. Knowledge of assessment in science includes knowledge of dimensions of science learning that are important to assess and knowledge of the methods by which that learning can be assessed (Magnusson et al., 1999; Tamir, 1988). Knowledge of dimensions of science learning includes the aspects of students’ learning that are important to assess within a particular unit of study (Magnusson et al., 1999). Knowledge of methods of assessment includes the ways a teacher can assess the specific aspects of student learning that are important to a particular unit of study (Magnusson et al., 1999). This includes “knowledge of specific instruments or procedures, approaches or activities that can be used during a particular unit of study to assess important dimensions of science learning, as well as the advantages and disadvantages associated with employing a particular assessment device or technique" (Magnusson et al., 1999, p. 109).

Knowledge of instructional strategies. Knowledge of instructional strategies is composed of two categories: knowledge of subject-specific strategies and knowledge of topic-specific strategies. Subject-specific strategies include general approaches to enacting science instruction and can include learning cycles, conceptual change strategies, and inquiry-oriented instruction, for example (Magnusson, et al., 1999; Park & Oliver, 2008). Topic specific strategies include strategies that pertain to teaching particular subjects within the science domain (Magnusson, et al., 1999; Park & Oliver, 2008).

Summary. The Magnusson et al.(1999) PCK model has been used in numerous empirical studies as a conceptual tool to identify the various domains that are necessary to be an effective teacher (e.g., Brown, Friedrichsen, Abell, 2013; Hanuscin, Lee, & Akerson, 2010; Park & Chen, 2012; Seung, Bryan, & Haugan, 2012). At the elementary level, Hanuscin and colleagues (2010) used the Magnusson et al. model to examine the PCK for nature of science of three elementary teachers who had been successful in improving their students' understanding of nature of science. Their findings highlighted a need for professional development that focused more on ways to assess the nature of science. At the post-secondary level, Seung and colleagues (2012) used the Magnusson et al. model to investigate the PCK that physics GTAs developed while teaching a new introductory physics curriculum. The researchers found that through the experiences of an intensive pedagogy-focused workshop and in teaching new curriculum, the GTAs developed three of the five knowledge domains in the Magnusson et al. model.

Developing PCK

PCK development takes time and "is complex, occurs in phases and relates to trainees' abilities to integrate knowledge from a variety of sources" (Kind, 2009, p. 16). Possession of content knowledge informs the development of PCK (Grossman, 1990) and is essential to PCK development (Kind, 2009). Although an important component, the work by Angell, Ryder, and Scott (2005) demonstrated that content knowledge is not all that is required in PCK development. In their three-year longitudinal study, the authors compared the PCK of novice and expert physics teachers and found little difference in content knowledge between the two groups. However, they reported that the expert teachers made more extensive links between their knowledge within different contexts and exhibited richer pedagogical skills, while the novice teachers were primarily concerned with transmission of correct content. This finding seemed to support the notion that teachers also acquire PCK from actual teaching experience as well as from professional development. While working with students, teachers learn about the strategies that work, as well as student misconceptions and prior knowledge of specific topics (Grossman, 1990).

By comparison, Veal (1999) believed that development of teachers' PCK is based on existing beliefs influenced by how they themselves were taught. He stated that in order for PCK to develop, teachers needed to reflect on their beliefs about epistemology and change existing beliefs to accommodate new beliefs. Hashweh (2003) stated that progressive outcomes occur when teachers undergo accommodative change, which is the change a teacher must endure in order to carry out current reforms in education. Teachers undergo accommodative change “when they are internally motivated to learn; become aware of their implicit ideas and practices and critically examine them; construct alternative knowledge, beliefs, and practices; resolve the conflicts between the prior set of ideas and practices and the new; and do so in a social climate characterized by collaboration, trust, reflection and deliberation” (p. 421). It is believed that teacher accommodative change can occur during the type of professional development called lesson study, which will be discussed in the following section.

Lesson Study

Lesson study involves a system of research and development that includes teachers refining their ideas about *best practices* through examination of live instruction (Lewis & Hurd, 2011). Participants involved in lesson study learn from one another, from outside specialists, from research, and from close observation of students involved in a lesson they designed (Lewis & Hurd, 2011). Originating in Japan, lesson study has gained much attention in the K-12 setting in the United States and has more recently found its way into universities (Cerbin & Kopp, 2006; Dotger, 2011). The next section will discuss the theoretical underpinnings of lesson study, the stages of lesson study design, and how lesson study can be beneficial for PCK development in GTAs.

Theoretical Model of Lesson Study

A theoretical model of lesson study proposed by Lewis and colleagues (2009) used the features of investigation, planning, research lesson, and reflection to create changes in teachers’ knowledge and beliefs, professional community, and teaching-learning resources. (The intervening changes in this model are based on the theoretical model of *situated learning theories*, which was conceived by Lave and Wenger (1991). In this theory, the authors described that learning is embedded within activity, context, and culture and is usually unintentional rather than deliberate. Brown, Collins, and Duguid (1989) developed Lave and Wenger's ideas further by claiming that learning advances through collaborative social interaction and the social construction of knowledge. Dotger (2011) stated that improving teaching is no longer grounded in individuals' practice, but instead "grounded in changing a system of thinking about teaching and learning where the individual teacher, his/her colleagues, and the context are considered together" (p. 158). As teachers participate in lesson study, they develop a new identity, a new set of knowledge, and a new set of skills commiserate with social learning theory (Lewis et al., 2009). The next section will focus on the stages of lesson study that practically support this theoretical foundation.

Stages of Lesson Study

Lesson study involves collaborative goal setting and planning, teaching, revision, and re-teaching of a lesson in order to improve student learning. Participant teachers build upon one another's knowledge of subject matter and of student thinking while observing student learning that occurs in each other's classrooms (Lewis & Hurd, 2011). The following sections will describe each of the stages of lesson study in detail.

Goal setting and planning. A lesson study begins with goal setting and planning in which the participants draw on a variety of experiences to discuss the goals for student learning (Demir et al., 2013). The topic that is chosen is either one that is important in the course, one that generates difficulty in student understanding, or one that is new to the curriculum (Cerbin & Kopp, 2006). Once a topic is generated, the participants discuss the misconceptions or difficulties that students may experience while learning the topic (Demir et. al., 2013). Participants then develop a plan that investigates how students will learn from the lesson by either modifying an existing lesson or starting with a new lesson (Cerbin & Kopp, 2006). The planning of the lesson coincides with planning of the study and will address the type of evidence the team will collect to evaluate student thinking and learning (Cerbin & Kopp, 2006). The end product of this phase is a written research lesson plan that describes in detail the design and rationale behind the design of the lesson (Fernandez & Yoshida 2004). Though not required, an outside specialist in either content or pedagogy can greatly enhance the research lesson plan to raise questions and add new perspectives to the lesson (Lewis & Hurd, 2011).

Teaching of the lesson. After the written lesson plan is completed, the participants move to the teaching phase in which one member of the group teaches the lesson as the other participants observe the lesson being taught (Demir et al., 2013). Instead of focusing on how the content is being taught, observers of a lesson study focus on how students respond to the lesson (Cerbin & Kopp, 2006). Observers of the lesson may take field notes and use rubrics or checklists to monitor student engagement, performance, thinking, or behavior (Cerbin & Kopp, 2006).

Revision of the lesson. After the lesson is taught, participants hold a debriefing meeting in which they discuss the results of their observations of the students during the lesson (Cerbin & Kopp, 2006; Demir et al., 2013). Participants discuss strengths and shortcomings of the lesson in addition to searching for patterns of student discourse and qualitative differences across students that may reveal important insights into the teaching practice and student learning (Demir et al., 2013). Following the debriefing session, team members use the results from the observations to make changes to the lesson by either altering the learning goals or changing the instructional approach (Demir et. al, 2013).

Re-teaching of the lesson. The revised lesson is taught by another member of the group. Depending on the circumstances this cycle of debriefing, revising, and re-teaching is repeated two to three more times (Demir et. al, 2013). Within the cycle, it is rare to see the same teacher teach the lesson twice because varying the teacher provides the group a broader base of experiences from which to learn (Fernandez & Yoshida, 2004).

The research lesson plan. The members of the group should document their field-tested lesson plan along with an explanation of the context and results of the investigation so that other instructors can review and learn from their work (Cerbin & Kopp, 2006). The lesson documentation should include learning goals, lesson plan, rationale for lesson topic and design, and supplementary materials such as student handouts, video clips, instructor notes, etc. (Cerbin & Kopp, 2006). In addition to student learning goals, the study documentation should include challenges, problems, and issues that were under investigation along with a description of the types and methods of data collection that were used to study the lesson. An explanation of the data analysis as well as a summary of findings including conclusions about the lesson should also be included in the study documentation. Supplementary materials such as rubrics, checklists, observation protocols, etc. should also be included (Cerbin & Kopp, 2006).

Lesson Study and GTAs

The literature has only one example of research conducted on lesson study with GTAs. Dotger (2011) explored the impact of lesson study on four GTAs in an Earth

Sciences department. She found that during the lesson study process, GTAs' talk initially focused on logistical issues, but through the lesson study process, conversations began to focus on the learner. There were several limitations in her study that seemed problematic. First, GTAs did not create a formal research plan which Dotger believed significantly impacted the outcome of the study. She claimed that a detailed plan allows articulation of the rationale behind the lesson design, and absence of a plan made it difficult to evaluate the lesson during observations. Second, Dotger found that GTAs did not know which aspects of the lesson were significant for students to learn because there were no overall course goals or objectives for them to follow. Dotger believed that because of this, the new lesson did not deviate far from the original lesson. Third, the GTAs were unfamiliar with alternative instructional strategies; therefore, their newly planned lesson included delivery of definitions with the expectations that students would connect the concepts on their own. Finally, all of the participants in Dotger's study were novice instructors who had never articulated instructional goals, written objectives, considered students' prior knowledge, observed other GTAs teach a lesson, or met to discuss learning outcomes which greatly limited their ability to design lessons outside their experience.

Despite these limitations, Dotger reported small changes in the GTAs' discussions involving pedagogy about teaching and learning. The greatest benefit was the regular forum that lesson study provided for the GTAs in order to explore their ideas about teaching. Lesson study provides GTAs opportunities to study teaching within content and context, which is a characteristic GTAs desire (Nicklow, Marikuent, & Chevalier, 2007). Weekly meetings may allow GTAs to understand what they are supposed to teach, but can be limiting to their investigations of how to teach the content or why they should teach the content (Nicklow et al., 2007). Dotger (2011) further argued that "lesson study builds from previous efforts in developing GTAs' knowledge with in-depth study of teaching in a particular context highly familiar and relevant to participants" (p. 166). Furthermore, lesson study allows participants to engage in various components that successful professional development programs should include, while developing their own theories of teaching that are "linked to and dependent upon student learning" (Dotger, 2011, p. 166).

Chapter Summary

GTAs are responsible for teaching a large amount of undergraduate students despite having inadequate training in the aspects of effective teaching (DeChenne et al., 2012; Luo et al., 2000). Many institutions of higher education offer some sort of professional development, but these programs are not necessarily meeting the needs of the GTAs (DeChenne et al., 2012; Gardner & Jones, 2011; Miller et al., 2014). A professional development model called lesson study has been very effective in Japan, and has recently been used in K-12 education in the United States in order to improve the quality of instruction our students are receiving (Cerbin & Kopp, 2006; Lewis et al., 2009). The theoretical model of lesson study put forward by Lewis, Perry, and Hurd (2009) proposed that the features of lesson study can create changes in teachers' knowledge and beliefs, which can lead to the development of PCK (Grossman, 1990; Veal, 1999). Currently, lesson study has been used in one known study in post-secondary education that demonstrated small changes in GTAs' knowledge and beliefs (Dotger, 2011). However, the researcher of this study will address the limitations in Dotger's study in order to investigate the PCK that can develop in a lesson study cycle among GTAs.

CHAPTER III: METHODOLOGY

Introduction

Laboratory instruction is a cornerstone of many science programs because it allows the students to be actively engaged in their learning (Herrington & Nakhleh, 2003). GTAs are responsible for teaching the majority of biology undergraduate laboratory sections (Gardner & Jones, 2011; Kendall & Schussler, 2012; Sundberg et al., 2005). Researchers have recognized, however, that GTAs are typically underprepared to do so (Kendall & Schussler, 2012; Luo et al., 2000; Muzaka, 2009) and professional development for GTAs is limited or non-existent (Rushing et al., 1997; Sundberg et al., 2005). Therefore, the purpose of this study was to examine the potential that lesson study, a form of professional development, holds for advancing GTAs' PCK. This chapter will begin with a description of the reshaping of the research question, research design, research context, and participants of the study. Next will follow a discussion of the instruments and procedures that will be used to collect the data. Then limitations and delimitations associated with this study will be addressed.

Research Design

The purpose of this study was to investigate changes that occurred in GTAs' PCK after participation in lesson study. The research design was qualitative in nature. Qualitative research is used when the goals of a study are to explore and become immersed in a phenomenon or issue in its natural setting in order to gain a deeper understanding of the phenomenon (Creswell, 2014). The phenomenon under examination was PCK development of GTAs during their participation in lesson study. A case study approach was utilized as it allows investigators to maintain the holistic and significant characteristics of real-life events (Yin, 2009). Case studies involve the study of a case within a real-life context in which the researcher "explores a real-life, contemporary bounded system or multiple bounded systems over time, through detailed, in-depth data collection involving multiple sources of information" (Creswell, 2014, p. 97). Furthermore, the interpretive study methodology lies in examining *process* rather than *outcome*, and in discovery rather than confirmation (Merriam, 1998).

A single-case design with multiple units of analysis was utilized for this study. The rationale for choosing this design was that the single case was a *representative* case in which the intention was to depict the circumstances and conditions of a commonplace situation (Yin, 2009). The single case in this study was the group of GTAs who participated in lesson study. The multiple units of analysis included the individual participants that were involved in the group because each participant's PCK development was a unique experience due to their unique backgrounds and prior knowledge (Yin, 2009).

This single case study was descriptive in nature. This type of case study was used to describe a phenomenon in its real-world context (Yin, 2014). The case study was analyzed based on the theoretical proposition developed by Lewis and colleagues (2009) that proposed that the features of lesson study can change teachers' knowledge and beliefs. The following were the central questions that were addressed in this study: How does the pedagogical content knowledge of graduate teaching assistants evolve, if at all, during participation in lesson study? What are GTAs' perceptions of lesson study as a form of professional development?

Reshaping the Research Questions

Prior to data collection, it was difficult to determine the data sources that would be required to address the first research question asking how PCK developed, if at all. As the researcher began to analyze the data collected, it became clear there were not enough data sources during the pre-lesson study and post-lesson study to determine whether PCK evolved within each participant. Patton (2002) encouraged qualitative researchers to recognize the dynamic nature of inquiry and to be attentive of design elements that may vary and surface as fieldwork is conducted. With the additional insight that was gained through the data collection process, the researcher reshaped the research questions to address the following:

(1) What components of pedagogical content knowledge emerge as Biology GTAs participate in lesson study?

(2) What are GTAs' perceptions of lesson study as a form of professional development?

Context

This study took place at a public doctoral/research university in the Southeastern United States that primarily serves in-state residents. Statistics from the fall semester of 2014 indicated that of the 22,729 students who were enrolled in the university, 89% were full-time undergraduate students. Students with a declared STEM major comprised 23% of the undergraduate population.

Departmental data indicated that in the fall of 2013, the Department of Biology had a total of 48 GTAs in which 54% were working on a master's degree, and 46% working toward a doctoral degree. Prior to each semester, the GTAs in the Department of

Biology participate in an orientation meeting in which departmental rules and guidelines are established. This is the only explicit training the GTAs receive. In the fall of 2014, the university offered five sections of the first semester biology course designated for students majoring in Biology, instructing approximately 397 undergraduate students. There were 26 sections of the laboratory to this course, which was a separate component of the class and taught by GTAs. Each laboratory section had approximately 24 students. This study occurred in the laboratory portion of this first semester biology course with four GTAs.

Participants

Purposeful sampling was utilized in this study to select individuals that could decisively inform an understanding of the research problem (Creswell, 2013). The participants of this study included four GTAs of varying backgrounds who taught the laboratory sections of the general biology course for students majoring in Biology. The participants were purposefully selected due to their various backgrounds in their teaching experience and teacher training. For their participation in this study, the biology department chair waived tutoring responsibilities to all of the participants. The facilitator of the group, Shannon, was a GTA with 10 years of teaching experience at the secondary level and four semesters of teaching experience in post-secondary education. This was her first semester teaching the biology laboratory for majors. Grace had two semesters of teaching experience at the university level, but had no formal training in the theories and practices in education. However, Grace had experience teaching the biology laboratory for majors. The other participants, Spencer and Clint, had not had any theoretical or practical teaching experience and were considered novice educators (see Table 1).

Table 1

Participant demographic data

Participant	Sex	Degree pursuing	Practical Teaching Experience	Theoretical Training in Education
1	Female	Ph.D. in Biology Education	10 years K-12 5 semesters higher education	Yes
2	Female	M.S. in Biology	2 semesters in higher education	No
3	Male	M.S. in Biology	None	No
4	Male	M.S. in Biology	None	No

Instruments and Data Sources

Yin (2009) stated that data from multiple sources are necessary to create a strong description of the participants' experiences when using case study methodology. Using multiple investigators, sources of data, and data collection methods to confirm emerging findings is known as triangulation (Creswell, 2014). This study utilized multiple data sources to observe GTAs' PCK development including: audio-recorded, semi-structured interviews with the researcher; written participant reflections; field notes collected by the researcher during classroom instructional sessions; a reflective journal written by the researcher; notes from two outside specialists; participant field notes; and two research lesson plans. Table 2 provides a summary of the data sources and collection methods used during the study.

Table 2

Data sources and collection methods used during the study

Data Source	Collection Method
Participants' written reflections	Computer template
Participants' weekly reflections	Responses to prompts via email
Participants' semi-structured interviews	Audio recordings
Classroom observations	Researcher field notes
Lesson study observations	Audio recordings and researcher field notes
Participant field notes	Observations during teaching and re-teaching of lessons
Research lesson plan	Developed during lesson study meetings
Notes from biology outside specialist	Interview with facilitator and researcher
Notes from biology education outside specialists	Emailed to researcher
Researcher journal and field notes	Observation of lesson study sessions

PRIME PCK Written Reflections and Interview Reflections

Participants wrote reflections and participated in interview reflections by using the PRIME PCK reflection template (see Appendix A) that was developed for Project PRIME (Promoting Reform through Instructional Materials that Educate), a multi-year study focused on examining the nature and growth of PCK among high school biology teachers (Gardner & Gess-Newsome, 2011). The PRIME reflection template was composed of two components. The first component asked participants to describe step-by-step their methods of teaching the topic, including what their students will do, and a rationale behind each instructional decision. Participants were able to use instructional materials such as textbooks or lesson plans to assist them in completing their reflection template. The second component of the PRIME PCK reflection template consisted of questions designed to elicit instructional decision-making of the participant. Although there was a scoring rubric available for scoring participants' PCK knowledge, this rubric was not used in this study. The decision not to use the scoring rubric was based on the PRIME researchers' use of the integrative PCK model developed by Gess-Newsome (1999) as their theoretical framework for developing the PRIME PCK rubric. In the proposed study, the researcher used the transformative model by Magnusson et al. (1999) as the theoretical framework.

Field Notes

The researcher observed the participants teaching in their assigned laboratory sections. Field notes consisted of a written record of occurrences during the lesson.

Audio Recordings of Lesson Study Sessions

Each lesson study session was audio-recorded by the researcher to ensure accurate collection of data. Audio recordings were transcribed verbatim for analysis.

Lesson Observation Log

The participants took field notes using the lesson observation log (see Appendix B) during the teaching of each research lesson in order to note their thoughts of the lesson plan itself.

Research Lesson Plan

The research lesson plan was an archive of group thinking that could facilitate data collection and reflection (see Appendix C and D). Documents relating to the teaching of the research lesson including handouts, formal assessments, supplementary information, and other documents were included with the research lesson plan.

Notes from Outside Specialist

There were two outside specialists in this lesson study. The first specialist, Dr. Sturgeon, was the faculty member in charge of the GTAs who taught the first semester biology laboratory course designated for students majoring in Biology. He served as the content specialist. The second specialist was a Biology Education faculty member. In lesson study, the role of the outside specialist is to raise questions and add new perspectives (Lewis & Hurd, 2011). The feedback given by the outside specialists via email was an additional source of data for this study.

Semi-structured Interviews

In addition to the interview questions from the PRIME PCK Reflection template, the researcher incorporated semi-structured interviews (see Appendix E) with the participants to determine their views of participation of the lesson study. Interviews were audio-recorded with a digital recorder and transcribed prior to analysis.

Researcher Reflective Journal

The researcher kept a reflective journal and field notes. The journal allowed the researcher to actively synthesize her reactions about conducting this research. According to Morrow and Smith (2000), the use of a reflective journal adds rigor to qualitative inquiry as the investigator is able to record his/her reactions, assumptions, expectations, and biases about the research process. In doing so, the researcher becomes an instrument in the study (Creswell, 2014). The qualifications of the researcher included14 years of teaching experience with 11 of those years in K-12 education and three years teaching students enrolled in biology courses but not majoring in biology. The researcher also had three years of coursework toward a Doctor of Philosophy degree in Mathematics and Science Education with a concentration in Biology Education. The coursework completed by the researcher included a course in qualitative research methods.

Procedures

This section will describe the steps that were taken to collect data for this study during the fall semester of 2014. The outline of topics of the course was predetermined by Dr. Sturgeon, the faculty member in charge of the GTAs who teach the first-semester majors' biology laboratory course. It was determined by the researcher that there would be two lesson study cycles during the 16-week semester. The researcher also determined the topics for the lesson studies. The topic for the first lesson study cycle (LS1) was photosynthesis, and the topic for the second lesson study cycle (LS2) was protists/algae. This decision was based on the amount of weeks that were available to conduct each cycle of lesson study. Table 3 displays the lesson component as well as the data sources collected during each week of the study.

Table 3

Timeline of the study

Week	LS component	Data Sources Collected
0	Intro to study and Lesson study; Participants complete PRIME PCK Reflection template with nature of science as the topic	Participant written reflections
1	Lesson design for LS1 (identify goals, review literature); Participant interviews for 9 questions on PRIME PCK Reflection template; Researcher will observe participants in classroom teaching nature of science	Participant semi-structured interviews; audio recordings of lesson study; researcher journal of meeting and classroom observations; field notes of classroom observations
2	Lesson Design for LS1	Audio recordings of lesson study; researcher journal/field notes; participant weekly reflections
3	Lesson Design for LS1	Audio recordings of lesson study; researcher journal/field notes; participant weekly reflections
4	Lesson Design for LS1	Audio recordings of lesson study; researcher journal/field notes; participant weekly reflections
5	Teach Lesson 1; Lesson Redesign; Re-teach Lesson 1	Audio recordings of lesson study redesign; researcher journal/field notes; notes from outside specialist; research lesson plan; participant field notes of research lesson; audio recording of lessons taught; participant weekly reflections
6	Lesson Design for LS2	Audio recordings of lesson study; researcher journal/field notes; participant weekly reflections
7	Lesson Design for LS2	Audio recordings of lesson study; researcher journal/field notes; participant weekly reflections

Table 3 (cont.)

8	Lesson Design for LS2	Audio observations of lesson study; researcher journal/field notes; participant weekly reflections
9	Lesson Design for LS2	Audio recordings of lesson study; researcher journal/field notes; research lesson plan; notes from outside specialists; participant weekly reflections
10	Teach Lesson 2; Lesson Redesign; Re-teach lesson 2	Audio recordings of lesson study redesign; researcher journal/field notes; notes from outside specialist; research lesson plan; participant field notes of research lesson; audio recording of lessons taught; participant weekly reflections
11	Participant will complete PRIME PCK Reflection template for the topic of fungi	Participant written reflections
12	Researcher will observe participants teach lesson on fungi; Participant interviews for 9 questions on PRIME PCK Reflection template	Audio of participant classroom observations; Audio of participant semi-structured interviews
13	Final Participant Interviews for their perceptions of Lesson Study	Semi-structured interviews

Pre-Lesson Study

After receiving Institutional Review Board approval (see Appendix F), participants were introduced to lesson study prior to the semester (week zero), which occurred after the Department of Biology GTA orientation meeting. During this meeting, the participants determined a weekly meeting day and time for lesson study sessions for the remainder of the semester. Group norms and roles were discussed. Participants were given a take-home assignment: to complete the PRIME PCK reflection template using the laboratory lesson one topic of nature of science. Participants had one week to complete the assignment, which was emailed to the researcher. During this initial meeting of participants, and the subsequent lesson study meetings, the researcher acted as a non-participant where she was an outsider of the group under study, watching and taking field notes from a distance (Creswell, 2013).

Lesson Study

Week one marked the beginning of the planning of the research lesson. The lesson study team identified goals for the photosynthesis lesson. The facilitator was responsible for guiding the group to become acquainted with the research of best practices, student conceptions, and recent advances in knowledge for teaching photosynthesis.

In addition to the lesson study meeting, the researcher interviewed the participants during week one using the interview protocol on the PRIME PCK reflection template over the topic of nature of science (NOS). Interviews were audio-recorded. Participants also taught a lesson over NOS in the laboratory, which was observed and audio-recorded by the researcher. During the lessons, the researcher acted again as a non-participant while taking field notes during the lesson.

During weeks two through five, participants continued planning the research lesson and developing the research lesson plan. They continued to read and discuss any further research or curriculum materials needed in order to inform planning. The researcher distributed the research lesson plan to the outside specialists for review. Participants determined that Spencer would teach the original photosynthesis lesson to his class of students, and that Grace would teach the revised photosynthesis lesson to her class of students.

During week six, Spencer taught the first iteration of the photosynthesis lesson, while the other team members collected data during the lesson using the Lesson Observation Log. The team later met to participate in the post-lesson discussion and redesign. The comments in this meeting were used to make the necessary changes to the research lesson plan. After the lesson revision, Grace taught the second iteration of the lesson to her class, while the other team members observed and collected data during the lesson using the Lesson Observation Log. The lesson study team met again to discuss the changes that were made to the lesson, and whether any more changes were necessary in the lesson. This concluded the first lesson study cycle in the study. Once complete, the participants began the second cycle of lesson study over protist/algae. The second cycle occurred during weeks six through 11, and utilized the same protocol used for lesson study cycle one using Shannon and Spencer as the observed instructors.

Post-Lesson Study

After both lesson study cycles, the participants were asked once again to complete the PRIME PCK reflection template for the post-lesson study observation using the topic of fungi during week 12. Participants had one week to complete the assignment, which was emailed to the researcher. The researcher interviewed participants during week 13 using the same questions on the PRIME PCK Reflection Template over the topic of fungi. Interviews were audio-recorded. All participants were also observed by the researcher teaching a lesson over fungi. During the final week of the study (Week 13), the researcher interviewed the participants using a semi-structured format to determine the participant's perceptions of lesson study (See Appendix E).

Data Analysis

The complexity of teachers' knowledge cannot be portrayed by a single instrument (Kagan, 1990). Evaluation of PCK requires an amalgamation of approaches that can gather information about what teachers know, what they believe, what they do, and the reasons for their actions (Baxter & Lederman, 1990). In this regard, data from multiple sources were necessary to create a strong description of the participant's teaching practice and knowledge (Yin, 2014) and included participant written reflections, participant interviews, classroom observations, researcher field notes and reflections, feedback from outside specialists, lesson research plans, and lesson study meetings.

According to Bogdan and Biklen (1992), "data analysis is the process of systematically searching and arranging the interview transcripts, observation notes and other field notes that the research accumulated" (p. 145). Once all data sources were obtained, the researcher coded them using qualitative data analysis software, *NVivo Ten,* in two phases. In the first phase, the coding scheme consisted of the five categories of PCK based on Magnusson et al. (1999) which include: (a) orientations toward science teaching, (b) knowledge of science curriculum, (c) knowledge of students' understanding of science, (d) knowledge of assessment in science, and (e) knowledge of instructional strategies.

After the initial coding, the researcher wrote a summary profile for each participant. The profiles were written as narratives and included evidence from multiple data sources that described each aspect of all four participants' PCK. Thus, triangulation through multiple data sources (Yin, 2014) was achieved. Participants in the study were given their summary profile for member checking in order to solicit their views of the credibility of the findings and interpretations (Creswell, 2014). In the second phase of data analysis, a cross-case analysis of the four participants was conducted which examined the data set for patterns and themes across individual participants. In case study research, the process of generating assertions and drawing conclusions from evidence is facilitated by identifying common themes and patterns (Miles & Huberman, 1994).

Limitations of the Study

A limitation was that the study was conducted during a 16-week semester, with only 14 weeks of instruction time. Each laboratory session lasted 2.75 hours, and the "teach, revise, re-teach, revise" portion was conducted all in the same week, which is not typical during a regular lesson study cycle. The large amount of time that GTAs must devote to this process during a one-week period may have induced stress to the participants who must also focus on their classes and personal research schedule. Therefore, participants may not have devoted as much effort as needed in the revision of the lesson. In an ideal situation, the re-teach and second revision portion of the lesson study would occur during the second semester of a year-long study.

An additional limitation included the amount of time it took for participants to create the first lesson over photosynthesis. Because they were still working on the research lesson plan the week before it was taught, the participants did not have enough time to discuss the outside reviewers' feedback in order to make modifications. Despite this, Shannon made changes to her PowerPoint presentation based on the biology education expert's feedback, but these changes were never discussed with the other members of the lesson study team. The biology expert did not provide feedback until after the photosynthesis lesson had been taught.

Delimitations of the Study

Determining GTAs' PCK that emerged during participation of lesson study was an important goal. However, the qualitative nature of the study limited the possibility of generalizing the findings beyond the specific cases that were presented in the study. The purpose of qualitative research, however, is not to generalize the results but rather to support their transferability to other contexts. By describing a phenomenon in sufficient detail, one can begin to evaluate the extent to which the conclusions drawn are transferable to other times, settings, situations, and people (Lincoln & Guba, 1985). Therefore, the use of thick descriptions and details supported the transferability of this study.

Chapter Summary

GTAs are responsible for teaching a large proportion of undergraduate students (Gardner & Jones, 2011; Kendall & Schussler, 2012; Sundberg et al., 2005), but many do not have the necessary training to do so effectively (Kendall & Schusler, 2012; Luo et al., 2000; Muzaka, 2009). The purpose of this study was to examine the potential that a type of professional development called lesson study holds for advancing GTAs' PCK. The study was a qualitative study utilizing a case study approach. There were multiple units of data that were analyzed in order to determine the aspects of PCK that emerged in GTAs after participating in lesson study.

CHAPTER IV: RESULTS

Introduction

This study examined the potential that lesson study holds for advancing GTAs' PCK while teaching an introductory biology laboratory course. The following research questions were addressed: What components of PCK emerge as biology GTAs participate in lesson study? What are the GTAs' perceptions of lesson study as a form of professional development?

This chapter answers the first research question by including a within-case analysis of the components of PCK that emerged within each participant throughout the semester of lesson study. This is followed by a cross-case analysis that describes the patterns that occurred within each component of PCK and across all participants. For the second research question, each participant's responses to a semi-structured post-lesson study interview were analyzed to determine GTAs' perceptions of lesson study as a form of professional development. The responses from participants were organized by questions that were asked by the researcher.

What Components of PCK Emerge as Biology GTAs Participate in Lesson Study?

This section will describe each aspect of PCK that emerged with each participant. Shannon, the facilitator of the lesson study, demonstrated a rich amount of PCK prior to, during, and after the lesson study. Therefore, her experiences during each of these time frames will be organized in a longitudinal fashion by section headings. However, for the remaining participants, the researcher found that there was not enough evidence to support the existence of every aspect of PCK for each of these time frames to organize in the same fashion as Shannon's narrative. For that reason, in the sections for the remaining participants, each construct of PCK will not be organized by pre-, during, and post-lesson study, unless there was enough evidence provided by the participants to do so.

Participant One: Shannon, the Facilitator

Shannon, the facilitator of both cycles of lesson study, was a white female who was 38 years old with more than 12 years teaching experience in K-16 education. Her teaching experience included five years of instructing 8th graders in physical science, four years instructing 6^{th} and 7^{th} graders in biology, chemistry, and earth science, and one year of instructing freshman and sophomore students in genetics, earth science, and chemistry. Additionally, Shannon had five semesters of teaching experience in higher education teaching biology to students not majoring in biology. Her educational background included a Bachelor of Science in Biology and a Master of Science in Natural Sciences. At the time of the study, she was pursuing a Doctor of Philosophy in Mathematics and Science Education with a concentration in biology education. Through her doctoral program, Shannon had extensive training in the theories and practices of teaching and learning. Despite her rich background in teaching, she had never participated in the lesson study process, nor had she taught a biology laboratory course designated for students majoring in biology. The following sections will include a detailed description of Shannon's PCK as she participated in this qualitative study.

Orientations toward learning. This section will be organized by Shannon's experiences through pre-, during, and post-lesson study.

Pre-lesson study. Shannon had strong beliefs of what science teaching should look like, and these beliefs were evident before the lesson study began. For the first lesson of the semester over nature of science (NOS), Shannon stated that she was going to ask the question, "*What is science?*" while her students discussed in their groups and hopefully disagreed with one another (Written reflection template, 09/29/14). During the observation of the lesson, Shannon allowed students three minutes to discuss this question in their groups (Researcher field notes, 08/28/14). When asked why this component to the lesson was important, she stated:

> It's really important for students to disagree so that multiple views of "*What is science?*" come up. I know which one I'm looking for; although, I want to see what they know. I'm trying to access what they know and then I want them to disagree so they can start thinking about it in different ways. (Pre-lesson study interview, 09/29/14)

Shannon's emphasis on students engaging in disagreement displayed her beliefs about how students learn science, which Friedrichson et al. (2010) categorized as conceptions of science teaching and learning. She believed encouraging students to disagree in their discussions exposed multiple views of science, which she hoped inspired students to restructure their own views.

In the next portion of the NOS lesson, Shannon stated she would show a diagram that she created in order to discuss NOS (Written reflection template, 09/29/14). She assimilated the information from research on NOS in K-16 education, and wanted to expose students to common misconceptions as she continued to talk about these ideas throughout the semester (Written reflection template, 09/29/14). The diagram included the title that stated "The Scientific Method—Not a Recipe," and listed each component of the scientific method, which Shannon called Science Inquiry (Researcher field notes, 08/28/14). The components were not in sequential order, but were all connected to each other. In the bottom corner was an image of scientists with the word “creativity” written above them. When asked about the diagram, Shannon replied:

> I have created a visual that helps [students] see that there is a little piece down there where the scientist has to be creative because they need to be creative, not just in designing their experiment but in interpreting data and in all aspects they have to be thinkers. Creativity means you’re a thinker. Many times we think of scientists as analytical, in a lab, following this cookbook recipe and that is not really what it is. Science is a process that *is* creative. It is all of these things, and I never knew that until I started reading the literature. (Pre-lesson study interview, 09/29/14)

This scenario exemplified Shannon’s understanding of NOS and the rich background that she had in the topic. Because of her research on NOS, she created her own diagram that emphasized the components of scientific inquiry in a way that demonstrated to students that scientists need to be creative and that science does not follow a prescribed approach.

For the final portion of the NOS lesson, Shannon mentioned that throughout the semester, she would continue to bring up the tentative nature of scientific knowledge, the process of science inquiry, and how questioning is the beginning of all scientific investigations (Written reflection template, 09/29/14). She stated the rationale for this was that it was vital to reinforce NOS and scientific inquiry throughout the semester because one lesson was not enough. Shannon believed students should have an informed understanding of NOS and scientific inquiry because they should be scientifically literate and successful thinkers as they enter their field (Written reflection template, 09/29/14). Throughout the lesson, Shannon mentioned the characteristics of NOS including creativity, tentativeness, relying on observations, and questioning (Researcher field notes, 08/28/14). This demonstrated that Shannon understood the meaning of NOS, including the various aspects of NOS as categorized by Lederman et al. (2002). Additionally, from the beginning of the semester Shannon demonstrated her goals for her students, to be scientifically literate and successful thinkers in their field.

When asked what else Shannon knew about NOS, she stated:

> This is an area where I have done extensive reading, especially the work by Lederman, specifically identifying aspects of NOS that are applicable in K-16 educational settings. There are instruments that we can use to assess student and instructor understanding of NOS and SI and these could be very helpful in guiding instruction. (Written reflection template, 09/29/14)

This statement indicated that Shannon had an extensive background in NOS and was familiar with assessment tools that can be helpful in directing instruction.

Before class began, Shannon had each student write his/her name on cardstock and display it on the table in front of them. Additionally, she had students form groups of four and asked each group to find three things that everyone in the group had in common (Researcher field notes, 08/28/14). When asked about this, Shannon replied:

> Knowing someone's name and knowing it correctly is really important in establishing this rapport with students that I find is one of the most important things with teaching, in general. I also think it's one of the things lacking at the undergraduate level whether it be lecture or lab. If there isn't that rapport, do we know our students? Do we know what they're interested in? I also have them write, inside their name tags, something they want me to know about them. Now,

> I know that I have a goalie on the soccer team. I plan to go to one of her games because I think that's important. I have another student who works at the zoo and she has offered to take my daughter on a back tour of the giraffes. (Pre-lesson study interview, 09/29/14)

Additionally, Shannon displayed a PowerPoint slide with five pictures that she stated represented her (Researcher field notes, 08/28/14). She then associated a word with each picture to describe her interests to the class. When asked about this approach, Shannon replied:

> If you don't know your students, that's bad, but if they don't know you, that's really, well, it's a two-way street. There has to be some opening up. Also, one of the reasons I [display information about myself] is that it opens [students] up. There is one group that hadn't said a whole lot but they saw that I had a daughter. Then, they told me they had five kids (it's a husband and wife that are in my class). See, I would have never known that if I had not put that picture up there. I also am interested in getting undergraduates interested in research so I always talk about my research: my prairie dog research or my nature of science. I discuss what I like to do and what questions I like to ask because I like to model that this is something you can do as Biology majors. You may go off onto this tangent and be a researcher. You don't have to necessarily go to medical school which most of these students seem to want to do, the medical school and nursing. I totally don't understand because they don't even know the options that are out there. So, that is one of the things, I mean, they need to know what's out there. I think GTAs are the links in helping [students] understand what careers they can pursue especially

> if they go on to get a master's degree or further. (Shannon, pre-lesson study interview, 09/29/14)

These remarks described Shannon's view that it is important for students and instructor to know each other. By doing this, Shannon felt that a rapport develops which she believed is one of the most important aspects of being a teacher. Additionally, she believed that she was instrumental in informing students about the variety of career options they can pursue.

During lesson study. As the facilitator of the lesson study team, Shannon felt compelled to pass on her knowledge of teaching and learning to the other participants. After two lesson study meetings, the team had not deviated far from the original lesson. "We are still confined to the current photosynthesis lesson, and I wondered what I could do to encourage the group to think outside the box and come up with brand new lessons" (Written reflection, 9/11/2014).

In Shannon's view, the GTAs wanted to improve their teaching, but they had little knowledge of the practices of effective teaching and learning. "The TAs are motivated to do a good job but are often not given the tools and support they need" (Written reflection, 9/12/14). Therefore, Shannon thought about what influenced her teaching practices during the first three years of teaching, including the 5-E learning model, Socratic questioning, and self-reflection on whether her instruction was teacher-centered versus student-centered. She decided she needed to introduce some of these educational concepts to the other members of the lesson study team.

> I have this knowledge to introduce these concepts to TAs that practically have blank slates when it comes to pedagogical strategies. The learning cycle is

> intuitive and provides a flexible model to think about inquiry instruction in a variety of contexts. I wanted to focus on this first since it provides structure and we were naturally heading in that direction. . . . I think the learning cycle model might actually result in moving from a teacher-centered to a student-centered learning environment in [the GTAs'] labs as well as get them thinking about how they can question students rather than tell them. (Written reflection, 09/12/14)

In this quote, Shannon displayed her beliefs about the role of the teacher, the role of the student, and how to teach science in ways that make it comprehensible. Based on her experiences, she believed the 5-E learning cycle was an instructional approach that would help the lesson study team design their lesson in a more student-centered way.

Shannon's focus on student-centered instruction continued in a written reflection as she addressed her teaching philosophy:

> I have learned so much about my teaching style and philosophy from this lesson study. When you lead other teachers you are forced to reflect on why you do what you do and make that explicit. I think the amount of reflection I've done in preparation to lead a lesson study has helped me see that I'm a true constructivist (I want students to do more than a cookbook lab) but at the same time I'm a pragmatist (if students don't get it, I'll be more explicit in helping them understand a concept). (Written reflection, 09/09/14)

This quote indicated that the lesson study process had contributed to considerable reflection on her teaching. Through these reflections, Shannon was able to identify herself as a constructivist, which is someone who believes students construct their knowledge through their experience (Lefrancois, 2006). Additionally, she understood that she was a realist, believing her role as a teacher is to guide students to better understand a concept when they are having difficulty.

Shannon’s goals for her students learning photosynthesis were made explicit to the other members of the lesson study team while she was discussing the literature about common misconceptions regarding photosynthesis. She mentioned the purpose for students in understanding from where the mass of a tree came.

> If we don’t have an informed populous about where trees’ mass come from, [students] can’t understand climate change, they can’t understand how to mitigate climate change, they can’t understand policy about climate change, and that is the issue that the next generations are going to be facing. (Lesson study meeting three, 09/12/14)

This quote indicated that Shannon believed it was important for students to understand concepts in order for them to be informed citizens in society.

Shannon’s beliefs about her goals for learning were also apparent during the second lesson study cycle, as the lesson study team was deciding on what aspects of protists/algae to focus to create the learning objectives. Shannon asked the lesson study team to:

> Try to come up with something that is going to really challenge students not to just look through a microscope or look at a specimen materially, [but to] think about the relationships of organisms. . . . We really need to think about why do we want [students] to memorize, and what is important. (Lesson study meeting five, 09/26/14)

This quote suggested that Shannon was more interested in students understanding the relationship of protists to one another and to other kingdoms of organisms than memorizing and identifying organisms by their scientific names.

Shannon mentioned the goal of less memorization and more conceptual learning several times during the lesson study meetings. During a weekly reflection, Shannon explained how she was going to achieve this goal with the lesson study participants during the second cycle of lesson study.

> I'm going to suggest things and keep asking [the lesson study participants] 'what exactly are your students doing that will help them learn something they don't already know?' or 'how will what you are planning help your students think deeper about protists?' And I'm going to play the role of the student and ask questions from their perspective to get them to see that telling is not teaching. (Written Reflection, 10/02/14)

In the above quote, Shannon expressed what she believed to be important as the role of a teacher. As the quote suggested, Shannon was going to continuously ask the other lesson study participants to think about how they can get the students to build upon their prior knowledge to gain a more in-depth understanding of protists/algae. Shannon firmly believed that "telling is not teaching," a phrase she said several times during the course of the lesson study meetings and reflections.

Shannon modeled this approach during a lesson study meeting as she discussed a question a student asked about the phenol red experiment in the photosynthesis lesson.

> Somebody asked in class, 'What would have happened if we hadn't put the light bulb on?' And I was like, 'What do you think would happen?' and they were like,

> 'It probably wouldn't [respire] and so it's probably not going to uptake [carbon dioxide].' I was like, 'We could test that, couldn't we?' (Lesson study meeting five, 09/26/14)

In the above scenario, rather than tell the answer to her student's question, Shannon asked the student what they thought would happen, based on their prior knowledge.

When trying to motivate the other participants to include alternative instructional approaches in the second cycle of lesson study, Shannon expressed her view of science teaching.

> I'm a firm believer [students] can understand if they are given a way to learn [the material], because the biggest issue is students don't know how to learn. The ones who do are the ones who are already doing well in your class. There are other ones, and the argument can be, well we don't really care about the other ones because if they cannot learn now, they cannot contribute to the field, but the reality is those are the people who usually have the creative ideas, that come up with really neat things, and we just weed them out, and we are losing a lot of creativity and a lot of potential people in science. (Lesson study seven, 10/27/14)

The above quote indicated that Shannon believed that science teaching should involve strategies that meet the needs of all learners, including the ones who do not necessarily have the immediate tools to learn the material.

Post-lesson study. Shannon continued to display her orientations toward science teaching during the post-lesson over the topic of fungus. At the beginning of the lesson, Shannon asynchronously displayed organisms in her PowerPoint presentation, and asked students to identify the phylum, genus, and special characteristics about each organism

(Researcher field notes, 11/13/14). When asked in the post-interview what she noticed during this review, Shannon replied, "I realized [the students] really didn't learn that stuff very well." When asked her thoughts as to why, she stated:

> It was almost like information overload with what [students] were supposed to learn in that class. . . .We're shoving all this information down their throat. We can't do that and do what I want to do, which is have them learn it conceptually. You can't do both. (Post-lesson study interview, 12/09/14)

Shannon held a belief that students should be learning topics in more depth rather than more breadth. Her view suggested that there are certain fundamental concepts that are more important or beneficial to master than others, and that spending focused time, at the expense of covering many other topics, was a more productive strategy. According to Shannon, this distinction of learning is in direct contrast with the curriculum that guides the instruction for the GTAs in this laboratory course.

Summary. The examples described above depicted Shannon's science teaching orientations, which shape the content and development of the other PCK components (Magnusson et al., 1999). Shannon had a strong understanding of NOS and strong representations of her beliefs about the goals and purposes of science teaching and learning. She felt it was important that she knew her students' interests, in addition to her students knowing about her. She felt a role of the GTA should be to expose students to the variety of fields that are available with a biology degree. She viewed herself as a constructivist and believed that instruction should be more student-centered, utilizing instructional strategies such as engaging students in discourse and shaping instruction around the 5-E learning cycle. Shannon also felt she was a pragmatist in that she understood her role as an instructor was to guide students to understand when they do not fully grasp the content. She felt that learning should be more conceptual with a deep understanding of fewer topics, rather than introducing a wide range of topics. Finally, Shannon thought that the purpose for students learning science was to help them become a more informed citizen and productive member of society, so they can understand issues that affect the population, such as climate change.

Knowledge of science curriculum. This section will be organized by Shannon's experiences through pre-, during, and post-lesson study.

Pre-lesson study. There were several instances of curricular knowledge displayed by Shannon prior to the lesson study. She mentioned learning goals and guiding questions in her written reflection template, during her classroom observation, and during her first interview.

> I have learning objectives, what do I want students to know and be able to do, but I pose that in a question so they have to answer that to meet that objective. . . . So, they should be able to look at that question and naturally answer it whereas the learning objective is for the teacher. The question is to guide the students in their learning. (Pre-Lesson Study Interview, 09/29/14)

When observing Shannon teach the NOS lesson, she displayed students' learning goals on the PowerPoint presentation. They included:

- Be able to describe the scientific process and how we gain scientific knowledge and understanding.
- Be able to formulate the null and alternative hypotheses for a scientific investigation.

- Be able to use statistical analysis (Chi-Square) to determine whether actual results are due to sampling error or due to a false null hypothesis. (Researcher field notes, 08/28/14)

Shannon also displayed a series of guiding questions that were embedded in her PowerPoint presentation for each learning objective. For example, for the first learning objective, "Be able to describe the scientific process and how we gain scientific knowledge and understanding," the following questions were embedded throughout her PowerPoint.

- What is science?
- How do we gain this knowledge?
- Must you follow the scientific method exactly in order to do good science? (Researcher field notes, 08/28/14)

This exemplified Shannon's knowledge of the need for goals and objectives as highlighted in *Vision and Change*, which suggests that biology educators should "define learning goals so that they focus on teaching students the core concepts, and align assessments so that they assess the students' understanding of the concepts" (American Association for the Advancement of Science [AAAS], 2011, p. 18). Beginning with the first lesson, Shannon stated the learning objectives for herself, and then molded them into a question for her students in order to guide their learning. This knowledge was particularly useful during the lesson study process, since goals and objectives had not yet been established for any of the lessons in the laboratory course in which this study was situated.

When asked if the laboratory manual over NOS had all of the aspects of NOS, Shannon responded:

> Definitely not. It was appalling for me to look through that first lesson and see that they even called it nature of science because, knowing what I know now, it was definitely perpetuating misconceptions and naïve understandings of nature of science. So, we have these undergraduates who come in, they've had science in high school, maybe they've never been introduced to the more philosophical side of science and that's our job at a university, so they open their lab manuals and it's got misconceptions of nature of science right there, written. If you think about the tentative nature of science and then one of the examples was do you accept or reject the hypothesis. The word accept completely gives the wrong idea that we know things for sure, that we prove things in science. One of the big things I say is that we never prove anything in science, we only falsify. (Pre-lesson study interview, 10/03/14)

This quote exemplified Shannon's belief that the lesson that was titled "Nature of Science" was not accurately named based on her research of NOS. She felt the curriculum hindered students' understandings of important aspects of NOS, such as science being tentative (Lederman, 2002).

When asked if she followed the curriculum in the laboratory manual during this first lesson on NOS, Shannon stated:

> I did and I regret it now. Looking back on it now, as I've taught it and as I've taught myself (I've never taught hypothesis testing before), I feel like it was done in a way that hindered student understanding. Now, if I went back to it, I don't

> think I would talk about hypothesis testing at all on that first day. If anything we would talk about questioning. That's the thing [the laboratory manual] forgot completely, that science begins with a question. That's a big one. I mean, all scientific investigations begin with some type of question. That was not emphasized. What was emphasized was creating a hypothesis. So, they jump to that and they don't even explain really what a hypothesis is or what form it should take, but then they say write your null. How can you go to a null if you don't even know what an alternative or an experimental hypothesis is, it doesn't make any sense to the students. I would do it completely different. I will if I teach this again. I will definitely be a little more explicit about how I am going to teach The Nature of Science aspects within the ideas. I can go with the basic ideas of that first chapter that we were supposed to teach but I would love to re-write the whole thing. I don't have time to do that, though. (Pre-lesson study interview, 10/03/14)

The above quote indicated that Shannon believed more emphasis was placed on hypothesis testing over questioning. Her explanation of her views of the problems with the curriculum in this lesson indicated Shannon had knowledge of curricular saliency, a term used to express how important a particular topic is to the overall curriculum (Geddis, Onslow, Beynon, & Oesch, 2006).

During lesson study. For the first semester of biology designated for students majoring in Biology, there were no overall goals or objectives that were explicitly stated to guide the GTAs' instruction. There were student learning goals and objectives outlined in each weekly exercise in the laboratory manual (except for the NOS lesson, which was created by Dr. Sturgeon, but these objectives were never made explicit to the GTAs.) Dr.

Sturgeon sent weekly instructions via email that explained the procedures of the activities GTAs should go over in their classes. Nevertheless, these weekly notes did not outline student learning goals and objectives. Shannon acknowledged this as she started the first lesson study meeting by saying:

> As we start to think about our objectives, what do we want [students] to know, and how do we design a lesson that touches on that and helps them to understand. So I think that is our first goal and we as a group need to think about what are the main concepts of photosynthesis. (Lesson study meeting one, 08/30/14)

Shannon then discussed with the group the importance of a teacher knowing the information that students already have on the topic, and whether there were any misconceptions within their knowledge. She gave herself the task of reviewing the literature for common misconceptions regarding photosynthesis, and also had Grace, who was the only GTA who had previously taught this lesson, write a list of items that students had issues with while performing the photosynthesis laboratories in the past (Lesson study meeting one, 08/30/14). In addition, the lesson study team asked the lecture instructors on what areas of photosynthesis did the lecture portion of the class focus to better align the photosynthesis laboratory experience with the photosynthesis lecture experience. The lecture instructors provided a study guide that listed the key components students should know about photosynthesis. When asked to reflect on the study guide provided by the lecture instructors, Shannon stated:

> This type of information could be very useful for EVERY lab to assist TAs (both novice and experienced) with better planning and teaching. Also, I volunteered for the task of looking for major misconceptions undergraduates have about

photosynthesis and in this search found lists of misconceptions about many topics covered in this introductory major's course. This type of information would be helpful for new TAs but it is nowhere to be found in any of the lab manuals and because there is little contact/communication with the lecture instructors, TAs are left to figure this out on their own (hopefully they do). (Weekly reflection, 09/02/14)

After obtaining these key pieces of information, the lesson study team created their first learning objectives for the first cycle of lesson study (Photosynthesis lesson plan, 09/25/14).

During the second lesson study cycle, Shannon again guided the lesson study team to create learning objectives for the protist/algae lesson. Before the objectives were created, it was discussed that students do not get any information over algae or protists in their lecture class, making the GTA the only instructor presenting this information to the students. As the lesson study team began thinking about what they wanted students to know, they realized they were uncertain of how protists fit into the classification scheme, and decided they needed clarification before going any further.

Grace: I was thinking, instead of calling this protists, [we call the lesson] algae, because protists are not correct. The chlorafida are not in protists anymore.

Shannon: Okay, if we really want students to learn, they need to have a conceptual map of where these fit in the domains, the kingdoms, and then how we go down further and further.

Grace: The green algae are more closely related to—it may even be within green plants now. And I don't even know if protista is even still called protista. I don't think it is. It's all changed so I—

Shannon: And it's constantly changing.

Spencer: I'm sure it also depends on who you talk to.

Shannon: It depends if you are looking at morphology or with the genetics and things that we have now that we didn't have five or 10 years ago. (Lesson study Meeting Six, 10/03/14)

After this discussion, the lesson study team decided they needed clarity from Dr. Sturgeon as to what constituted a protist and what he deemed important for students to learn (Lesson study meeting six, 10/03/14). After receiving this information, the participants were better informed of a direction for their lesson and were able to create a set of learning objectives for the lesson (Lesson study meeting seven, 10/03/14).

While constructing the objectives, Shannon explained the goal of the objectives to the other participants.

> A learning objective should be something that [students] look at and can answer. So they can put in the form of a question. I call those guiding questions. So you take number one, 'Students should clearly explain protists in terms of biological diversity.' The question you can ask on an exam could be, 'Clearly explain three examples of protists you saw in lab in terms of biological diversity.' So you should be able to convert that objective into an actual question that is testable and measurable and you can easily see if they get it or they don't. (Lesson study meeting seven, 10/27/14)

The above quote portrayed Shannon's knowledge of the purpose of learning goals, and how she believed student assessment should be aligned with these goals. She believed learning objectives should be transformed into guiding questions in order for the learner to determine if he/she understands the content.

Post-lesson study. During the post-lesson study observation of the fungus lesson, Shannon displayed the learning objectives with the class, as she had been doing throughout the semester. Before displaying the learning objectives, she had her students review what they had previously learned with algae and other protists. When asked about this review during her post-lesson study interview, Shannon explained:

> I wanted to connect to what we had already done since the objectives are almost the same. Doing the same format objectives, [students] could see how fungi were different and why we put them in there differently (Post-lesson study interview, 12/09/14).

The above quote indicated that Shannon organized her learning objectives over the topic of fungi to be similar to the learning objectives over protists. Because of this, she reviewed the organisms that belonged in the protist phylum so that students could compare and contrast the new information to that which was previously learned.

When asked if she made any changes to the curriculum over fungi, Shannon replied:

> I make changes whenever I think what we are supposed to be teaching is too confusing for students. The changes I make aren't with the content but instead are how I would present the information. For example, if all students do is look at something under a scope they aren't likely to understand the big idea of what we

> want them to know (what is this, what is unique about this, and where does this fit into the classification scheme). I would add or change the activity to make sure that students are given everything they need to learn what I want them to learn—I won't leave it up to them. It's our job as instructors to provide students with the appropriate tools to be able to learn what we are asking them to learn. (Post-lesson study interview, 12/09/14)

This quote indicated that the curriculum decisions that Shannon makes depend on whether students are having difficulty with the content. Similar to the lesson over the topic of protists/algae, Shannon felt students should understand more about fungi than identifying the varieties under a microscope. She believed that students should understand how fungi are related to one another as well as other kingdoms of organisms. In order for students to understand this, Shannon felt that students should create concept maps. This was an instructional approach that she utilized during this lesson (Researcher field notes, 11/13/14).

Summary. The above representations are examples of Shannon's knowledge of science curriculum. Her knowledge in this category was high throughout the lesson study because she set learning goals and objectives for her students prior to each lesson, she turned the goals into guiding questions, she explicitly stated the learning objectives and guiding questions to her students, and she guided the lesson study team in determining the learning goals for each lesson study cycle. Shannon felt the curriculum in the laboratory manual for the NOS lesson should be revised, because she believed the aspects of NOS were not explicit. She followed the curriculum for the NOS lesson, but regretted doing so. She felt the study guide that was created by the lecture instructors was useful and could be helpful for all GTAs while planning and teaching. *Vision and Change* (AAAS, 2011) suggests that instructors should clearly articulate expected student learning outcomes and follow students' progress in achieving those outcomes, which was a practice that Shannon conducted throughout the lesson study process.

Knowledge of students' understanding of science. This section will be organized by Shannon's experiences through pre-, during, and post-lesson study.

Pre-lesson study. For the NOS lesson, Shannon stated that the first thing she would do is ask the question, "What is science?" She described that students will discuss this question in groups, sharing their answers, and "hopefully disagree." Her rationale behind this method was to:

> Get students thinking about their prior experiences with NOS and [science inquiry]. [This will] allow me to gauge where [students] are and assess whether their ideas are informed or naïve. My instruction will be guided by student responses and prior knowledge. (Pre-lesson study written reflection template, 09/29/14)

Although the above example was used to discuss Shannon's orientations toward science teaching, it also portrayed her knowledge of student understanding of science. According to Magnusson et al. (1999), orientations to science teaching is the lens that all other components of PCK can be viewed. Therefore, Shannon believed that participation in discourse exposed students to multiple views of science, which was a goal for student learning. However, this exercise played a dual role in that it also allowed Shannon to gauge the number of students who had naïve views of science versus a more informed point of view, which further guided her instruction.

During the teaching of this lesson, Shannon went to each table and listened briefly to the group discussions. After groups had time to discuss their answers, she called on individual students from each group in order for the class to construct a common meaning for the definition of science (Researcher field notes, 08/28/14). This example demonstrated Shannon's understanding of the importance of knowing what students already knew about the topic to guide her instruction in a way that was more helpful for her students.

During lesson study. At the end of lesson study meeting one, Shannon handed out tasks for the other participants in order for them to prepare a list of learning goals for the lesson. She assigned herself the task of identifying the common misconceptions in the literature and realized this was an area of her teaching practice in which she had not been completely thorough.

> My assignment last week was to compile a list of misconceptions about photosynthesis that undergraduates have and I found some in the literature that I was not aware of. I compiled the list and now it sits at the top of my lesson plan and I want to make sure that these are addressed as we design our lesson. There is a lot of work that has been done on misconceptions and I think that I have not delved into this area in my teacher preparation or my practice enough. I realize that I take into account what I think student misconceptions are about a topic prior to teaching, BUT I don't delve into the literature and look at a more complete list. This is going to be first on my list (along with identifying my learning objectives) prior to teaching any lesson. (Written reflection, 09/04/14)

One of the misconceptions that Shannon shared with the other lesson study team was an example from *Minds of Our Own*, a film produced by the Harvard-Smithsonian Center for Astrophysics (1997). She had participants watch a brief introduction of the Harvard study that showed graduates from prestigious universities repeatedly identifying soil and water as the primary contributors to the mass of wood in a tree trunk, instead of carbon dioxide.

> It is very difficult to change a misconception. We want to think students come to us as these blank slates and we can give them knowledge, but if you don't take into account what they know or think that they know and really work to give them a discrepant event or something that makes them change. . . . they're never going to change [their thinking]. They're going to walk away after an entire semester of hearing amazing people tell them things, and they're going to think the same thing that they thought when they walked into that class. (Lesson study meeting three, 09/12/14)

Shannon's discussion of the student misconceptions prompted the lesson study team to assess students' prior knowledge, and therefore add the question, "Where does the mass of a plant come from?" to the beginning of the photosynthesis lesson.

In planning the photosynthesis lesson, Shannon was trying to guide the participants to incorporate the lesson into a 5-E learning cycle. During meeting four, Shannon was explaining each aspect of the 5-E cycle and giving rationales for why the cycle is useful. In explaining the *engage* portion Shannon stated:

> In engagement, that's where we are activating prior knowledge. So, this is a time for us to figure out what [students] know, we engage them, we can watch them,

> observe them, and we can be like, ‘Oh my gosh, they do not get that,’ and that allows [us] to change our instruction. It also hooks them. (Lesson study meeting four, 09/20/14)

Later in the conversation, Grace asked Shannon how they could engage their students in the photosynthesis lesson. Shannon responded:

> The engage [portion] could be doing the marker activity and then while [students] are waiting saying, ‘What do you know about photosynthesis?’ And you are going to have students over here who could tell you the whole thing. And you are going to have students over here say, ‘Something with sunlight.’ And then even with that, ‘Where does the mass of a plant come from?’ So you could start asking these general questions to get at what they know or don’t know. (Lesson study meeting four, 09/20/14)

This demonstrated Shannon’s knowledge of understanding students’ knowledge before instruction occurs. By utilizing the 5-E approach in the lesson, Shannon was guiding the other participants to gain this understanding of student knowledge before the instructors continued with their teaching. When asked specifically how to approach this, Shannon gave examples that the participants incorporated into their lesson plan.

During the second lesson study cycle, the lesson study team was deciding on the learning goals for the lesson. Clint stated that he thought an important concept for students to understand was the idea that a gamete does not have to be small or unicellular, but can be what students think of as the “main organism,” and that the main structure does not have to be diploid to be big. Shannon responded by saying:

> I bet that's a big misconception that [students] have, especially if you have gone over meiosis and you have talked about gametes and how they come together to make the whole organism. . . . Now I'm thinking back of how I taught meiosis, and how I probably should have said something. (Lesson study meeting seven, 10/27/14)

This interaction demonstrated growth in Shannon's knowledge of student understanding because of a comment from a fellow lesson team member. Shannon had not thought about this possible misconception when she was teaching mitosis and meiosis the previous week. After Clint expressed his goal for learning algae, she realized that she did not make this aspect explicit when discussing meiosis.

Shannon's knowledge of this construct of PCK during the lesson study process can be portrayed by the following quote.

> I think that sometimes we overestimate what undergraduate biology majors can assimilate because we overestimate (or are completely unaware of) their prior knowledge and experiences. The key to successful instruction in lab courses is to quickly figure out what [students] know and give them what they need. (Written reflection, 10/02/14)

This quote indicated that Shannon believed that in order for instructors to know what tools students need to be successful, they must ascertain the level of each student's understanding.

Post-lesson study. Shannon continued to demonstrate knowledge of student understanding of science at the end of the lesson study when observing the last lesson over the topic of fungi. Shannon started the lesson with learning objectives, and she asked students what they already knew about fungi (Researcher field notes, 12/13/14). When asked her reason for this, she replied:

> I assumed that all they knew was what I knew which was mushrooms and that was probably it. They probably hadn't made those connections that it was a very diverse group and why we were learning it. Just to make sure they hadn't learned it before, I needed to know where they were and it confirmed that it was exactly where I had started. (Post-lesson study interview, 12/09/14)

The example above demonstrated Shannon's knowledge of her students' understanding of science, including their misconceptions and areas of difficulty. This knowledge can be summarized by one of her favorite quotes that she wrote about in a weekly reflection (10/16/14).

> If I had to reduce all of educational psychology to just one principle, I would say this: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach them accordingly" (Ausubel, 1968, p. 18).

Summary. From the first lesson that Shannon taught, she demonstrated her view on the importance of understanding students' prior knowledge to determine if students' ideas were informed or naïve. Before the lesson study team determined learning goals for the photosynthesis lesson, she looked up common misconceptions in the literature regarding photosynthesis. Shannon stated that she was accustomed to thinking of misconceptions according to her point of view, but had never considered looking at what the literature stated about common misconceptions before she taught a topic. She stated that identifying common misconceptions in the literature was going to be a common practice for her in the future. She expressed the importance of knowing common misconceptions of their students to the other members of the lesson study team, which guided their instruction for the photosynthesis lesson. Shannon felt that GTAs generally overestimate what their students can assimilate, due to an unawareness of prior knowledge and experiences. She felt as though the key to successful instruction was to determine what students know, and then give them what they need to fill the gaps in their knowledge.

Knowledge of assessment in science. This section will be organized by Shannon's experiences through pre-, during, and post-lesson study.

Pre-lesson study. When Shannon was asked what changes she made to the NOS curriculum, she replied, "Student responses and understanding would guide the changes I make in my instruction. I would want to assess whether the learning goals I've set are being met" (Written reflection template, 09/29/14). When asked how she assesses this, she replied, "It's what we as teachers should be doing with every emphasized interaction with our students" (Pre-lesson study interview, 09/29/14). These interactions were apparent in her written reflection template where the words *ask*, *share*, *discuss*, and *compare* were written numerous times when explaining what the teacher will do and what the students will do.

A specific example of Shannon's knowledge of assessment was portrayed by the following quote from her pre-lesson study interview for her lesson over NOS. When asked how she ensured her students were able to correctly write the null hypotheses in the lesson, Shannon stated:

> I went around to each of the tables and asked [students] if they could do it, and then I looked over their shoulders. So, if they said yes but then covered up their work, I knew they really couldn't do it or they didn't quite know, so I would have them say it to me. (Pre-lesson study interview, 09/29/14)

This quote portrayed Shannon's understanding of how to assess students during the lesson. She believed that sometimes students will say they understand a topic, even if they do not. Therefore, Shannon went a step further than asking students if they understood. According to her response, she also looked at students' actions to determine if they grasped the material.

During lesson study. While creating the photosynthesis lesson, the lesson study team had not determined how they were going to assess student learning. During the last meeting before photosynthesis was taught, Shannon thought of an idea for assessment throughout the lab, and shared her idea with the rest of the group.

> I don't want to add anything to our plate, but I was really trying to think, how do we know if [students] understand the phenol red? How do we know that they understand starch production? How do we make sure they were connecting it to the big idea? I was looking at the photosynthesis equation, and it came to me last night, the big picture that we want [students] to know, is everything that we do in lab, could they put it on this picture right here? You've got these words like pigments. If you went to a group, and at any point in the lab - and you've got that equation up there - and you said, 'Hey, what are we doing right now? Where does that fit in that equation?' They should be able to tell you. When they're blowing in the phenol red, they should be able to tell you that's carbon dioxide uptake by

> plants. Where does a plant's mass come from? That's right here. And if they can't do that, then they don't understand what they're doing in lab, and they don't understand photosynthesis. I was thinking of that more of a formative assessment, so at the end, and then using that to base what we do our quizzes on. (Lesson study meeting four, 09/20/14)

After some discussion, the lesson study team decided on a list of words from the activities students would be performing in labs. They determined that groups of students would write each word on a sticky note, and then place the sticky note on the component of the photosynthesis equation that would be appropriate (see Appendix G). This quote indicated that Shannon saw value in incorporating formative assessment into the lesson in order for students to be able to relate each activity to the accurate portion of the photosynthesis equation.

After the teaching and re-teaching of the photosynthesis lesson, Shannon reflected on the teaching of the lessons:

> I honestly don't know if [the lesson study team] knows how little their students are learning. They say their exam scores are low but they don't see that as a big red flag that 1) maybe their teaching objectives (implicit ones since neither lesson had objectives stated or mentioned other than to "do the lab") aren't aligned to their assessment 2) maybe what [the GTAs] are doing isn't effective or 3) maybe [the GTAs] think that their students are learning but they just aren't doing well on the quizzes and assessments. I took one look at [students'] sticky note posters and it was clear to me they had no idea how to make connections between the

> activities and the content. In fact, could the other GTAs correctly complete the task? (Written reflection, 10/02/14)

This quote indicated that after observing the sticky note formative assessment activity taught by the GTAs, Shannon observed that the students did not clearly understand the connections between each activity and the photosynthesis equation. She felt that the other GTAs were not aware of the lack of students' understandings.

During the next lesson study meeting, the lesson study team was talking about the next lesson over protists/algae. Shannon tried to provoke the lesson study team to think about how they know if their students were really understanding the material. The team came up with the following learning objective, "Students should be able to articulate why the red algae produce spores in the overall life cycle and explain how this increases an organism's fitness." Shannon then stated:

> What would [students] be doing, so that we could know that they really—that they could articulate that? Do they just repeat it back to you? Do they talk amongst themselves, so that we know they are learning that? How do we know they get it? (Lesson study meeting six, 10/03/14)

Shannon was asking the lesson study team questions to get them to think about how they know if their students are learning the objectives for the lesson.

Post-lesson study. For the lesson over the topic of fungi, Shannon stated that the first thing she would do is introduce the idea of fungi by reviewing what students learned (Written reflection template, 12/02/14). At the beginning of the lesson, Shannon displayed a picture of various protists (which was a review from the previous two lessons) and asked students to identify the phylum, genus, and special characteristics of each. She allowed students time in their groups to look at their notes and talk with each other to determine the answer. Additionally, throughout the lesson, she walked around and asked students various questions about the organisms at which they were looking (Researcher field notes, 12/13/14). When asked to elaborate on this, Shannon replied:

> The two lessons before that were on algae and protist. I wanted to connect to what we had already done since the objectives were almost the same. . . . [Students] could see how fungi were different and why we put them in there differently. (Post-lesson study interview, 12/09/14)

When asked what she noticed about her students during the review questioning, Shannon stated, “I realized they really didn’t learn that stuff very well” (Post-lesson study interview, 12/09/14). This indicated that Shannon utilized diagnostic assessment before the fungi lesson, in order for students to remember the characteristics of protists and relate what they learned to the new topic of fungi. While doing this, Shannon determined that her students had not retained the information from the previous two weeks.

In addition to the diagnostic assessment at the beginning of the lesson, Shannon included formative assessment during the lesson as students were viewing the preserved and prepared specimens (Researcher field notes, 11/13/14). On the overhead, she displayed a variety of pictures of fungi and asked students the phyla and special features of each slide.

When asked during the post-interview how she knows when her students are learning, she replied:

> I ask them. . . . I felt like they aren’t really good at looking at slides, so after they’ve looked, you have to put something up that’s a good representation and

> then they can make that connection. They realize what they were supposed to see if they didn't see it or it confirms they saw the right thing. (Post-Lesson Study Interview, 12/09/14).

During the teaching of the lesson over the topic of fungi, Shannon went to each group and talked with each individual to check for understanding (Researcher field notes, 11/13/14). This scenario indicated that Shannon understood the importance of asking her students questions in order to check for understanding.

Summary. Shannon demonstrated knowledge of both formative and diagnostic assessments throughout the lesson study process. She indicated before lesson study began that students' understandings guide the changes she makes to her instruction. Shannon indicated that instructors should be monitoring student learning during every emphasized interaction. She demonstrated monitoring of student learning in every observation throughout the semester. Shannon created a formative assessment (i.e., the sticky note activity) for the lesson study team during the first lesson study cycle over photosynthesis. Additionally, she tried to guide the other participants of the team to assess student learning during their lessons by asking questions such as, "How do you know students are learning?"

Knowledge of instructional strategies. This section will be organized by Shannon's experiences through pre-, during, and post-lesson study.

Pre-lesson study. Shannon displayed numerous examples of her knowledge of instructional strategies throughout the semester, beginning with the NOS lesson. Since NOS is an area of Shannon's research interests, it was important for her to introduce her students to other aspects of the nature of science that were not included in the laboratory manual or the GTA handouts given by Dr. Sturgeon (Written reflection template 09/29/14).

To do this, she asked each group of four students to create a team name. After allowing students a couple of minutes to talk, she asked groups to share their names with the rest of the class. She then mentioned the aspect of creativity in the nature of science and asked the students if they can think about how creativity is associated with science. A student answered that scientists have to think about things in a different way (Researcher field notes, 09/28/14). When asked about this strategy in an interview, Shannon stated:

> That kind of formed this community, you could say, within four people that they came up with a common name. It was hard for some groups and they really struggled to be creative about it. Being creative requires you to figure out relationships so their name had to be something that they all agreed upon and something that described them. I will keep bringing that back up during the semester when I ask them to look at data and be creative. I think it's a neat way that you can tie in nature of science. (Pre-lesson study Interview, 09/29/14)

This was an example of a topic-specific instructional strategy that Shannon devised for students to better understand the relationship with creativity and NOS. In the lab manual, this lesson was called NOS, even though it did not have all of the aspects of the nature of science as categorized by Lederman and colleagues (2002). Shannon felt strongly that since the lesson was called NOS, she should inform students about all aspects of NOS, including creativity.

During lesson study. During the lesson study meetings, Shannon introduced various strategies that are utilized in education to help students learn including flipped classrooms, the 5-E learning cycle (Bybee, 1997), concept maps (Novak, 1990), and a KWL chart. However, before Shannon introduced these terms to the other participants, she felt it was important for them to understand why these strategies were important. She introduced the idea of the learning pyramid.

> Basically it is one of the first things you get when you start teaching, because we always teach the way we are taught. So I have been lectured to my whole life, so when I first became a teacher, I would lecture to [students], and then I saw this diagram, and I looked and I thought, oh my, they get about 20% of what they hear, so about 80% of what I'm saying, they are not retaining or they do not understand. So it really changed my approach why I was doing what I was doing. . . . So back to our [lesson], how do we know when they don't know and how do we get them to retain more down in this lower part of the triangle than at the top? (Lesson study meeting two, 09/05/14)

In the above quote, Shannon explained to the other participants her reasoning for the phrase she said numerous times during the lesson study meetings, "Telling is not teaching." By showing the lesson study team this diagram, she was giving them a basis for the need of different instructional methods, such as concept mapping and the 5-E learning cycle.

As Shannon was explaining the 5-E learning cycle to the other participants, she discussed the type of instruction that occurred during each aspect.

> When students "explore," this is more than what I think we do in the 1111 labs, where we're doing some type of hands on; [students] are manipulating variables. This is the interesting part of the cycle. The explanation doesn't occur until after

> the [engage and explore components]. And I think a lot of times, if you watch the lab, the first thing we do is give [students] all the info. We get out the PowerPoint, we tell them about osmosis. (Lesson study meeting three, 09/12/14)

In this quote, Shannon explained to the participants how instructors should do more than telling students the information. She was guiding the participants to this understanding by explaining how the 5-E learning model can be beneficial to instruction.

During the second lesson study cycle, Shannon reflected on how the lesson study team could make the protist/algae lesson more conceptual for students.

> It just makes sense to me that in order for students to learn details (such as where phyla and genera fit into classification) they have to have a big picture understanding. The concept mapping idea came to me when I myself was trying to learn about algae and make sense of the lab we are going to teach. If you sat out a bunch of specimens and told me to look at them and learn their names I would struggle. Maybe someone with a great memory wouldn't—but what would they GET out of looking at them? BUT if I had an idea of what algae were (a group in the junk drawer of classification) and why they were important (economically and ecologically), I'd have something to hook these new names onto and that person who memorized them would remember more than just their names. (Written reflection, 10/16/14)

In lesson study meeting seven, Shannon introduced the idea of concept mapping to the other participants, in hopes that they would agree to try this instructional strategy.

> So we talked about last time. . . . We don't want [students] to memorize it. We want them to actually assimilate all of this knowledge into understanding. . . . Are

> you guys familiar with concept mapping? To show students how things are grouped together, to help them make sense of it in a pictorial way? I had an idea about a concept map. Because when you come into protists, and classifying something with all these words and they are all jumbled up, you have to step back and make it make sense for them, so possibly make a concept map to how protists fit into the classification, into hierarchy (Lesson Study Meeting Seven, 10/27/14).

The above reflection and statement from Shannon demonstrated how she was trying to understand protists herself, and therefore decided to create a concept map. While doing this, she thought it would be an effective way for students to be introduced to this diverse kingdom of organisms. She presented her idea to the other members of the lesson study team, who had not heard of the idea of concept mapping. After explaining the process, she had the other participants use the same words she used to create a concept map over the topic of protists.

Post-lesson study. When asked what changes were made to the fungus lesson that were different from the existing curriculum, Shannon talked about how she always makes changes whenever she thinks the curriculum she is supposed to be teaching is too confusing for students (Written Reflection Template, 09/29/14). “If all students do is look at something under a scope, they aren’t likely to understand the big idea” (Post-lesson study interview, 12/09/14). Since Shannon believed students should be learning organisms such as protists and fungi on a more conceptual level, she felt she needed to include instructional changes that allowed them to do so.

Before her students looked at the microscopes at the different phyla of fungi, Shannon introduced her students to fungi by explaining what the basic structures looked like, and introduced new vocabulary, while drawing illustrations of the structures on the board. Once a general overview of fungus was achieved, she introduced the various phyla of fungi one at a time. She introduced the new vocabulary of each phylum by illustrating the structures on the board and showing pictures on her PowerPoint slides. She identified the structures that characterized the organisms that belonged to each phyla. She had students look at the preserved and prepared specimens to each phyla before discussing the next phyla. She gave students plenty of time to observe the specimens before she moved on to the next phyla. If students finished observing organisms of each phyla early, they could work on the individual concept maps, an assignment given at the beginning of the class. Throughout the entire lesson, she also had various images embedded in her PowerPoint slides, and asked groups to identify the names of the organisms, names of various structures on the organisms, and the name of the phylum the organisms belonged.

The above scenario of the lesson over the topic of fungi displayed a variety of instructional strategies that Shannon utilized in order to ensure students' understanding. She illustrated the important features of fungi on the board and through pictures on PowerPoint, used a concept map, and ensured that the instructor-centered portion of the lesson was broken into smaller pieces instead of one big block of instruction.

Summary. The above examples portrayed Shannon's knowledge of instructional strategies for teaching science. Shannon displayed a high level of knowledge for this construct, which was important for the development of both lesson study cycles. Shannon introduced the 5-E learning cycle and concept mapping. In addition, she guided the other participants in utilizing instructional strategies that were focused more on student-centered learning.

Participant Two: Grace

Grace was a white female who was 23 years old with a Bachelor of Science degree in Biochemistry. At the time of this study, she was working toward a Master of Science in Biology with an emphasis in Phylogenetics and was in her third semester of graduate school. Grace had no prior training in theories and practices of education, but had taught the laboratory for students majoring in biology for the previous two semesters. Her research interests included phylogenetics, biogeography, and chloroplast plastomics. This was Grace's first experience with any type of teaching professional development, including lesson study. The following sections will include a detailed description of Grace's PCK as she participated in this qualitative study.

Orientations toward science teaching. This section will be organized by Grace's experiences through pre-, during, and post-lesson study.

Pre-lesson study. Prior to the lesson study, Grace was asked what she intended for her students to learn about NOS. She replied, "The steps of the scientific method; what science is. I hope they have an understanding of how science works and why it is important at the fundamental level" (Written reflection template, 08/30/14). She believed that NOS was important in the study of biology because "an understanding to how science is conducted is important to anyone who will conduct research in the future" (Written reflection template, 08/30/14).

When asked to elaborate on the reflection template about what else she knew about NOS, Grace discussed what students typically knew about science, instead of what else she knew about NOS. "I suppose I could say that on exams, students typically remember the fundamentals of science: how science starts with observations and asking questions, what the hypotheses are and the components of primary literature" (Written reflection template, 08/30/14). When asked if there were other aspects of NOS besides the scientific method that she felt important, Grace replied, "Yeah, I'm not sure. It seems like in everything we do we can relate back to the scientific method" (Lesson study pre-interview, 09/04/14).

The above responses suggested that Grace was not familiar with all of the aspects of NOS as categorized by Lederman and colleagues (2002). Her lesson was closely aligned to the curriculum in the laboratory manual, which primarily focused on the empirical nature of science as categorized by Lederman et al. (2002). However, during the first lesson over NOS, Grace mentioned to her students that in science, we try to falsify hypotheses instead of proving them correct (Researcher field notes, 08/26/14), which correlated with Lederman et al.'s characteristic of NOS that states, *Scientific knowledge is tentative but durable.* Despite knowing this characteristic of NOS, Grace did not identify the tentative nature of science as being a category of NOS. Grace may have known other aspects of NOS; however, the only characteristic that she identified as NOS was the scientific method, which would be categorized by Lederman and colleagues (2002) as *Science is empirically based*.

Grace identified her beliefs regarding the role of the teacher and role of the student when asked how much of the responsibility should be on an educator for student learning. She responded:

> At this level, I think it is [the instructor's] responsibility to present [the material] the best we can and do what we can with what we have at hand but [the students]

> do have a responsibility to study and put in the effort. (Pre-lesson study interview, 09/04/14)

This response suggested that Grace believed that she was partly responsible for her students' learning, while the students were also responsible for putting in effort. That belief, coupled with her enjoyment of teaching, as stated in her written reflection template (08/30/14), displayed Grace's willingness to improve her practice in order to better the learning experience for her students.

***During lesson study*.** Throughout both cycles of lesson study, Grace wrote several times in her weekly reflections about revising her teaching to a more conceptual approach for her students. The idea of students learning more conceptually started as early as the first reflection over the first lesson study meeting.

> I appreciate the ideas flowing around the table at the lesson study meeting. I implemented some of the ideas in my class this week. . . . It also helped me think about my lesson plan for this week, which was a very involved and lengthy lab. I revised my PowerPoint and spent more time emphasizing major ideas that I want students to take away, rather than details that they will forget. (Weekly reflection, 09/03/14)

The strategy of emphasizing major ideas instead of minute details was aligned with a more conceptual approach to learning. This idea continued in the next weekly reflection when Grace discussed how the first two lesson study meetings directly affected her teaching because she was:

> Thinking about lesson plans and what I want students to take away from the lesson more. I am thinking more about the big ideas that I want [students] to

remember, rather than the definitions and formulas that they probably won't remember due to memorization. (Weekly reflection, 09/10/14)

The above quote suggested that Grace was reflecting more about her teaching, and was beginning to place more value on students' understanding the big ideas of biology and less value on memorizing definitions and formulas.

Grace mentioned the idea of more conceptual learning with her students again during her weekly reflection after lesson study meeting six.

> When it comes to teaching now, I think more about the large concepts I want students to take away, rather than the details that they will memorize and promptly forget. I think about the concepts that I didn't quite grasp when I was a freshman, and instead got that light bulb in a later class. If I had grasped some concepts early on, I would've become interested in research much earlier (and probably wouldn't have failed 1110 the first time around). (Weekly reflection, 10/13/14)

This quote indicated that Grace possibly believed that a more conceptual understanding of science early on could lead to an increase in student interest in biological research and perhaps increased student retention.

Finally, Grace mentioned again the idea of conceptual learning and how her philosophy toward teaching had changed over the course of the lesson study process when reflecting over both cycles of lesson study.

> My philosophy towards teaching has changed very much over the course of this semester. Instead of throwing information at students and expecting them to simply absorb and memorize the information, I want the labs to be fun and full of

discovery and more interactive. The students appreciate it more and remember the concepts better. (Written reflection, 11/04/14)

The above quote demonstrated Grace's change in her philosophy due to her experiences with the instructional approaches that she utilized through lesson study. She believed that through these approaches, the students were more able to grasp the material.

Post-lesson study. While observing Grace during the post-lesson study lesson on the topic of fungal diversity, the researcher noticed evidence of her presenting information in a more conceptual way. For example, she provided articles that represented each phyla of fungi, and she had each group of four students read an article to present interesting and important aspects of that particular fungi. She also provided students with a short video clip of *Cordyceps*, a topic of one of the articles. *Cordyceps* is located in the phylum Ascomycota, and the video showed what happens when an ant ingests a parasitic *Cordycep* spore. The spore takes over the brain of the ant, and the fungi will start to grow from the ant (Researcher field notes, 11/16/14). In using this approach, students were able to understand the importance of each phyla of fungi without the instructor telling them.

The researcher also noticed that Grace did not use a PowerPoint during her post-lesson study observation (Researcher field notes, 11/16/14). When asked about this, she replied, "It's a lot more interactive to talk and write on the board. With PowerPoints, [students] kind of just stare at them and you don't observe anything because they just think they can look at this later" (Post-lesson study interview, 12/02/14). This quote indicated that Grace believed that PowerPoint presentations hindered students from talking and discussing during the lesson.

Summary. The examples above demonstrate Grace's orientations to science teaching. She could not define NOS, although she was able to describe the tentative nature of science, which is a component of NOS. She believed teachers have a role to do the best they can in their teaching, while students also have a responsibility to put in effort. During the lesson study process, Grace started to develop her philosophy of teaching, which included utilizing a conceptual approach. From the second lesson, Grace began revising her teaching to fit into this new philosophy by emphasizing major ideas rather than details that she believed students would forget. By the end of the lesson study, she believed the classes should be more interactive and full of discovery. She believed a way to do this was to focus less on PowerPoint presentations and to provide more opportunities for class discussion and interaction. In her post-lesson study observation, Grace offered a more conceptual approach to her students by asking them to read and present articles about each phyla of fungi. She decided to use this approach instead of telling students what they needed to know. Grace's conceptions of her goals of science teaching demonstrated growth, while her conceptions of NOS and the role of students and teachers did not produce evidence of change.

Knowledge of science curriculum. When asked what teaching strategies were considered in addition to those suggested in the curriculum, Grace responded, "The curriculum in the lab manual is set up to be read aloud along with notes on the white board. I use my own PowerPoint instead of reading from the curriculum" (Written reflection template, 08/30/14). When asked to elaborate, Grace mentioned that she created her PowerPoint presentations from the lab manual and stated, "In almost every lab period, I told [the students] to use the lab manual. Everything I use comes from it and it's a great study tool for exams, but I don't necessarily teach from it" (Pre-lesson study interview, 09/04/14). The previous responses indicated that Grace used the curriculum that was provided by the laboratory manual as a reference, but created her own PowerPoint to direct students instead of following and reading the laboratory manual.

During cycle one of the lesson study, Grace again mentioned the laboratory manual when the lesson study team discussed their confusion with a change in the protocol that was sent out by Dr. Sturgeon. "We don't use [the manual]. I'll show [students] where everything is located in the manual, but I instruct them on everything and all the procedures and walk them through it" (Lesson study meeting three, 09/12/14). When asked by the facilitator if Grace had procedures and changes in the protocol on the PowerPoint, Grace responded, "Usually I'll have something on the PowerPoint" (Lesson study meeting three, 09/12/14). Grace then commented, "They really don't need these manuals" (Lesson study meeting three, 09/12/14).

The above quotes suggested that Grace used the provided curriculum in the laboratory manual herself, but summarized the information for her students on her PowerPoints. However, in the post-lesson study interview, Grace mentioned that she no longer used the PowerPoints because when she utilized PowerPoint, the class became less interactive.

Another example of Grace's knowledge of science curriculum occurred while the lesson study team was deciding on the learning objectives for photosynthesis by reviewing the study guide the lecture instructors created for their students. Grace commented:

> On the study guide the lecture instructors provided, there are things on there we don't cover in this lab, or we don't even talk about it; like the Calvin cycle and electron transport chain. We've never focused on that. But that seems to be what they're focusing on, so I can see how students are like, 'I don't see how this is related at all.' (Lesson study meeting four, 09/20/14)

This statement implied that Grace had students mention the idea that the lecture and laboratory classes were not well-aligned. Grace then commented about the study guide:

> I've never mentioned electron transport before, so maybe we should try to relate all of these things to that and tie it in, because it seems like in lecture that's mostly what [the lecture instructors] are concentrating on. I don't see anything in pigments or carbon dioxide uptake or the production of starch or anything like that. (Lesson study meeting two, 09/05/14)

This statement indicated that Grace felt that because the lecture instructors spent a great deal of time focusing on the electron transport chain, she believed the lesson study team should demonstrate how the activities in the photosynthesis lab related to the electron transport chain.

For the lesson over the topic of fungi, Grace was asked what changes she made to the curriculum. She responded, "I made the class more interactive and hands on; students also got a little practice skimming articles and presenting information to peers" (Written reflection template, 12/01/14). This would indicate that Grace included the same content in her lesson, but changed her approach in teaching the content by including outside resources as well as facilitating student learning in other important scientific skills not directly related to the content.

The data showed that Grace used the laboratory manual as a guide in her instruction, but she did not ask students to use the manual during the laboratory class. She believed the study guide created by the lecture instructors was beneficial, and since the lecture classes greatly emphasized the electron transport change, the lesson study team should display how the activities in the laboratory relate to the electron transport change. At the end of lesson study, Grace said she changed the curriculum to be more interactive by having students read and present articles.

Knowledge of student understanding. This section will be organized by Grace's experiences through pre-, during, and post-lesson study.

Pre-lesson study. Grace demonstrated evidence of this aspect of PCK during her pre-lesson study interview. When asked what students typically knew about NOS, she replied, "[Students] generally know the basic idea of what a hypothesis is" (Written reflection template, 08/30/14). She elaborated in her interview by saying, "It's probably safe to say that almost all of them have heard almost all of these concepts at least once in high school, but I've found that most of them don't remember any of it" (Pre-lesson study interview, 09/04/14). When asked what they typically struggle with when studying NOS, Grace mentioned statistical analyses, null hypothesis, and alternative hypothesis as concepts that are harder for students to grasp (Written reflection template, 08/30/14).

During the classroom observation (08/26/14), the researcher noticed that Grace highlighted the concepts of null hypothesis and alternative hypothesis several times. She began by describing that in science there are two hypotheses; she then described each of these hypotheses. Following this, Grace wrote the terms on the board, with the definitions, and repeated again the definition of each. She also gave keywords for students to remember for each, which remained on the board for student viewing throughout class. Next, she applied these terms to a scientific question by having students write a null and alternative hypotheses for the question (Researcher field notes, 08/26/14). When asked about this approach, she responded that students consistently get the terms backwards when working out practice problems as well as on the exam so, "I try to stress it as much as possible" (Pre-lesson study interview, 09/04/14).

This example suggested that Grace was familiar with where students typically have difficulty in understanding material from the NOS lesson. Because of this understanding, Grace stressed the importance of the two hypotheses and the difference between them. After emphasizing the difference between the two hypotheses, Grace had students practice writing hypotheses to a particular question.

During lesson study. Because Grace was the only lesson study team member who had previously taught the laboratory course for biology majors, she was able to offer insight to the other team members as to where students usually had difficulty with the material. During the first lesson study meeting, Shannon asked Grace to write a list of student difficulties when teaching photosynthesis. Below is the list of items in which Grace had noticed students having difficulty.

1. [Students] don't grasp the purpose of the Rf value. The exercise is good, because it demonstrates the different pigments found in a spinach leaf, but students don't absorb what the Rf value is, and miss questions about it when tested.
2. Need to discuss the concepts of absorption and reflection of light by the pigments, and the visible light spectrum. Some of them won't remember these concepts

from high school. Especially the concept of absorption—this takes a minute to sink in. Therefore, the concept of the absorption spectrum is the most confusing.

3. Students usually understand carbon dioxide uptake, but we use the equation . . . . to explain why water becomes basic when you blow into it, it doesn't seem like it sinks in. (Email correspondence to lesson study team, 09/03/14)

Grace reiterated the idea of the absorption spectrum again during lesson study meeting two. "[Students] have a hard time with the absorption spectrum and when they make the graph of the absorption of different wavelengths, they don't really understand what they are graphing" (Lesson study meeting two, 09/05/14). She then discussed that there was so much background information required for this lab, and it would be helpful if students could read about it in the laboratory manual and refresh their memories about how light works.

> In this lab it is assumed that [students] know what [the visible light spectrum] is and they understand how wavelengths relate to colors of light, but when I ask my students if they remember that, three or four raise their hands. (Lesson study meeting two, 09/05/14)

This quote suggested that Grace believed that in order to understand the absorbance spectrum of light activity, students needed to have prior knowledge of absorption and reflection of visible light. Based on her previous experience in teaching this lesson, however, only a few students had this prior knowledge.

Similarly, Grace was able to offer insight into students' area of difficulty while learning protists/algae during the second cycle of lesson study, as the lesson study team was again deciding on the objectives for the lesson. "In the past, I've taught it to where [students] would be able to –if they identify the organism, they would be able to say which life cycle they used, but I think very few of them really understood" (Lesson study meeting six, 10/03/14). Because students typically had difficulty with understanding the life cycles, Grace did not believe that students needed to be introduced to all three of the life cycles of protists/algae.

> There are three life cycles that we'll talk about: gametic, zygotic, and sporic meiosis. I was thinking it's pointless to make [students] memorize all three. [We] could just choose one to go over really well. . . . I mean, if we just want [students] to understand the diversity of protists, making them also understand all of their life cycles might be a little too much. (Lesson study meeting six, 10/03/14)

Grace believed that learning all three life cycles of protists/algae would be overwhelming to students, especially if the main goal was for students to understand the variety of the kingdom.

Post-lesson study. During the post-lesson study observation over the topic of fungi, Grace gave a mini-lecture to her students about each phylum of fungi. She then allowed students to observe the specimens for the remainder of the class. As students were viewing the specimens, she displayed each specimen for approximately two minutes each on the overhead microscope. For each specimen, she highlighted the important characteristics (Researcher field notes, 11/16/14). When asked why she used this method, she responded, "If you turn [students] loose with the slides, there is a lot of stuff on the slides, and they don't know what they are looking for" (Post-lesson study interview, 12/02/14). This quote suggested that Grace displayed each specimen on the overhead microscope in order to ensure students were able to clearly see the organisms as well as the various structures of the organisms that were discussed in class. She believed that students did not understand the structures they were expected to identify if the instructor allowed them to work independently on their own accord. Therefore, she believed that displaying each slide and pointing out the various structures helped students in understanding what they were looking at.

Summary. Grace had a high amount of knowledge about students' understanding of the material because she had taught this course for three previous semesters. She was able to identify areas of student difficulty in the pre-, during, and post-lesson study, and many of her instructional decisions seemed to be driven by this understanding. Additionally, Grace was able to offer insight to the other participants of the lesson study team as they created the lessons during both cycles of lesson study.

Knowledge of assessment. Throughout both lesson study cycles, Grace claimed that her philosophy of teaching had changed to a more conceptual approach. This change in her orientations toward science teaching should also have led to changes to all other aspects of her teaching, as suggested by Magnusson et al, (1999). Grace mentioned during the final lesson study meeting that she would include questions on the last exam that would incorporate more conceptual questions. "I want [students] to know some concepts that we've talked about. I'm thinking about doing, at least, a few questions with more of a conceptual-type answer" (Lesson study meeting 10, 11/03/14). When asked in the post-lesson study interview if she did this, she replied:

> I asked more questions about some of the uses and some of the cool things about fungi and some of the all-encompassing features of fungi. I got a lot of answers from that portion so it shows that they retained some cool stuff. I didn't have

> many questions where I would put out a specimen and just ask them to identify it. (Post-lesson study interview, 12/02/14)

This statement indicated that when assessing students, Grace did not focus on students identifying the organisms. Instead, she believed she focused more on asking questions about the uses and interesting features of fungi.

After the lesson from the first cycle of lesson study was taught, the lesson study team reflected over aspects of the lesson that went well and aspects that needed improvement. One of the concerns of the lesson study team occurred during the sticky note activity. They noticed several students waiting in line until other groups were finished placing their sticky notes. Additionally, the team observed a number of students glimpsing to see where other groups placed the sticky notes and positioning theirs in the same location. The lesson study team discussed the possibility of each group of four students creating their own poster with the photosynthesis equation. The groups would then place their sticky notes on this poster that they created. Grace took this idea a little further during the conversation:

> What if we did two posters? At the beginning, we could write down this equation and give them the words and say, "Okay, put these where you think they go." And then I'd keep that, and at the end we'd do it again and see if anything changes. (Lesson study meeting five, 10/26/14)

After this comment, Grace decided she was going to use the same idea of a pre-/post-assessment and instead ask students to write everything they know about photosynthesis before the lab and everything they know about photosynthesis after the lab. "I was thinking about just having the groups get a piece of paper and just collectively write down everything they know and then doing the same thing at the end and see how it changes" (Lesson study meeting five, 10/26/14). The previous quotes suggested that Grace found value in obtaining information from the students about what they knew about the topic before the lesson begins, and comparing that information to what students knew at the end of the lesson.

At the beginning of lesson study, Grace was asked how she knew if her students were understanding the material. She responded, "When they're answering questions or even willing to try to answer questions. Usually, how they interact with each other when I let them loose on experiments, you can always tell some understand more than others" (Pre-lesson study interview, 09/04/14). Grace believed that she was able to understand when students had difficulties based on their behavior when they worked with their groups, and whether they attempted to answer questions in class. The researcher noticed during the NOS observation that when questioning students, she questioned the whole class, and a small number of students tended to answer Grace's questions (Researcher reflection, 08/26/14).

When asked how she knows her students understand the material at the end of lesson study, Grace responded, "I feel like if I can ask them a question in class and they can answer it, they have a grasp on it" (Post-lesson study interview, 12/02/14). During the post-lesson study observation, the researcher observed Grace going to individual tables and asking questions to individual groups of students. This was a shift from the beginning of lesson study in which Grace relied on questioning the entire class, with only a few students responding.

Grace displayed small changes in this aspect of PCK. Because she was using a more conceptual approach in her teaching, Grace mentioned asking students more conceptual questions on the formal examinations. She thought of an assessment strategy during the re-teaching portion of the photosynthesis lesson that involved asking students to write everything they knew about photosynthesis before and after the lesson. Additionally, Grace demonstrated a change in questioning techniques at the end of lesson study that involved checking individual groups' understanding. This is in contrast to asking the entire class questions, with only a few responding; a practice she demonstrated at the beginning of lesson study.

Knowledge of instructional strategies. This section will be organized by Grace's experiences through pre-, during, and post-lesson study.

Pre-lesson study. When completing the pre-lesson study reflection template for the lesson over NOS, Grace explained that as she goes over the steps of the scientific method, students will "take notes and interact in discussion" (Written reflection template, 08/30/14). When asked how she persuaded students to interact in discussion, she responded, "I try to build my PowerPoint so everything is just laid out so I can ask them questions like, 'How do you think the scientific method starts?' [and] 'What do you think you're going to do next?'" (Pre-lesson study interview, 09/03/14).

While observing the NOS lesson, the researcher saw Grace ask the class questions throughout the laboratory (Researcher field notes, 11/16/14). Most of the questions were displayed on the PowerPoint, and required students to recall facts. For example, in the NOS lesson, Grace mentioned that science is the way we gain knowledge about the world around us, and then asked, "Anybody have a guess in how we gain knowledge?" Most of the questions that Grace asked were at a *knowledge* and *comprehension* level according to Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956).

After she reviewed the steps of the scientific method in the NOS lesson, Grace mentioned that she would then demonstrate analyses by performing chi-square problems while the students "participate in practice problems" (Written reflection template, 08/30/14). During the observation of this lesson, Grace asked for student volunteers to come to the board and work the problems for the rest of the class (Researcher field notes, 08/26/14). When asked if there was a reason for this, Grace responded that her main reason was to keep students engaged. "Once the students interact with each other, they're less shy about helping each other out and shouting at the board to say what comes next or say if they're doing that wrong" (Pre-lesson study interview, 09/04/14). Grace made these changes because, "I don't find [the NOS] section in the book interactive or interesting, and I don't think the students do either" (Written reflection template, 08/30/14). The above examples suggested that Grace believed that asking students questions throughout the lesson, and having them work problems on the board, facilitated the interesting nature of the lesson.

During lesson study. During Grace's weekly reflection, she mentioned positive aspects of the various instructional strategies the group employed. For example, after only two lesson study meetings, Grace reflected on how the pedagogical knowledge she was exposed to during lesson study had already changed her teaching in the classroom. "I am more interactive with students and we have more fun in class this semester than we have in the past" (Weekly reflection, 09/10/14). When asked to reflect about her experience after the first cycle of lesson study was complete, Grace responded, "I like that we are incorporating a lot of group work and discussion into the lesson plans" (Weekly reflection, 10/06/14). Grace's reflections suggested that she enjoyed being more interactive with her students and that group work and discussions were strategies that she enjoyed incorporating into her lessons.

When asked to reflect over her entire experience of both cycles of lesson study, Grace responded:

> I have enjoyed teaching more this semester, in part because the lesson plans have become more fun, and in part because the students are enjoying it more as well. Because of that, I will definitely be utilizing the strategies used this semester in future semesters. I will be applying these strategies to all of the labs I teach in the future, in the hopes that students enjoy the labs more and get more out of them. The lesson over protists went much better than it has in the past with the usual lesson plan. It was a lot more interesting and interactive than lecturing and presenting the specimens. (Written reflection, 11/04/14)

This quote implied that Grace believed the strategies she had learned as a result of lesson study contributed to enjoyment for both the instructor and the students.

Post-lesson study. For the post-lesson study observation over the topic of fungi, Grace employed several strategies the team utilized during the second lesson study cycle over protists/algae. Prior to class, she found articles over the different phyla of fungi. During instruction, Grace had students form groups and read and report on the interesting features about that particular fungi (Researcher field notes, 11/16/14). When asked about the advantages of the teaching strategies, Grace stated, "[The articles] made the class more interactive and hands on; students also got a little practice skimming articles and presenting information to peers" (Reflection template, 12/01/14). While observing this portion of the lesson, the researcher noticed Grace writing important points on the whiteboard and restating certain parts of each article to the entire class. When asked about why she did this, Grace responded:

> I read all the articles and there were certain things I wanted them to know. So one reason was to make clear the things I wanted them to know and write down. I also did it to make sure everyone heard because some of the students were pretty quiet. (Post-lesson study interview, 12/02/14)

The above scenarios suggested that Grace used the articles because she believed the articles offered students an opportunity to peruse information and provide an opportunity to present information to their peers. She believed this approach was more interactive in students' learning. After each group presented their information, she reviewed what she deemed important to ensure everyone had a chance to hear the information that students presented.

Additionally for the fungi lesson, Grace created a chart for students to organize their notes, which was similar to the one that Shannon created in the algae lesson (Researcher field notes, 11/16/14). The chart included the phylum, common name, genera, life cycle, and special characteristics/description of each phylum of fungi. As students viewed each specimen, they were expected to complete the chart to better understand how the organisms in each phyla were related to one another, as well as other organisms in other phyla. When asked about why she utilized this strategy, Grace responded:

> After we did the protist chart, I figured out that they needed something like that as a reference so they can take notes. Some are not very good at taking their own notes and that just really seemed to organize the content. When I'm teaching, I can refer to it also, and that helps a lot. (Post-lesson study interview, 12/02/14)

This example suggested that Grace created the chart for her students because she felt it was a way students could organize the information. Grace also believed the chart was useful as she was discussing important aspects of each phyla of fungi.

When asked how her students responded to the different instructional approaches the lesson study team utilized, Grace answered:

> I think they enjoyed it. It made it more interesting. There was more for them to do. In the past, and for a lot of the TAs, it's just lecturing with a PowerPoint and then letting [students] do whatever activity. The way [the lesson study team] structured the lesson plans was a lot more fun for the kids. (Post-lesson study interview, 12/02/14)

Grace later stated that lesson study inspired her to do away with the PowerPoints. "The lesson plans we came up with didn't really rely on a PowerPoint and so after we did the first one, that's kind of when I quit using the PowerPoints all together" (Post-lesson study interview, 12/02/14). The above statements suggested that Grace believed students liked the new strategies the team included in their lessons because the new approaches were more interesting. She felt that a great deal of instruction that occurred within these laboratory classes involved mostly lecture, and that the strategies the team devised did not need PowerPoints. Because of this, Grace stopped using PowerPoints in her classes.

Summary. In the beginning of lesson study, Grace relied on her PowerPoint presentations to deliver instruction. Embedded within her PowerPoints were questions she would ask students. For some of the questions that involved working problems, Grace had students come to the board to work the problems for the rest of the class. She felt this method was more engaging for students. By the end of lesson study, Grace stopped using PowerPoints because she felt the techniques she learned from lesson study helped in engaging students, and she believed the PowerPoints were no longer needed. Grace felt the instructional strategies she learned through lesson study helped her become more interactive with her students and this enabled her classes to be more fun. Because of this, she enjoyed teaching this semester more than she ever had and stated she would be utilizing the strategies she learned in future semesters in order for students to understand the laboratories more in addition to getting more enjoyment from the instruction.

Participant Three: Spencer

Spencer was a white male who was 25 years old with a Bachelor of Science degree in Biology and a minor in Chemistry. At the time of this study, he was working toward a Master of Science in Biology with an emphasis in fisheries science. Spencer had no prior training in theories and practices of education, and this was his first semester teaching. His research interests included population dynamics and anthropogenic factors affecting fish distribution success. This was Spencer's first experience with any type of teaching professional development, including lesson study. The following sections will include a detailed description of Spencer's PCK as he participated in this qualitative study.

Orientations toward science teaching. The first lesson of this laboratory was entitled "Nature of Science" and focused on the *science is empiricallybased* aspect of NOS. Prior to the lesson study, Spencer was asked what he intended students to learn about NOS. He replied, "[Students] needed to learn the general concept of the scientific method and the steps that make it up" (Written reflection template, 09/02/14). When asked if he had heard of NOS before, he responded, "No, not really. I knew about the scientific method because, it's what you have to do to get new scientific information or research" (Pre-lesson study interview, 09/11/14).

During the teaching of the NOS lesson, Spencer followed the curriculum in the laboratory manual by discussing the steps of the scientific method, including a segment on statistics by using a PowerPoint presentation (Researcher field notes, 08/27/14). Because he followed the curriculum in the laboratory manual, his lesson addressed the *Science is empirically based* aspect of NOS, as categorized by Lederman and colleagues (2002). There was no mention of other aspects of NOS, because these aspects were not mentioned in the curriculum. The above examples implied that Spencer was not familiar with NOS, and used the terms NOS and scientific method interchangeably. He directly followed the lesson in the laboratory manual, which was titled NOS, and focused on the empirical nature of science.

An understanding of Spencer's teaching philosophy developed throughout the lesson study process. During meeting number four, Shannon mentioned the idea that the lesson had a number of activities and asked the team if they should prioritize in case they ran out of time. Grace responded to this question by asking the group if they could "wing it" and change the final lesson based on how the first teaching of the lesson went. To this, Spencer replied, “My teaching style is very as I go. I don’t tend to lesson plan” (09/20/14). However, during his first reflection over lesson study meeting one, he stated, “I hope to gain some insight as to how a teacher should go about planning to teach a topic and then executing that plan by following it in a classroom setting” (Weekly reflection, 09/08/14). When asked in the post-lesson study interview if he was able to achieve this goal after participating in lesson study, he responded “Yes, definitely. I think so. It helped me in working with a group. It helped me realize how much planning does go into a lesson” (Post-lesson study interview, 12/04/14).

The above comments indicated that Spencer hoped to gain insight into how to plan a lesson at the beginning of the lesson study process. Although he seemed to teach without planning his lessons, he placed value on being able to plan a lesson from the beginning. After four meetings, he stated that he did not plan out his lessons. However, by the end of both cycles of lesson study, he felt as though working with the lesson study team helped him in realizing how much planning went into a lesson.

When asked what he learned about teaching through the lesson study process, Spencer answered:

> Being prepared is one of the most important things. My goal was to be able to present [students] with as much relevant information about the topic as I could and be able to answer any pertinent questions they might have. (Post-lesson study interview, 12/04/14)

The above quote suggested that Spencer believed that it is important to be prepared before teaching a lesson. To him, being prepared involved being knowledgeable about the topic in order to present the material to his students as well as answer any questions that may arise.

When asked what he learned about students through the lesson study process, Spencer replied:

> You have good students and bad students. The good students will put in the appropriate amount of work and their grades will reflect it. With the bad students, you can try to help them as much as you want, but if they aren't willing to meet you half-way, nothing is going to happen; they will either drop the course or get a poor grade. (Post-lesson study interview, 12/04/14)

The above quote demonstrated Spencer's conceptions of science teaching and learning. He believed that regardless of what the instructor does, students who do not put in effort will not be successful in their learning.

When asked in the pre-lesson study interview about how much of the learning is the responsibility of the student, and how much is the responsibility of the teacher, Spencer responded, "In my opinion, definitely the majority is on the students. You can still learn about something yourself even without a teacher" (Pre-lesson study interview, 09/11/14). This philosophy remained when Spencer was reflecting on lesson study six, as the lesson study team discussed the summarizing portion of the photosynthesis lesson (10/03/14). During this portion of the lesson, the instructor asked students to form groups based on the activity with which each student felt more comfortable. Each group then wrote and presented a summary about that particular topic (Photosynthesis lesson, 09/25/14). Spencer noticed that some of the activities did not have a large representation of students who understood the topic. To this, he responded:

> Hopefully the students can recognize which parts of photosynthesis they need to learn independently after they leave lab. There's only so much an instructor can do, I've realized. Students also must be willing to do work outside of class in order to learn. (Lesson study meeting six, 10/03/14)

The above comments suggested that Spencer placed the responsibility of learning primarily on the student. Additionally, Spencer again showed his belief that an instructor is limited in his/her role, if the student is not willing to work outside of the classroom.

Overall, Spencer did not spend time planning out his lessons during the beginning of lesson study. However, lesson planning was a goal that Spencer said he wanted to learn as a result of the lesson study experience. By the end of the study, Spencer claimed that he was able to see the amount of hard work and time that it took to plan a lesson. His philosophy in teaching was one that placed the responsibility of learning on the student. He felt that the role of an instructor is limited, especially if the student does not work outside of class. He also believed that as an instructor, he needed to know enough information about the topic in order to present enough relevant information and to adequately answer questions that students may have.

Knowledge of curriculum. When asked if he changed the curriculum of the NOS lesson, Spencer answered:

> No, I did not. I just went directly from the [laboratory manual] and that's probably just because I've never taught [the material] before so I didn't really know what the best way to do it was. I figured Dr. Sturgeon did it this way for a reason. (Pre-lesson study reflection template, 09/02/14)

This indicated that Spencer did not deviate from the laboratory manual because he was unsure of alternative approaches because he had never taught this lesson or any lesson before. Because of this, Spencer taught directly from the laboratory manual.

Spencer not only had the challenge of being a first semester teacher, but he also was unable to attend the weekly laboratory meetings due to a conflict in his schedule. When asked about this, Spencer stated, “It makes it a little more stressful than I think it should be just because I’m not sure what I’m supposed to emphasize, but that’s all right.” Because Spencer was not able to attend the weekly laboratory meetings, the lesson study meetings were the only time he could collaborate and discuss issues with his peers.

Spencer’s uncertainty of the curriculum surfaced again as Shannon was trying to solicit information from the other team members about the type of items the photosynthesis lesson plan should include. She asked the team about the weekly laboratory notes Dr. Sturgeon sent and what type of things the team should include in their plan that would help their understanding of what and how they should teach. Spencer responded, “That’s all I do, that’s in there, that’s all I’ve done so far” (Lesson study meeting two, 09/05/14). Shannon then asked Spencer what he thought of the weekly notes, and Spencer replied, “I have no idea what Dr. Sturgeon is talking about. I need to go watch [the lesson taught by another GTA]” (Lesson study meeting two, 09/05/14). These quotes would indicate that because Spencer was in his first semester of teaching, he relied a great deal on knowledgeable others including Dr. Sturgeon and observations of other GTAs.

Spencer’s uncertainty about the curriculum and reliance on knowledgeable others surfaced again as the lesson study team was developing learning objectives for the protist/algae lesson. The group was unclear as to the main points of the lesson and decided to email Dr. Sturgeon for clarity. Upon receiving guidance from Dr. Sturgeon as to his beliefs for the learning objectives for the lesson, the lesson study team decided that each individual would email the main points he/she believed should be included in the protist/algae lesson. Spencer deferred to Dr. Sturgeon and stated:

> I just looked at what Dr. Sturgeon said the students should learn in order to determine what I want my students to know. I figure he knows better than me, so I'll just go with that to form a foundation on. (Email correspondence to lesson study team, 10/12/14)

This statement suggested that Spencer relied on knowledgeable others, rather than his knowledge of the curriculum, to inform his teaching.

When asked what changes Spencer made to the curriculum during the post-lesson study lesson over the topic of fungi, Spencer discussed how he brought in articles like the lesson study team did for the protist lesson because he "liked how [the articles] engaged the students and they worked together" (Written reflection template, 12/04/14). This statement suggested that Spencer viewed curriculum as strategies utilized to teach the topic.

The examples above indicated that Spencer was unclear of the learning objectives that students should be learning in the course. Although Dr. Sturgeon sent out weekly notes, Spencer was uncertain of important points to teach because he was not able to attend the weekly laboratory meetings. As this was his first semester teaching, Spencer relied on knowledgeable others to inform his teaching, rather than his knowledge of the curriculum.

Knowledge of student understanding. When completing the reflection template over the NOS lesson, Spencer wrote that he would explain statistics (i.e., chi-square) while the students listened and performed an example test. His rationale behind this approach was that "students should be able to run statistical tests to analyze data" (Pre-lesson study reflection template, 09/02/14). When asked if he thought students could run statistical tests and analyze data after his lesson, Spencer replied, "I think they would stumble through it. If they tried to figure it out, they should be able to, but they probably would have a question about a step or two here and there" (Pre-lesson study interview, 09/11/14). When asked if he thought students were able to understand chi-square, he responded:

> I think they understood why, but I'm not sure if they understood how to do it even after I showed them. I don't know if they had ever seen it before, so with a first time quick run through on the white board, I'm not sure if they got it. (Pre-lesson study interview, 09/11/14)

During the teaching of the NOS lesson, Spencer performed the chi-square problem that was in the laboratory manual for his students. He did not have the students do practice problems on their own (Researcher field notes, 11/10/14). The above examples proposed that Spencer believed that students would not be able to analyze data by performing a chi-square test on their own. According to his orientations of science teaching, the student is responsible for the majority of the learning (pre-lesson study interview, 09/02/14), and therefore he believed that presenting the information to the students is what was required from the teacher. He felt that it was up to the student to make sure he/she understands how to apply and use the information that is learned. Since

Spencer did not provide an opportunity for students to struggle with it during class, perhaps he believed students should spend the time at home to "stumble through" the problems.

On the written reflection template over NOS (09/02/14), Spencer wrote that students typically struggle with the concept of null hypothesis, alternative hypothesis, and sample error during this lesson. When asked if he thought his students understood the difference between the two hypotheses after the lesson, he responded, "I think so because it has been talked about since that first initial lab. We have gone over it another time or two and each time I ask them to tell me the null and alternative hypothesis" (Pre-lesson study interview, 09/11/14).

When asked if his students understood sample error, Spencer responded:

> No, I don't think so because it is something that I haven't really, well, that's just part of the chi-square, I think, so I haven't really messed with that in a while. It was something that I had to go back over and re-learn myself. (Pre-lesson study interview, 09/11/14)

The above quote implied that Spencer was not comfortable with the topic of sample error, because he had to re-teach himself the concept. As a result, he may have felt inadequate in presenting this information to the students, and consequently, his students may not have gained a complete understanding of the concept.

Spencer asked an interesting question about student understanding during lesson study meeting three while the lesson study team discussed a way to assess prior knowledge about photosynthesis (11/12/14). Shannon mentioned that some of their students were not going to know anything about photosynthesis, while others could tell you “exactly what’s going on with the chemical equation” (Lesson study meeting three, 11/12/14). Spencer responded:

> That’s what it seems like in most of my labs. There are students up here with their content knowledge and then there are students down here that they don’t have a clue. How do you adjust to keep these students interested in learning, and how do you catch these students up? (Lesson study meeting three, 11/12/14)

This quote suggested that Spencer recognized that there was a wide range of knowledge in his students. To this, he posed a question as to how an instructor, within the timeframe of the class, gets everybody on the same level. This question implied that Spencer acknowledged the diversity of his students and demonstrated his interest in learning strategies to meet all students’ learning needs.

Overall, Spencer’s knowledge of student understanding remained stagnant throughout lesson study. Spencer acknowledged that he did not believe that students understood how to perform a chi-square problem after they did an example on the white board. According to Spencer’s orientations to science teaching, he believed that students were responsible for the majority of their learning. Therefore, Spencer possibly believed students should continue their practice with chi-square on their own.

Knowledge of assessment. When asked how he knew if a student understands, Spencer responded, “If it’s in a regular lab, I will see other students going to them and they are able to explain it. That happened several times. Also, I can tell when they have good exam grades” (Post-lesson study interview, 12/04/14). This quote suggested that Spencer believed that a student understood the material when they were perceived by their classmates as being able to explain the concept to others. It appeared that the main strategy of assessment of Spencer's students included summative evaluations.

When asked to reflect on evaluation methods, Spencer responded:

> I think evaluation can be done any number of ways. Obviously there is the traditional way of using tests/exams to show [students'] knowledge of the subject. A way that I think is more effective is to have them do a lab report. It just shows that they actually learn the subject instead of memorizing answers for exams. To show learning during the actual lab, I think that after each procedure it would be good to have some questions that the students answer either as a group or individually. These questions could be specific to the procedure of more open ended concerning the topic of photosynthesis as a whole. I think this is a good way to make sure the students remain engaged in the lab and are following along the entire time. (Written reflection, 09/22/14)

In the above quote, Spencer discussed two types of summative evaluation methods when mentioning laboratory reports and tests/exams. Spencer believed that writing laboratory reports was more effective than exams, because they would assess understanding of material in contrast to recollection of facts. In addition to discussing summative evaluation methods, Spencer also mentioned formative assessment methods, including asking students questions after each procedure. He also stated this form of assessment could be used as a strategy to engage students throughout the class.

Spencer mentioned the value of asking students questions throughout the lesson again when he discussed the embedded guiding questions the lesson study team implemented throughout the photosynthesis lesson. Spencer mentioned he asked the guiding questions to his students regarding the mass of a plant, and he had students go to the whiteboard and write their answers. At the end of the class, he had students go back to the whiteboard to write down their thoughts as to where the mass of a plant came from, and his response to the group was, "I was like, 'Wow! They're learning!'" (Lesson study meeting five, 09/26/14).

This point was reiterated during a weekly reflection when Spencer was discussing the strengths of the photosynthesis lesson. "I think some strengths of the lesson are that we plan on keeping the students engaged and thinking the whole time with our questions that sort of directs what they should be trying to learn during each procedure" (Weekly reflection four, 09/20/14). In this quote, Spencer mentioned the engaging component of guiding questions, rather than using them as a method of assessing students' knowledge of the material. It is important to note that although Spencer saw the value in guided questions, this did not translate to the classroom while teaching the post-lesson study lesson on fungi. When teaching this lesson, Spencer did not ask individuals or groups questions for understanding at any time during the laboratory period (Researcher reflection, 11/10/14).

On several occasions during the lesson study, Spencer stated several forms of summative and formative evaluation techniques. He mentioned the guiding questions as a strength of the photosynthesis because it guided students' learning and kept them engaged. He did not mention using the questions to check for students' understanding, and did not ask individual students or groups of students questions during the pre- or post-lesson study observations.

Knowledge of Instructional Strategies. This section will be organized by Spencer's experiences through pre-, during, and post-lesson study.

Pre-lesson study. When completing the pre-lesson study reflection template for the lesson over NOS, Spencer explained that he would first introduce the scientific method as students listened and took notes (Pre-lesson study reflection template, 09/02/14). When asked how he introduced the scientific method, Spencer replied:

> I went through the handout that was supplied in the lab notebook that the lecture professors gave us. I took out the main steps of the scientific method and pretty much went through those one by one. I tried to make sure [students] understood what each step was and how it was important to perform an experiment. (Pre-lesson study interview, 09/11/14)

After introducing the scientific method, Spencer stated that he would go over the steps of the scientific method while students took notes. When asked how he went over the steps of the scientific method, Spencer responded, "I went over each step and there are seven of them. Each step had a slide and we talked about the proper ways to do that step" (Pre-lesson study interview, 09/11/14). When asked if he saw students taking notes, Spencer replied, "Yes, most people did take notes. I noticed they were trying to write down whatever was on the PowerPoint slide instead of listening to me" (Pre-lesson study interview, 09/11/14). When asked if he felt that his students were engaged in their learning, Spencer replied, "I think so, yeah. They seem to be taking good notes and paying attention" (Pre-lesson study interview, 09/11/14).

During the teaching of this lesson, Spencer first asked the question, "Could someone give a brief definition of what science is?" (Researcher field notes, 11/10/14).

Since no one responded with an answer to his question, Spencer then read the answer from the PowerPoint presentation. After this, Spencer continued to read the steps of the scientific method from his PowerPoint to his students. He then told students they would be going through a scenario that would help them understand the steps of the scientific method. Spencer then read this scenario in the laboratory manual aloud as students followed along.

The above situation demonstrated that Spencer did not deviate from the curriculum in the laboratory manual. He highlighted key points the laboratory manual stated about the scientific method and tried to ask his students a question as he began going over the steps. Because no one answered, however, he continued to answer his own question and read the remainder of the steps of the scientific method from the PowerPoint slides. He thought students were engaged because they were taking notes, but later said while students were taking notes that they did not appear to be listening to him. It is important to note that this lesson was Spencer's first time teaching and he mentioned in the pre-lesson study interview that he was a little nervous and felt his students were a little nervous also. "They were a little quiet. They've opened up since then" (Pre-lesson study interview, 09/11/14).

During lesson study. Throughout both cycles of lesson study, Spencer spoke of several instances in which he realized benefits of the alternative strategies the lesson study team used. For example, when talking about the sticky note activity the team created, Spencer commented, "I like the sticky note [activity]. It just shows that [students] can apply it" (Lesson study meeting five, 09/26/14). In a weekly reflection, Spencer mentioned that his favorite part of the photosynthesis lesson was the sticky note activity.

> The students were able to discuss amongst themselves and figure out where certain words went where. It was good to see them helping each other out and work as a team. Watching [the photosynthesis] lesson, it just seemed to me that students don't have very long attention spans. They are obviously more engaged when they had an activity to do. (Weekly reflection, 10/06/14)

Spencer spoke of the sticky note activity again in a later weekly reflection by stating, "I think the students really benefitted from that critical thinking and also from having to work in groups to come up with a conclusive answer" (Weekly reflection, 10/16/14). When asked if he would utilize the strategy in future lessons, Spencer responded, "Maybe, if there's an equation like that or some process that a lot goes into, maybe" (Post-lesson study interview, 12/04/15).

The above examples implied that Spencer believed the sticky note activity that the lesson study team created was beneficial in helping the students apply the information they were learning to each activity of the photosynthesis lesson. He believed the activity supported the students in critically thinking and working together as a group. He thought activities such as the sticky note exercise were engaging and helped in the learning of students who had difficulty in learning. Despite this, when asked if he would use the strategy again, Spencer's reply was more tentative.

A strategy that Spencer did not enjoy as much as other strategies was the concept map. When asked about his thoughts regarding the concept map, Spencer responded:

> I think there could be a better way to do that. I felt like it was a little rushed, maybe. I would maybe have them do it before the lab, like before they even come in. They would just come in and not have any idea what they were going to talk about that day and I think it would be helpful if they made a concept map. (Post-lesson study interview, 12/04/14)

When asked if he would implement a concept map in his teaching again, he responded:

> Maybe. [Concept maps] weren't bad, but they are just so different and [students] had no idea what the protists were and they were just confused. It might be easier to do a concept map for different things. It might have been easier for fungi than the protists just because the protists are so different. (Post-lesson study interview, 12/04/15)

When asked if Spencer had ever heard of a concept map before lesson study, he responded:

> I knew the general idea. It kind of just makes sense and I could figure it out but I don't think I had done one before. I think I had seen them used as a study tool, but I don't think I had ever done one myself. (Post-lesson study interview, 12/04/15)

When Shannon introduced the idea of a concept map to the lesson study team, she asked the team to create one over algae, in order to determine if this activity was something they would be willing to incorporate into the algae lesson. The researcher asked Spencer if he thought doing the concept map with the other team members helped him to understand protists better. He responded:

> Yes. I hadn't looked at protists since Biology I, so I knew what they were but that was it and I'm sure things have changed in the six years since I took it. As we

went through [the concept map], light bulbs clicked on. It was cool. (Post-lesson study interview, 12/04/14)

The above quotations indicated that Spencer felt that the concept map he did with the other lesson study team members was helpful to him in understanding protists. Despite this, he felt that he did not enjoy the concept map the lesson study team incorporated in the protist lesson because he believed the material was too complex and the activity felt rushed. He thought a better approach would be for students to perform a concept map on their own, prior to the lesson.

Post-lesson study. For the post-lesson study topic over fungi, Spencer stated he was going to introduce students to the kingdom of fungi while the students took notes from the PowerPoint and read articles (Post-lesson study written reflection, 12/04/14). During the teaching of this lesson, Spencer utilized alternative teaching strategies. "I brought articles for students to read that were about different types of fungi, then [students] had to summarize for a quiz grade" (Post-lesson study written reflection template, 12/04/14). He stated he made these changes because he noticed when the lesson study team utilized these strategies in the teaching of the algae lesson he "liked how [the articles] engaged the students as they worked together" (Written reflection template, 12/04/14). When asked how he thought that portion of the lesson went, he responded:

> It went well, I think. I showed a video. [Students] always like visual stuff like that. They were able to interact with each other and I think that helps get the lab going; that's what I thought about the protist lesson. (Post-lesson study interview, 12/04/14)

The above scenario suggested that Spencer found value in the instructional strategy of bringing in outside resources for students to read and report.

For the next portion of the lesson, Spencer said he was going to talk about the basic structures of fungi while the students paid attention to key words (Written reflection template, 12/04/14). When asked how he approached this, Spencer responded, “[We] just [went] through the PowerPoint using the lab manual that the students have. I made a PowerPoint from that highlighting all the key words and I explained those terms to the students” (Post-lesson study interview, 12/04/14). When asked if he thought students understood those key words, Spencer responded, “I think it was kind of the same with all the PowerPoints. They just kind of glance at it and think they will just look at this later on D2L, so I don’t know” (Post-lesson study interview, 12/04/14). When asked if he noticed students taking notes, Spencer responded, “Yes. Some students took notes all year long, but they were in the minority” (Post-lesson study interview, 12/04/14). It is important to note that Spencer primarily read the information directly from his PowerPoint slides (Researcher field notes, 11/10/14).

The researcher asked Spencer to give an example of how he had revised his teaching since participating in lesson study. Spencer replied:

> I used more outside resources like the articles, looking for videos and stuff rather than just using the lab manual. I realize that the students have a lab manual and if you just teach from that it’s nothing more than they could just do at home so you need to have outside resources, I feel. (Post-lesson study interview, 12/04/14)

The above scenario implied that Spencer valued outside resources such as articles and videos in his teaching. His primary method of presenting information remained the utilization of the PowerPoint presentation, which he created from the laboratory manual. He said his students took notes from his PowerPoint, but those students were in the minority.

Summary. This component of PCK displayed the largest representation of Spencer's knowledge. Before lesson study began, Spencer did not deviate from the laboratory manual. Throughout both lesson study cycles, he found importance in a variety of the instructional strategies the team utilized. He believed these strategies were engaging, collaborative, and applicable to students. He utilized one of these strategies in the teaching of his post-lesson study lesson over the topic of fungi. He believed that instruction needs to include outside resources that supplement the laboratory manual. He deemed that utilizing these strategies creates a richer experience for the students in his laboratory.

Participant Four: Clint

Clint was a white male who was 23 years old with a Bachelor of Science degree in Biology with a concentration in genetics and biotechnology, and a minor in Chemistry. At the time of this study, he was working toward a Master of Science in Biology with a concentration in genetics, biotechnology, and microbiology. Clint had no prior training in theories and practices of education, and this was his first semester teaching. His research interests included genetics and epigenetics and using bioinformatics and genomics to analyze genetic sequence information. This was Clint's first experience with any type of teaching professional development, including lesson study. The following sections will describe Clint's PCK as viewed through the lens of this qualitative study.

Orientations toward science teaching. This section will be organized by Clint's experiences through pre-, during, and post-lesson study.

Pre-lesson study. When asked what he intended students to learn about NOS, Clint replied:

> I want students to understand that science is a process and a methodology used to add to the collective human knowledge about the natural world. [Students] should understand the concept of a theory and a hypothesis along with the scientific method and be able to demonstrate the ability to develop their own testable hypotheses. (Written reflection template, 09/02/14)

Clint stated that NOS is important in the study of biology because "the scientific method is a fundamental process from which all scientific and biological knowledge originates and any new information must also come from the scientific method" (Written reflection template, 09/02/14). To the question of whether he considered the expressions scientific method and NOS as terms that could be used interchangeably, Clint replied, "There might be other aspects of the nature of science, but I addressed it like the scientific method *was* the nature of science. . . . I was using the terms interchangeably, I guess" (Pre-lesson study interview, 09/04/14). When asked what else he knew about NOS, he stated, "I understand science to be a way of viewing the world. It is based on empirical evidence and is a method that has sequential steps" (Written reflection template, 09/02/14).

The above situation implied that Clint was not familiar with the term NOS. His teaching of the NOS lesson was closely aligned with the laboratory manual, which focused on the empirical nature of science, as categorized by Lederman and colleagues

(1992). Despite his unfamiliarity with this term, Clint unknowingly mentioned other aspects of NOS while teaching the NOS lesson (Researcher field notes, 08/22/14). For example, he claimed that science is always changing and because of this, scientists are always revising their ideas. Additionally, he commented that revisions often happen in science because we are constantly learning and improving theories. Both of these comments were aligned with Lederman et al.'s (1992) aspect of NOS that claims science is tentative but durable.

Clint also mentioned the importance of theories to science while discussing NOS, a category also designated by Lederman et al. (1992) "I told [students] that one of science's greatest strengths is that theories can be revised and we're constantly making progress" (Pre-lesson study interview, 09/04/14). Although Clint was unable to explicitly categorize the various aspects of NOS, his teaching of the lesson and answers about NOS in his pre-lesson study interview implied that he was familiar with several of its characteristics, even though he was not able to explicitly identify associated terms.

Clint mentioned his goals of student learning during the pre-lesson study interview when he was discussing the lack of participation within student groups. He claimed that there were several strategies that he wanted to implement into the NOS lesson, but because there was limited interaction within several of the groups, he opted to change his approach. Due to the inadequate communications within groups of students, Clint stated that he was going to have students participate in an ice-breaker activity in the next lesson.

> I think [interacting in groups] is a good idea to prime [students] for learning. There are other things going on besides [students] just learning about biology.

> They are starting college, 1111, and I want them to learn how college works and that you can use your peers to help you learn. I want them to feel comfortable. (Pre-lesson study interview, 09/04/14)

This statement suggested that Clint believed group participation can be beneficial for students beyond learning science, and that students' peers can aid in individual learning. This was a theme that occurred throughout the semester with Clint.

Clint's beliefs in student learning surfaced again when he was asked about his content knowledge regarding NOS. Clint claimed that he understood NOS in the terms of an individual experiment and that he was "beginning to appreciate the Nature of Science in a more philosophical sense" (Written reflection template, 09/02/14). When asked to elaborate, Clint responded:

> I think people are more apt to take something at its value just going on what someone has told them and I want [students] to take what we did in this experiment, not necessarily for every situation in their life, but I want them, in making decisions about products on an infomercial and deciding if it's a scam, questioning the information. That can improve their life. It can help them with their health when they talk to doctors or to pseudoscience. (Pre-lesson study interview, 09/04/14)

This statement implied that Clint wanted students to understand science in a way that helped them make informed decisions about their daily lives.

During lesson study. During both cycles of lesson study, Clint discussed the ideas of "laying down layers" of learning for his students. An example of this occurred during the second lesson study meeting, as the team was looking at the list that Grace created of common difficulties that students had during the photosynthesis lab. One of the difficulties was during the phenol red activity, which demonstrated uptake of carbon dioxide during photosynthesis. Phenol red (phenol-sulfonphthalein) is a pH-indicator that turns yellow-orange in an acidic solution and becomes red in a neutral to basic solution. During this activity, students were asked to use a straw and blow into two beakers halfway full with phenol red until the color changed from red to yellow-orange. Next, students were to add a piece of *Elodea* to one of the beakers, and place both beakers in front of a 100-watt bulb for 30 minutes. After 30 minutes, students observed that the beaker with *Elodea* turned back to a reddish color, while the beaker without *Elodea* remained yellow-orange. In lesson study two, Grace stated that students usually had difficulty understanding the chemistry behind this scenario. To this, Clint responded:

> I would talk about it for a little bit and then—I like to think of it as laying down layers. So the more times they hear it, even if it's not in my class, it'll sink in. They're like, 'Oh, I've learned about that in biology. I had no idea what they were talking about,' but when they get in chemistry they'll be like, 'This is an acid and a base. This is a buffer.' I just remember when I was in Biology 1111, I didn't understand most of what we did. Then when I went onto organic and went on to gen-chem and other biology classes, I remember doing it and then I was like, 'If I'd known then what I know now, my life would have been so much easier. (Lesson study meeting two, 09/05/14)

In these series of quotes, Clint displayed a limited constructivist philosophy. Clint felt that although the understanding of the chemistry concepts in the activity was difficult for students to grasp, he would still discuss the chemistry in order to expose his students to the concept. He believed that it may not make sense to his students at first, but once students moved forward in their educational career and completed chemistry courses, the concepts would then become clear.

The idea of "learning in layers" surfaced again during lesson study meeting four when the participants were discussing photosynthesis as a concept that incorporated chemistry and physics, which were courses that most of their students had not yet had. Shannon asked the group, "How do you get students to understand [photosynthesis] without saying, 'Oh, you'll get to that in another class' " (Lesson study meeting four, 09/20/14). To this, Clint responded:

> I'd tell them enough for them to – your conception of an idea gets more and more complex the more you encounter it. And it's like, I can't go into the physics, I can't go into the chemistry, but if I can tell them this is what we observe in biology, and this is the reason. I just want them to be able to tie the pieces together, when they do learn about it. And I want them to be able to apply the information biologically. (Lesson study meeting four, 09/20/14)

This quote exemplified Clint's limited view on constructivism. He believed students should be exposed to the concepts of other subjects, so that they can assimilate the knowledge when they continue their education in other science courses.

This philosophy became apparent when Clint taught this lesson during the first iteration of the first cycle of lesson study. Clint introduced the phenol red activity to his students by explaining that phenol red was a chemical indicator. He stated that students were going to introduce an acid to the chemical indicator in order to see the color change, and he said the acid was going to come from their bodies. He asked his students how they thought that could happen. He then clarified to the class that when carbon dioxide is dissolved in water, carbonic acid is formed. He stated that when students breathe into the phenol red (which is mixed with water), they will be blowing carbon dioxide bubbles, which will change the color of the phenol red from red to orange. He explained this was because the carbon dioxide was going to dissolve into carbonic acid, which will lower the pH of the solution, causing the chemical indicator to turn from a red to an orange. He attempted to draw the chemical equation on the board, in order to explain how this occurred at the molecular level, but could not remember the formulas for the equation and stated that this was one of those things his students were going to have to "trust him on" (Researcher field notes, 09/18/14). This scenario demonstrated that Clint explained the chemistry behind the activity to provide the students with an explanation as to how the phenol red activity worked, but when he got to the specifics at the molecular level, he was unable to do so. Based on Clint's beliefs of student learning, he explained enough to give students a "layer of their learning," and the remaining layers could be added when they take a chemistry course.

Post-lesson study. Clint's goals for teaching emerged during his last weekly reflection on lesson study, in which he wrote:

> The expectations I had for teaching were based on my experiences as a student and I did not give very much thought to my methodologies. My approach to teaching before participation in the lesson study was to simply present the information and guide the students through the lab exercises. The lesson study has given me a new appreciation for teachers and the craft of teaching. Learning pedagogical techniques like concept mapping and the 5 E's has influenced how I

> prepare my lessons and gauge my students' understanding. The two most valuable lessons I will take away from the experience are the importance of inspiring interest and enthusiasm in students and the superiority of conceptual learning to rote memorization. I want to instill a sense of curiosity about the natural world in my students and to foster the creativity needed for the synthesis of new ideas in tomorrow's scientists and engineers. (Weekly written reflection 10, 11/03/14)

This quote suggested that as Clint began his teaching at the beginning of the semester, he had not given much thought to his approaches in instruction. He believed he should teach how he was taught, which was to present the information while guiding students as they work through the laboratory exercises. However, after participating in lesson study, he began to appreciate teaching in a different way, while learning a variety of instructional approaches to inspire students to become interested, enthusiastic, and curious about the natural world.

Clint was asked what he learned about teaching and learning during the lesson study process and he replied:

> Teaching is about finding out what students know and then adding to that and building off what they already know. It's not like you get everyone in the class to reach a certain bar. It's like everyone in the class is somewhere along the progression and the idea is to have everyone move up to some extent. They aren't going to move up the same amount. Also, tie the information that they know, instead of just having it like one dimension, like their test scores improve this much. I want them to understand about this concept and then tie that to five or six different concepts. That way, their understanding becomes not just facts about

> organisms or a group of organisms which is related to this. (Post-lesson study interview, 12/02/14)

This comment implied that Clint saw value in determining what students already knew, so that he, as the instructor, could build upon that knowledge. Furthermore, he felt that the goal of teaching was not to get all students at the same place, because he understood that each student came to this course with differing amounts of previous knowledge. With this in mind, Clint believed the goal of teaching should be to get each student to a higher point on the learning continuum. Finally, he thought that teaching was not merely about learning facts, but about introducing students to a concept in a way that will allow them to integrate what they learned into other concepts of biology.

When asked to give an example of how he revised his teaching, Clint responded:

> I focused a lot more on giving students a conceptual understanding rather than just checking off a list of topics [students] need to talk about. I learned some really good exercises like concept mapping and a lot of pedagogical techniques that I probably wouldn't have had access to had I not undergone this. (Post-lesson study interview, 12/02/14)

This quote suggested that Clint wanted to give his students a more conceptual understanding of biology. He felt that through participation in lesson study, he was exposed to instructional strategies and approaches that enabled him do this.

Summary. Clint was knowledgeable about several components of NOS, although he could not categorize them as NOS. Additionally, Clint believed that peers can be helpful in student learning and that students should understand science in a way that will help them make informed decisions about their lives. Furthermore, he felt as though learning occurred "in layers," and the role of an instructor of this course was to introduce students to concepts in order for them to have existing knowledge to build upon when they are enrolled in higher level chemistry and biology courses. Clint considered his role in teaching was not to get all students to the same level, because he recognized students came to class with differing levels of prior knowledge. Because of this, he believed his goal in teaching was to get each student at a higher level on the learning continuum. Because of lesson study, Clint believed he had revised his teaching by offering students a more conceptual understanding of biological topics, and felt as though he learned a variety of approaches in the lesson study in order to do this.

Knowledge of curriculum. During the lesson study team's first meeting, Shannon asked the group what were the big ideas that the team wanted students to know. Clint replied, "I want [students] to know that photosynthesis is a lot more complex than the formula, because that is what I remember learning in school, and when I got to Biology 1110, I was like, 'What is this?'"(Lesson study meeting one, 08/30/14). This statement suggested that Clint's goals for students learning photosynthesis needed to go beyond the formula that represents photosynthesis.

In trying to determine the goals for student learning during the photosynthesis lesson, the lesson study team decided to ask the lecture instructors to identify the aspects of photosynthesis on which the GTAs should focus. To this request, they received a study guide created by the lecture instructors over the topic of photosynthesis. When asked about his thoughts regarding the study guide, Clint responded, "The study guide was helpful in that I know what to spend more time covering and planning good analogies for" (Weekly reflection, 09/07/2014).

When Clint was asked about the outside reviewer's comments regarding the photosynthesis lesson plan created by the group, Clint responded, "It seems that it is important to have very specific learning objectives and activities that directly address these objectives. The best teachers I've had did exactly this" (Written reflection, 10/29/14). This comment suggested Clint saw value in establishing learning objectives and ensuring each aspect of the lesson addressed the specific learning objectives.

During the second lesson study cycle, Shannon again asked each participant to email the lesson study team the main ideas he/she wanted to emphasize while creating the protist/algae lesson. Clint's email to the other group members included:

- Students should understand protists in terms of biological diversity, ecology, reproduction, human health, industrial uses, and potential research fields.
- Students should understand various protist life cycles and reproductive strategies and understand the changes in ploidy in each stage.
- Protists are a diverse group of eukaryotic microorganisms and do not form a natural group. They use a range of unique reproductive strategies. Protists can have a large impact on the environment e.g. red tide, algal blooms etc. Some protists are implicated in human diseases such as malaria, Chagas disease, and sleeping sickness. Compounds like carageenan have found commercial use as food additives. Some species of dinoflagellates are being studied for their ability to produce lipid for use as biofuels.
- To gauge student understanding of protist life cycles, I will have them match ploidy to stages in the life cycle. I may need to give a brief recap of

> mitosis/meiosis and explain the pros and cons of sexual reproduction and multiple sets of chromosomes. (Email to lesson study team, 10/12/14)

The above learning objectives demonstrated Clint's ability to think about the specific objectives that are important for students to learn. When the group was deciding the learning goals from the compilation of each participant's email of learning goals, Clint stated:

> I think an important concept for them to get is that a gamete doesn't necessarily have to be unicellular, but it could be the protists or the algae's main—what you think of when you think of that organism. It could be large algae. . . . It doesn't have to be diploid to be big. (Lesson study meeting seven, 10/27/14)

This quote suggested that Clint understood the life cycles of protists, which can be different from life cycles of other organisms with which students are more familiar, such as humans.

When asked what changes Clint made to the curriculum before lesson study began, Clint talked about switching the order of problems the laboratory manual asked students to work. "I chose to use the simplest problem for a demonstration and gave them the more difficult problem to work on their own" (Written reflection template, 09/02/14). In the observation of this lesson, Clint followed the curriculum, highlighting key points using PowerPoint. The notes sent to the GTAs by Dr. Sturgeon included two examples of Chi-square goodness of fit problems. Clint went over the second problem with his students, and then had students perform the first problem on their own while still in class (Researcher field notes, 09/18/14).

At the end of lesson study, Clint answered the same question about curriculum by writing, "I focused less on the life cycles because I wanted to devote more time to describing the specimens and associating them with key words" (Written reflection template, 11/24/14). In the teaching of this lesson, Clint followed the curriculum that Dr. Sturgeon highlighted in the laboratory notes by using the laboratory manual with his students. Like Clint stated, he did not highlight the life cycle of fungi with his students (Researcher field notes, 11/13/14).

When asked what Clint found important for students to learn, he was able to articulate either broad goals (as in the planning of the photosynthesis lesson) or specific goals (as in the planning of the protist lesson). However, he did not make those learning goals and objectives explicit while teaching in the classroom. While teaching the NOS lesson (08/28/14), the photosynthesis lesson (09/18/14), and the fungus lesson (11/13/14), Clint did not display or discuss the learning objectives with students at any time. Clint followed the curricula highlighted by the laboratory notes/manual during the pre-lesson study observation, and mostly during the post-lesson study observation, with the exception of highlighting the life cycle of fungi.

Throughout the lesson study process, Clint demonstrated an understanding for goals for student learning. Clint thought the study guide created by the lecture instructors and the outside reviewer comments were helpful in the planning of his lessons. Furthermore, he followed the curriculum in both the pre- and post-observations with exception to a few instructional decisions. Finally, Clint expressed value in establishing specific learning goals for his students, but never explicitly stated these learning goals to his students.

Knowledge of student understanding. This section will be organized by Clint's experiences through pre-, during, and post-lesson study.

Pre-lesson study. When asked what students knew about NOS, Clint replied, "[Students] were familiar with some version of the scientific method and the steps involved. Most could give a good definition of hypothesis" (Written reflection template, 09/02/14). This suggested that Clint felt his students understood the steps of the scientific method and hypothesis. When asked what students typically struggled with when studying NOS, Clint replied, "Students were not familiar with hypothesis testing and related terminology. Some students did not seem interested and I heard one student say, 'This is so stupid.' Conveying the relevance of the scientific method was difficult to students that did not already appreciate it" (Pre-lesson study interview, 09/04/14). This suggested that Clint found it complicated to transmit the information to students who did not have an appreciation for the scientific method, and he possibly lacked the knowledge to motivate students who did not find the topic interesting.

During lesson study. One of the first aspects of teaching that Clint said he learned occurred during the first lesson study meeting and involved student understanding. In his weekly reflection over this meeting, Clint wrote, "I enjoyed learning about lesson study and discussing potential points of misunderstanding. Being able to anticipate misconceptions will have an immediate and positive effect on my teaching" (Weekly reflection one, 08/30/14). This quote implied that Clint saw value in knowing where students had misconceptions.

Clint's knowledge of student understanding surfaced again during the debriefing of the photosynthesis lesson. The lesson study team was discussing their observations of the sticky note activity. Team members noticed that some students were looking at other groups in order to correctly place their sticky notes. While discussing the modification of this in the second teaching of the lesson, Clint stated:

> The people that were participating are the ones that were comfortable with the information so it allowed the people that weren't quite as [comfortable] to just coast and rely on their group members. Because when I'm teaching I don't really notice when people are texting or – but I guess the more times they hear it, the better. So even if they're not actively participating, they're listening to the lesson plan and they're absorbing information, hopefully. (Lesson study meeting five, 09/26/14)

This comment suggested that Clint felt as though it was not easy for some of the students to learn the information, and they relied on their group members to complete the task. Despite this, Clint believed the activity was beneficial to these students. Based on his beliefs about student learning, the more times students are exposed to the information, the more likely they are to learn the content.

Post-lesson study. When asked what he thought about the sticky note activity, Clint responded:

> I liked that we could use [the sticky note activity] to gauge the student's understanding. The thing that I learned about that exercise and about teaching is that students don't want other students to know that they don't know something. To get through an exercise, they would put their post-it note where somebody else put it. It's like a psychology thing. Once you can get past being okay with not knowing something or having other people know that you don't know something,

> then I think you can learn so much more effectively. . . . When you struggle with something like how to figure out a math problem or knowing a concept or memorization, is when your mind kind of wrestles with it. Then you figure it out and you know it and that's when learning actually takes place. (Post-lesson study interview, 12/02/14)

This statement implied that Clint liked the sticky note activity because it could be used to ascertain a student's understanding. However, he noticed that when students did not know where to put their sticky note, they would look to see where other people put theirs. He felt that students should not be concerned with placing their sticky notes in the incorrect place, because the struggle of determining the correct placement of the sticky note was how learning occurred.

Because the lesson study team noticed groups of students looking at where other student groups placed their sticky notes, they decided to modify the activity. In the modification, each group of four students had their own poster. When asked if Clint thought if that helped, he responded:

> I do think breaking [the activity] up into smaller groups helps with the social problem because there is a smaller group and they are less uncomfortable about displaying what they do know or don't know. I think people are also more apt to communicate and give their reasoning. (Post-lesson study interview, 12/02/14)

The above quote implied that Clint believed the modification of the activity was helpful, because it allowed students to better communicate and give their reasoning in a smaller setting. He believed the new approach in the activity better met the needs of the students.

For the lesson over the topic of fungi, Clint was asked what students knew and what they struggled with when studying fungi. To this, Clint responded, "[Students] know about mushrooms and mold, but not much else. They had trouble learning the terminology and identifying structures on the microscope" (Written reflection template, 11/24/14). This implied that Clint understood where students had difficulty in their learning.

Summary. Clint could identify points of learning difficulty for students during the pre-lesson study lesson over NOS as well as the post-lesson study lesson over the topic of fungi. Additionally, Clint stated he knew when his students understood by asking them, although he realized that students are not always forthcoming with that information. Furthermore, Clint thought activities such as the sticky note activity were beneficial in gauging a student's understanding. He felt learning occurred when students struggled while placing their sticky note, and that the activity was more suitable in smaller groups. Based on his philosophy of student learning, Clint also felt the activity was beneficial for students who relied on their group members to answer for them; the more students are exposed to a topic, the better they understand.

Knowledge of assessment. Dr. Sturgeon required GTAs to administer a weekly quiz over the material students learned the previous session, in addition to four laboratory exams throughout the semester. During lesson study meeting two, Shannon mentioned to the group the idea of creating common quizzes for the photosynthesis lesson as well as common exam questions (09/05/14). Clint's response included:

> I told my students I don't want to test them over something that I didn't mention explicitly, and at least provide. . . . some sort of tangible [information], so they

> can go back and say, 'This is where I learned it,' and then study for [the quiz or test]. I know a lot of them aren't going to remember [the information] the first time I talk to them about it. So, I'm trying to be fair, but not a push over . . . . My tendency would be to write the test way too hard, because it's at my level of understanding. So then you have to take a couple steps back, but you don't know how many steps back you should take. (Lesson study meeting two, 09/05/14)

This comment suggested that Clint did not have knowledge of the dimensions to assess in science.

When asked how he knew if his students understood, Clint responded:

> I ask them, but you're not going to get many verbal responses from them. I have to determine based on whether I'm getting quizzical looks. I get some of those. Surprisingly enough, many people seem to not be paying any attention at all. (Pre-lesson study interview, 09/02/14)

When asked how he knew that students were not paying attention, Clint stated:

> [Students] were turned away from me and I had mentioned that I would have some version of the chi-squared problem on the test, and some of them tried to discuss it amongst themselves and figure it out while I was trying to explain it myself. I guess they thought they were better off asking their peers rather than [me]. (Pre-lesson study interview, 09/04/14)

The above quotes suggested that Clint checked for student understanding during the lesson, but did not expect many verbal responses stating whether students understood. Therefore, Clint gauged student learning based on looks the students were giving. In doing this, Clint noticed many students getting help from their classmates during his instruction, and therefore not paying attention to him. It is important to note during the teaching of this lesson, Clint asked a few questions to the class as a whole group, but did not go to individual groups to check for understanding (Researcher field notes, 08/22/14). During the teaching of the photosynthesis lesson, Clint did not visit various groups to assess student learning, but at the end of the lesson study during the teaching of the fungus lesson, Clint did formatively assess multiple groups (Researcher field notes, 11/13/14).

During lesson study meeting three (09/12/14), the lesson study team decided to utilize the 5-E learning cycle for the photosynthesis lesson. They had a component for every aspect of the 5-E's except for evaluation. The group was asked to reflect on strategies the team could use, and when those strategies should be utilized in the lesson. Clint responded:

> I think the best way to assess students' understanding would be to have them answer questions in essay form. It would be good to have [student] answers before and after the lesson. That way, we could see how their understanding changes after the lab. (Weekly reflection three, 09/26/14)

This comment suggested that Clint had knowledge of diagnostic assessment, since he suggested testing students before and after the lesson in order to determine student growth.

At the beginning of lesson study, Clint stated that he was able to determine students' understanding based on quizzical looks they gave. He asked the entire class questions, but did not go to individual groups to check for understanding. At the end of lesson study, Clint traveled to each group to check for understanding. Clint also demonstrated knowledge of diagnostic testing when mentioning strategies that could be used to assess students' understanding of the photosynthesis lesson. This demonstrated a growth in Clint's knowledge of assessment.

Knowledge of instructional strategies. This section will be organized by Clint's experiences through pre-, during, and post-lesson study.

Pre-lesson study. While completing the written reflection template, Clint stated he would explain the scientific method by defining it as well as giving examples, while students "hopefully" took notes (09/09/14). During the teaching of this lesson, Clint explained the steps of the scientific method using a PowerPoint presentation (Researcher field notes, 11/13/14). When asked if he noticed students taking notes, he replied, "I think there were actually a handful that did take notes" (Pre-lesson study interview, 09/04/14). He later stated that he believed that because he posted his PowerPoint online, students thought maybe they did not have to take notes (Pre-lesson study interview, 09/04/14). Clint stated that he wanted students to take notes so "they can listen to what I'm saying, because there is more information than what is on the PowerPoint. The PowerPoint is just a guideline for me to guide through lecture" (Pre-lesson study interview, 12/02/14).

In the written reflection template, Clint also mentioned he would ask students to create their own examples of experiments because some students needed to participate fully to understand concepts (Pre-lesson study reflection template, 09/02/14). Additionally, he stated he was going to give examples of faulty hypotheses and ask students for critiques. He stated this approach would "force the students to apply their own understanding and help them to identify gaps in their own knowledge" (Pre-lesson study written reflection template, 09/02/14). When observing the lesson, the researcher did not see evidence of either of these approaches in Clint's teaching (Researcher field notes, 09/02/14). When asked about this, Clint stated, "I wanted [students] to do that. I didn't expect them to have so much trouble with it, but I guess I should have accounted for that" (Pre-lesson study interview, 09/02/14).

The above quotes demonstrated that Clint utilized PowerPoint to deliver his instruction. He had planned to incorporate other components into his lesson, but because students were having difficulty, he abandoned the intended approaches to teaching.

During lesson study. Clint mentioned the idea of peer-tutoring several times during the lesson study process. He first mentioned this in the pre-lesson study interview when he expressed the importance of utilizing peers to help students learn (Pre-lesson study interview, 09/02/14). The idea emerged again during lesson study meeting three after Shannon exposed the lesson study team to the 5-E learning cycle. The team started having conversations about when and how to explain the experiments to the students. Clint suggested:

> Maybe we could have them teach each other, because when you have to teach something, you really have to understand the concept. And we could have a system [of asking] the people that really know it [to] come teach me. If I check them off, then they can go teach somebody else, and then they can certify them. (Lesson study meeting three, 09/12/14)

He explained his idea further by stating:

> I guess with that idea, you'd have to limit how much you try to teach them and get them to understand. I'd pick out maybe four or five key things and then have [students] be able to really understand that, and then teach the whole class. Then

> say, ‘From everybody in their group, whoever understands this the best, come up to me and then I want you to explain it to me.’ Then I’ll have a checklist. Even if I have to coach them a little bit, if I can just go through that and get them to explain their understanding to me. Then once I can certify that, they go back to their group and they have to do the same process. (Lesson study meeting three, 09/12/14)

Shannon asked Clint what the students who were not with the instructor doing at this point (Lesson study meeting three, 09/12/14). Clint responded, “Writing down what they don’t understand or why they don’t understand it. Having them come up with their own questions to ask their coach or mentor” (Lesson study meeting three, 09/12/14). The group agreed they would try this approach, since Clint was the lesson study team member who was teaching the first iteration of the photosynthesis lesson. Shannon asked Clint to type a description of his approach to this, in order to put in the lesson plan. Clint did not send a written explanation of this approach for the lesson plan over photosynthesis. As a result, the lesson plan did not include this portion of the lesson.

During the teaching of the photosynthesis lesson, Clint modified this approach from the initial discussion and asked students to form into groups based on the topic they felt most comfortable discussing. Clint assigned a location in the laboratory for six topics, and students formed into groups. In their groups, students were asked to discuss the topic with their peers and write a summary about that topic to present to the rest of the class (Researcher field notes, 09/18/14). When asked about changing his approach, he responded:

> I think peer mentoring would be a lot better technique for maybe a skill or a technique that [students] could learn rather than something conceptual, just because concepts are something you either get or don't get, it's not so gradual. There are pieces that help you get to the final point, but it's kind of just like it clicks and you understand it. There are many ways of explaining. Then there are also some problems to that because if [students'] understanding of [the concept] is incomplete, then they could pass along erroneous information and that just does them a disservice. I do still like the idea, but it has to be specific for the activity we are doing. If there was a lab technique, I think that would be an excellent strategy. (Post-lesson study interview, 12/02/14)

The above scenario suggested that Clint found value in peer tutoring, and he offered an approach to this in the lesson. However, this approach was never explicitly described in writing, and it was not completely clear as to what this would look like in the actual lesson. During the lesson, Clint modified the peer-tutoring activity because he felt this teaching approach would be difficult for students in understanding conceptual information. Therefore, the approach became a collaborative summary that each group presented to the rest of the class.

When asked when he made the decision, Clint responded, "I have an idea in my head of how a lesson is going to go, and sometimes it completely changes and I just go with whatever is working the best" (Post-lesson study interview, 12/02/14). This suggested that Clint changed the approach because he felt a modification was needed to best meet the needs of his students.

Post-lesson study. For the post-lesson observation, Clint first stated that he would describe the various taxa while students took notes and described the different structures associated with each group. Next he would show pictures along with microscope slides and the larger specimens while students viewed or held the specimens and drew pictures. Finally, Clint explained he would relate how the different groups of fungi affect humans, while the students associated previously known concepts with new biological concepts. The rationale behind this last strategy was that many students already knew about the byproducts of fungi, but may not have connected the two ideas (Post-lesson study reflection, 11/24/14). When asked to elaborate on this final step of the lesson, Clint stated:

> I told [students] about Alexander Fleming and the discovery of penicillin and antibiotics and how big an impact that had. I also told them about black mold and how they should watch out for that in remodeling an old house and how it could cause health problems. I told them how a lot of fungi are saprophytic and they're decomposers helping break down food and return biomass to the food. (Post-lesson study interview, 12/02/14)

In addition to the above examples of how fungi affect humans, Clint also mentioned Saccharomyces, commonly known as yeasts, and explained how bread and alcohol are made by using yeasts (Researcher field notes, 11/13/14).

During the teaching of this lesson, the researcher noticed Clint did not utilize a PowerPoint presentation, like he did during the teaching of the first lesson. When asked about this, Clint replied:

> I started posting PowerPoints at the beginning of the semester and I found that nobody was paying attention in my lectures. My PowerPoints aren't really that descriptive. It's just to compliment my lecture. When I realized nobody was really listening, I started posting the PowerPoints after my lecture and I saw some of the students, at least, taking some notes.

The above statement suggested Clint stopped posting his PowerPoint presentations before the lecture. However, he did not state that he stopped using PowerPoints in class. The researcher noticed that Clint did not use a PowerPoint presentation while teaching the photosynthesis lesson (09/18/14) or the lesson over fungi (11/13/14).

As mentioned previously, Clint changed his approach during the teaching of the photosynthesis lesson, because he had an idea of how a lesson should go, and sometimes it changed based on his perceptions of what worked best for his students (Post-lesson study interview, 12/02/14). Another example of how Clint changed his approach during the lesson occurred during the teaching of the topic of fungi. At the beginning of class, Clint gave students a study guide that incorporated each phylum, common name, and genera of the fungus the students were observing. On the study guide there was a place for students to write notes about each phyla's life cycle, special characteristics, and description. On the back of the study guide, there was a list of terms related to fungi. After distributing the study guide, Clint highlighted the keywords and told the students they would be completing a concept map together (Researcher field notes, 11/13/14). After talking about each phyla of fungi, Clint asked students to get out a sheet of paper and to write at the top or middle of the paper the term "fungi." He then asked students to write the four major phyla of fungi down on the paper, and he stated they were going to associate the different words on the back of the study guide to each phyla of fungi. He began by asking students to look up the first word, *dikaryotic,* and tell him what it meant. Students found the word meant "two nuclei." He then asked students if they found the term *karyogomy* in the source that they found the meaning of the word, dikaryotic. No one responded, so he asked students to turn to a page in their laboratory manual, so they could determine what karyogomy meant. He read the sentence from the laboratory manual, and then stated the two phyla for this term (i.e., Ascomycota and Basidomycota). He then continued to the next word, which was *coencytic*.

At this point, a student raised her hand and asked a question which was inaudible to the researcher. To the student's question, Clint explained that they were sorting through these words and putting them in their phyla. He continued by telling students what the next word, coencytic, meant, which was "multiple nuclei." He then mentioned this happened in a lot of fungi, and went to the next word, *parasitic.* He asked students what parasitism was, in which a student answered correctly, and then he restated the definition of parasitism, and compared parasitism to other relationships between species such as commensalism. He then went to the next word, *spores*, and asked students where on the concept map they would put spores. He continued through the rest of the list, but not in order. He never asked students where they thought the terms went or explained to students where the rest of the terms fit on their concept map. There was no time between the explanations of each word for students to determine the placement of each word on their own.

On the post-lesson study template, Clint mentioned the concept map when asked about other teaching strategies he considered. "I considered having the students make a concept map, but I decided to have a list of key words that we covered and associated with a particular specimen" (11/24/14). In the post-lesson study interview (12/02/14), the researcher stated that she remembered Clint doing a concept map, but saw on the reflection template that he said he was not going to do a concept map. According to her researcher field notes, he told the class they were going to do a concept map together, and then attempted to do so. Clint responded:

> I ended up not having them do a concept map. Initially, I wanted them to, but then there was so much new terminology that I just wanted them to know what the word meant. I felt like the branches of the diagram would have gone in a lot of different directions and ideally you want there to be kind of like one key idea and branches that go off of that like a root or a tree. (Post-lesson study interview, 12/02/14)

When asked if he made the decision in the middle of class, Clint replied:

> I asked them if they wanted to, while taking notes, make a concept map. I still think they were a little hesitant to do it. I wanted them to do whatever they would actually do. We went over the study guide together. I went over each of the terms and then showed them the specimens. (Post-lesson study interview, 12/02/14)

The above scenario suggested that Clint intended to have students create a concept map together as a class. However, at some point while he was trying to lead the class in making their concept map, Clint decided to abandon making a concept map because he stated he wanted to ensure students understood the meaning of each term. However, the researcher did not realize he abandoned the concept map, until she asked for clarification from Clint about the discrepancy between the written reflection template and what she observed in the teaching of the lesson.

In the post-lesson study interview, Clint was asked if he would use any of the strategies the next semester, Clint replied, “I will. I will try and incorporate the group teaching, concept mapping, and the post-it note exercise. I liked not being confined to the exercises that you were given” (Post-lesson study interview, 12/02/15). This statement about not being confined to exercises may address why the researcher noticed Clint changing his approach during the teaching of the NOS lesson, photosynthesis lesson, and the lesson over the topic of fungi. Before teaching each lesson, Clint mentioned instructional strategies that he was going to utilize. However, during each lesson, Clint chose to change, abandon, or omit the strategy he initially said he was going to perform.

When asked about the instructional strategy of incorporating articles that the lesson study team used in the protist lab, Clint responded:

> I like the idea of getting [students] interested in the topic, but I don’t think [students are] conditioned or motivated to read. The higher up you get, the more and more you realize that reading is what you do to learn things, but they kind of like to be spoon fed. Maybe a video would be good. I want to foster their ability to read and learn for themselves, but maybe a cool video would be a good idea for engaging. You’re reading text, then visualizing and thinking about it, but when you see a video, you see it happening, hear it, and then it’s a lot more accessible. (Post-lesson study interview, 12/02/14)

These comments suggested that Clint found value in introducing students to the articles, but he felt as though it was not a successful strategy for student engagement. Clint believed a video would be more engaging, and did show students a cordyceps video that demonstrated the fungi growing out of insect heads after the insects ingested the spores (Researcher field notes, 11/13/14).

When asked how his students responded to the different instructional approaches, Clint replied:

> I had mixed reactions. I think a lot of it has to do with the expectations that I set and they didn't necessarily know what they were coming into in the classroom. I think if you implement any of the strategies at the beginning of the semester, then [the strategies] will be more effective. That way, they'll know, coming in, how they are going to be taught. (Post-lesson study interview, 12/02/14)

This suggested that Clint believed that instructors should establish classroom routines and expectations for class instruction at the beginning of the semester and apply these consistently in order for the strategies to be more effective.

Summary. At the beginning of the lesson study, Clint utilized PowerPoints to deliver the material to his students and did not deviate from the lesson that was in the laboratory manual. He had hoped students would take notes, but noticed that they did not. He believed this was because the PowerPoint presentations were posted online. By the end of the lesson study, the researcher did not observe Clint using a PowerPoint. Clint stated he no longer posted his PowerPoints online before the lesson because he noticed students were not listening during class. Throughout the lesson study process, Clint mentioned several times that students could benefit greatly from their peers, and he believed peer-tutoring was an instructional strategy that could highlight this. During his first attempt at engaging students in peer-tutoring, Clint modified the activity based on meeting the perceived needs of his students. Clint stated that he typically envisioned how lessons would be enacted, but sometimes realized during the lesson that he needed to adjust the approach to better meet the needs of his students. The researcher noticed this tendency to change instructional plans during the post-lesson study observation over the topic of fungi while creating a concept map. Clint found value in many of the instructional strategies the lesson study team utilized, and planned to use the concept mapping, group teaching, and sticky note activity in future semesters.

Cross-Case Analysis

This section presents a synthesis of the findings from each embedded case within the broader case of the lesson study team. It begins with an analysis of each component of PCK and how it emerged across the analytic unit of the case (the lesson study team). Then, an analysis of common themes that occurred throughout the lesson study process across the case will be presented.

Orientations toward science teaching. This section is organized by participants' conceptions of the sub-components of orientations toward science teaching: the Nature of Science, science teaching and learning, and goals of science education. As noted by Magnussen et al.'s (1999) model of PCK, these three aspects are the critical sub-components of orientations toward science teaching.

Conceptions about the Nature of Science. The first lesson of the semester was titled Understanding the Nature of Science, which was a special insert that was developed by Dr. Sturgeon and added to the laboratory manual for the course. The purpose of the exercise was to "introduce [students] to the process of science by posing a question and then taking [students] through the Scientific Method in order to answer that question"

(Vodopich & Moore, 2014, Activity One). The lesson in the manual did not mention the categories of NOS as categorized by Lederman et al. (2002). Due to her background in science education research, Shannon was the only participant of the lesson study team who could explicitly state the aspects of NOS, and recognized that the lesson focused primarily on the empirical nature of science (Shannon, Pre-lesson study interview, 10/03/14) at the expense of other components.

Spencer stated he had never heard the term NOS before, (Spencer, Pre-lesson study interview, 09/11/14) and both Grace and Clint believed the terms NOS and scientific method could be used interchangeably, (Grace, Pre-lesson study interview, 09/04/14; Clint, Pre-lesson study interview, 09/04/14), an idea not currently supported in the literature. Additionally, Grace and Clint discussed that scientists are always revising their ideas, which can be categorized by Lederman et al.'s (1992) tentative but durable aspect of NOS, but neither could explicitly identify this as an aspect of NOS.

The lesson in the laboratory manual was titled NOS, but focused on just one aspect of NOS. Because of this, the participants, other than Shannon, primarily focused on this one aspect of NOS, which limited their understanding of this construct of orientations toward science teaching.

Conceptions about the goals of science education. During the lesson study meetings, Shannon expressed that the reflections that she had been completing as a result of participating in the lesson study process had enabled her to see that she was a constructivist and that she wanted her students to do more than "cookbook labs" (Shannon, weekly reflection, 09/09/14). During lesson study meeting three, Shannon decided to introduce the 5E learning model to the lesson study participants in order to guide the participants from a teacher-centered approach to a student-centered learning environment as well as to get them to "think about how [the lesson study team] can question students rather than tell them" (Shannon, written reflection, 09/12/14). Shannon mentioned the concept that "telling is not teaching" several times within the learning cycle process. This idea did not seem to translate to Clint who stated in the post-lesson study interview:

> I like telling [students] what they need to know because I understand their main concern is they have an exam and want to do well on it. I want to tell them everything they need to know for the exam. Then, I want to give them extra stuff to peak their interest. (Clint, post-lesson study interview, 12/02/14)

From the beginning of the second cycle of lesson study over the topic of protists/algae, Shannon introduced the idea to the lesson study team about utilizing strategies that challenge students to think about the relationship of organisms (Lesson study meeting five, 09/26/14). In her written reflection she discussed concept mapping as a strategy in obtaining this goal. "When [students] start with a big picture understanding, [they] can learn almost anything" (Shannon, written reflection, 10/16/14). Shannon's beliefs were aligned with constructivist approaches that reflect the belief that meaningful information is constructed by learners rather than given to them by the teacher (Lefrancois, 2006).

This idea seemed to translate to both Grace and Clint during the process of lesson study. Grace discussed how her philosophy of teaching changed over the course of the semester: "Instead of throwing information at students and expecting them to simply absorb and memorize the information, I want the labs to be fun and full of discovery and more interactive" (Grace, written reflection 11/04/14). Similarly, Clint acknowledged that he revised his teaching after participation in lesson study by focusing more on giving students "conceptual understanding rather than just checking off a list of topics [students] need to talk about" (Clint, post-lesson study interview, 12/02/14). In spite of this, Clint also mentioned that he wanted to "tell students what they need to know" which would not be aligned with a constructivist philosophy (Clint, post-lesson study interview, 12/02/14). Therefore, Clint may hold a transitional view that conceptual understanding is superior to rote memorization, but may be confined to instruction that is instructor-centered rather than student-centered.

In contrast, Spencer believed his goal in teaching was "to present [students] with as much relevant information about the topic as I could and be able to answer any pertinent questions [students] might have" (Spencer, post-lesson study interview, 12/04/14). This statement implied that Spencer's goal was in contrast with the other participants' goal of providing students with a conceptual understanding of the topics of science. Overall, Shannon's view of constructivism seemed to guide both Grace and Clint to focus more on conceptual understanding with their students, but not with Spencer.

Furthermore, Shannon's goal was to guide the other participants to the understanding that "telling is not teaching" and that the lesson study team should design lessons that focus on student-centered instruction instead of teacher-centered instruction. Shannon's beliefs were aligned with constructivist approaches to teaching and were aligned with *Vision and Change* (AAAS, 2011) which states science courses in undergraduate education should be developed around inquiry and investigative experiences for all students. The authors recommend designing instruction that is student-centered in order for students to shift from the role of listener to that of active learner. Both Grace and Clint saw the value in this type of instruction, but may not be able to fully implement since Clint still held a belief that he wants to tell students what they need to know.

Conceptions of science teaching and learning. Participants had differences in beliefs when discussing the role of the teacher and the role of the student. Shannon believed the role of the teacher was “to quickly figure out what [students] know and what they don’t know - and give them what they need” (Shannon, written reflection, 10/05/14). Alternatively, Clint felt that his role as a teacher was to “lay down layers” of students’ learning because their “conception of an idea gets more and more complex the more they encounter it” (Clint, lesson study meeting four, 09/20/14). Additionally, Clint felt his role was to “instill a sense of curiosity about the natural world. . . . and to foster the creativity needed for synthesis of new ideas” (Clint, weekly written reflection, 11/03/14).

Both Shannon and Clint expressed a more developed conception about teaching and learning than Grace or Spencer. Grace believed the role of the teacher was to “present [the material] the best we can. . . . but [students] do have a responsibility to study and put in effort (Grace, pre-lesson study interview, 09/04/14). Spencer felt the role of the instructor was not as important as the role the student played. “There’s only so much an instructor can do, I’ve realized. Students must be willing to do work outside of class in order to learn” (Spencer, written reflection, 10/16/14).

Both Shannon and Clint stated the goal for students’ learning should be to produce informed citizens in society. Shannon stated to other lesson study team members, “If we don’t have an informed populous about where a tree’s mass comes from, [students] can't understand climate change, they can't understand how to mitigate climate change, [and] they can't understand policy about climate change" (Shannon, lesson study meeting three, 09/12/14). Similar to Shannon, Clint claimed he wanted his students to understand science in a way that they could question information so that when encountering issues such as "making decisions about products on an infomercial ad, [they can decide] if it's a scam. . . . [Understanding science] can help with their health when they talk to doctors or to pseudoscience" (Clint, pre-lesson study interview, 09/04/14). Neither Grace nor Spencer expressed similar or contrary views to Shannon and Clint for their beliefs in students' goals for learning.

Overall, both Shannon and Clint felt the role of a teacher was valuable to student learning. Shannon felt it was important to determine the tools her students needed, and provide those tools, while Clint believed it was important for instructors to "lay down the layers" for students in their learning. In contrast, Grace felt the role of the teacher and students were relatively equal, while Spencer believed the teacher played a limited role, if the student did not do work outside the classroom.

Summary. As the facilitator of lesson study, Shannon felt it was important to guide the participants to an understanding that "telling is not teaching" and to introduce teaching strategies that were more student-centered in their approach. She believed more emphasis should be placed on conceptual learning than rote memorization. Both Grace and Clint seemed to gain an understanding of this viewpoint: Grace in claiming her teaching had become more interactive, and Clint by claiming he had revised his teaching to a more conceptual understanding of the topics. Despite expressing this view, Clint stated he wanted to tell students as much as they needed to know in order to do well on examinations. Spencer did not mention this view of teaching, perhaps because he placed a majority of the responsibility for learning on the student.

Knowledge of curriculum. This section is organized by participants' knowledge of curricular materials and participants' knowledge of learning goals and objectives. The knowledge of curricular materials includes the study guide created by the lecture instructors as well as the laboratory manual and instructor's notes created by Dr. Sturgeon.

***Knowledge of curricular materials*.** The curricula that were available to the GTAs included the laboratory manual and the notes from Dr. Sturgeon. The notes included activities the GTAs should perform, procedural information, important terminology, specimens to observe, explanations of how to prepare extracts, and cautionary statements about laboratory safety. In addition to these sources, the lesson study team decided to seek input from the instructors who taught the lecture portion of this course. To their request, they received a study guide that was created by the instructors over the topic of photosynthesis. This section will discuss the study guide written by the lecture instructors and the laboratory manual/notes written by Dr. Sturgeon.

Study guide created by lecture instructors. During the first lesson study meeting, Shannon expressed to the other participants that the first goal the team needed to accomplish was to think about the main concepts of photosynthesis and determine "what do we want [students] to know, and how do we design a lesson that touches on that and helps [students] understand?" (Shannon, lesson study meeting one, 08/30/14). In deciding these goals, the team decided to refer to the following three sources: the literature to determine common misconceptions; the faculty who taught the lecture portion of the course; and Grace, who identified common difficulties that students had in previous years.

The faculty who taught the course created a study guide for students that highlighted the key aspects of photosynthesis that were discussed in lecture (see Appendix H). Each lesson study participant acknowledged the study guide as an important factor in their understanding of the curriculum for the laboratory portion of the course. Shannon confirmed, “This type of information could be very useful for EVERY lab to assist TAs (both novice and experienced) with better planning and teaching” (Shannon, weekly reflection, 09/02/14). When discussing the study guide during a lesson study meeting, Grace acknowledged that the study guide had a lot of focus on the electron transport chain and stated that she had never mentioned electron transport chain before. “Maybe we should try to relate all of these things to [the electron transport chain] and tie it all in” (Grace, lesson study meeting two, 09/05/14). Similar to Shannon and Grace, Clint found the study guide valuable and believed it helped him understand “what to spend more time covering and planning good analogies for (Clint, weekly reflection, 09/07/14). Spencer also thought the study guide was helpful in planning the lesson and stated, “[the study guide] covered several topics that are important for the student to learn” (Spencer, written reflection, 09/08/14). The above statements demonstrated that the study guide created by the lecture instructors seemed to clarify the curriculum for all participants.

Laboratory manual and instructor notes. Each participant followed the curriculum outlined by the laboratory manual and instructor notes during the pre-lesson study observations. However, the approach each participant utilized varied. Shannon stated that although she followed the curriculum for the NOS lesson, she regretted it because she felt like it "hindered student understanding" (Shannon, pre-lesson study interview, 10/03/14). She then discussed how the curriculum focused a lot on hypothesis questioning, and not enough focus was placed on formulation of a research question, which highlighted Shannon's knowledge of curricular saliency. During the post-lesson study observation, Shannon claimed she made changes to the curriculum whenever she thought the material was too confusing for students.

> The changes I make aren't with the content, but instead are how I would present the information. For example, if all students do is look at something under a scope, they aren't likely to understand the big idea of what we want them to know. I add or change the activity to make sure that students are given everything they need to learn what I want them to learn—I won't leave it up to them (Shannon, post-lesson study written reflection template, 12/02/14)

This quote indicated that the changes that Shannon made in the curriculum occurred when she felt that students needed another approach in order to gain a better understanding of the content.

At the beginning of the lesson study, Grace stated that "the curriculum in the laboratory manual was set up to be read aloud, along with notes on a white board. I use my own PowerPoint instead of reading from the curriculum" (Grace, pre-lesson study written reflection, 08/30/14). Grace commented that she created her PowerPoint presentations from the laboratory manuals, but did not necessarily teach from it (Grace, pre-lesson study interview, 09/04/14). She then claimed she did not use the manual, and that she showed her students where the material was in the manual, but "instructs them on everything and all the procedures and walk [students] through it" (Grace, written reflection, 09/12/14). By the end of the lesson study, Grace did not use PowerPoints or the laboratory manual during her instruction (Grace, researcher reflection, 11/16/14). During the post-lesson study observation, Grace said she changed the curriculum in order to make the class more "hands-on and active" (Grace, post-lesson study written reflection template, 08/30/14).

Unlike Shannon and Grace, who elected to modify the delivery of the lesson, Spencer claimed he followed the curriculum in the laboratory manual because "I've never taught [the material] before so I didn't really know what the best way to do it was" (Pre-lesson study reflection template, 09/02/14). When asked about how he changed his curriculum in the post-lesson study observation, Spencer said he "engaged the students and they worked together" (Spencer, post-lesson written reflection template, 12/04/14).

When asked about changing the curriculum at the beginning of lesson study, Clint discussed switching the order of two practice problems that were included in the instructor notes. At the end of lesson study, Clint stated he focused less on life cycles because, "I wanted to devote more time to describing the specimens and associating them with key words" (Clint, written reflection template, 11/24/14).

Overall, each participant did not deviate from the curriculum at the beginning of the lesson study. Clint and Grace mentioned small changes made, but these changes were minimal. At the end of lesson study, Grace, Spencer, and Clint discussed instructional decisions they made to the curriculum in order for students to become more engaged, to interact, or to devote more time to associating the specimens to key words. In contrast, Shannon stated any changes she made to the curriculum also involved instructional changes, but for the purpose of helping students understand the material.

Knowledge of goals and objectives. From the beginning of lesson study, Shannon explicitly stated both learning objectives and guiding questions to her students. She continued to do this during the protist/algae observation (10/30/14) as well as the fungus observation (11/13/14). During the first lesson study meeting, Shannon directed the team to create learning objectives by asking them to think about what was important for students to learn. Clint mentioned that he felt it was important for students to understand that there was more to photosynthesis than the formula that represented photosynthesis. From this idea, the lesson study team created a lesson that engaged students to think about what aspects of the photosynthesis equation each activity represented.

During the second cycle of lesson study, Shannon asked the lesson study team to email their thoughts about what was important for students to know about protists/algae, based on a guideline provided by Dr. Sturgeon. Grace did not submit learning goals, and Spencer deferred to the key points Dr. Sturgeon stated. Clint, however, produced a response to what he believed were key points the lesson study team should address when planning this lesson. During the next lesson study meeting, the team determined the guiding questions based on Clint's response and the ideas of Dr. Sturgeon. In determining these goals, Shannon stated to the lesson study team:

> A learning objective should be something that [students] look at and can answer. So they can put in the form of a question. I call those guiding questions. . . .so you should be able to convert that objective into an actual question that is testable and

measurable and you can easily see if they get it or they don't. (Lesson study meeting seven, 10/27/14)

Clint stated, "It seems that it is important to have very specific learning objectives and activities that directly address these objectives. The best teachers I've had did exactly this" (Clint, written reflection, 10/29/14). However, during classroom observations, Clint was not explicit in stating these learning goals for his students. Neither Grace nor Spencer stated learning objectives for their students either.

Summary. All of the participants of the lesson study team believed the study guide created by the lecture instructors was helpful in guiding their planning of the lesson. Each participant followed the curriculum outlined in the laboratory manual at the beginning of lesson study, even though each had a different approach. At the end of lesson study, all of the participants stated they made instructional changes. However, each participant stated a different reason for this: Shannon stated for the purpose of helping students better understand; Grace for the purpose of engaging students; Spencer tried to make the class more interactive; and Clint said he made the changes to devote more time to associated key words to the specimens. Shannon was the only participant that explicitly stated learning objectives to her students. She guided the other participants to establish clear learning goals during both cycles of the lesson study, but none of the other participants explicitly stated these learning goals to their students.

Knowledge of student understanding. This section is organized by student misconceptions and other student difficulties, which include abstract ideas or concepts that lack connection to students' common experiences (Magnusson, Krajcik, & Borko, 1999).

Student misconceptions. From the beginning of lesson study, Shannon engaged students in activities in order to ascertain their prior knowledge. For example, in the NOS lesson, she had students form groups in order to answer the question “What is science?” She did this to gauge where [students] are and assess whether their ideas are informed or naïve” (Shannon, pre-lesson study written reflection template, 09/29/14). She claimed she had always had an understanding of where students typically have learning difficulties; however, she realized after searching the literature, that “there is a lot of work that has been done on misconceptions and I think that I have not delved into this area in my teacher preparation or my practice enough” (Shannon, written reflection, 09/04/14).

Shannon discussed the importance of knowing student misconceptions during the first lesson study meeting when she stated, “We want to think students come to us as these blank slates and we can give them knowledge, but if you don’t take into account what they know. . . . they’re never going to change [their thinking]” (Shannon, lesson study meeting one, 08/30/14). Shannon’s beliefs seemed to transfer to Clint, who stated in his weekly reflection after this meeting that “being able to anticipate misconceptions will have an immediate and positive effect on my teaching” (Clint, weekly reflection one, 08/30/14). When using the sticky note activity to assess student learning, Clint noticed several students struggling to identify the correct placement of the sticky note. He stated that during this struggle of determining the correct placement was “how learning actually takes place” (Clint, post-lesson study interview, 12/02/14). Despite this, there were no incidences during the post-lesson study lesson over fungus in which Clint assessed students’ prior knowledge about the topic of fungi.

In the literature, Shannon found four major misconceptions regarding photosynthesis that included:

1. the majority of a plant's mass comes from soil or a visible component;
2. plants do not respire or only respire at night;
3. leaves reflect all green light, or do not use green light in photosynthesis;
4. glucose is the major product of photosynthesis.

During their post-lesson study interview, each participant was asked whether the photosynthesis lesson that the team created addressed each of these misconceptions. The responses for each misconception follow.

The majority of a plant's mass comes from soil or a visible component. At the end of the lesson, the lesson study team did not feel as though the students had a full understanding that the mass of a tree came from carbon dioxide instead of soil and water. Shannon felt that their lesson did not "wrap-up and do the synthesizing we needed at the end to get that to hit home" (Shannon, post-lesson study interview, 12/09/14). Like Shannon, Grace felt that not every student understood because "I asked that question on the exam and it was about half and half" (Grace, post-lesson study interview, 12/02/14). Likewise, Spencer thought that students should have understood but that he was "not sure if the students grasped [it] or not" (Spencer, post-lesson study interview, 12/04/14). Unlike the other lesson study participants, Clint believed the students understood the mass came from carbon dioxide, but he "doesn't know if [students] understand why" (Clint, post-lesson study interview, 12/02/14).

Plants do not respire or only respire at night. Most of the participants believed the lesson did not address or completely address this misconception. Shannon felt the lesson did not address that misconception (Shannon, post-lesson study, 12/09/14). Grace said, “Maybe. I remember we talked about how plants are always respiring. I’m not sure if [the lesson] really drove it home” (Grace, post-lesson study interview, 12/02/14). Alternatively, Spencer claimed, “That should be clear. I think we clarified that” (Spencer, post-lesson study interview, 12/04/14). Clint said he did not talk about that misconception “as much” (Clint, post-lesson study, 12/02/14).

Leaves reflect all green light and do not use green light in photosynthesis. All of the participants felt as though their lesson addressed this misconception. Shannon stated, “The summary paragraphs at the end of the lesson, along with my own assessment, demonstrated students’ understanding of this misconception” (Shannon, post-lesson study interview, 12/09/14). Similar to Shannon, Grace believed the graphs that students created from the spectrophotometer demonstrated that “some light was used in the green spectrum, but just not as much” (Grace, post-lesson study interview, 12/02/14). Likewise, Spencer claimed, “I made sure [students] knew. . . . we covered the wavelengths of light. . . . I feel like we focused on that enough” (Spencer, post-lesson study interview, 12/04/14). Finally, Clint felt that “the pigment activity helped [students] understand what pigments do. I think that probably helped them” (Clint, post-lesson study interview, 12/02/14).

Glucose is the major product of photosynthesis. There were mixed reactions with this misconception. Shannon and Spencer did not believe the photosynthesis lesson they created helped with this misconception. Shannon commented:

> I don’t think [students] got that. I think we actually may have perpetuated that misconception. . . .We didn’t go into any detail about the biochemistry and what

> the plant does after it makes the glucose. Some of my students were asking me about that. I realized we didn't even go into that. So they have no idea what we take that molecule and do with it to make all the cool things that plants do. (Shannon, post-lesson study interview, 12/09/14)

Spencer stated, "Maybe not so much with that one" (Spencer, post-lesson study interview, 12/04/14). In contrast, Grace and Clint believed the lesson addressed this misconception. Grace liked how Clint talked about how "glucose is not only used for food, but it is also used for their cell walls and turned into cellulose" (Grace, post-lesson study interview, 12/02/14). Clint felt that the lesson helped students understand that "sugars were the end product" (Clint, post-lesson study interview, 12/02/14).

Summary. All participants were in agreement of student understanding with two misconceptions: *the majority of a plant's mass comes from the soil* and *leaves reflect all green light and do not use green light in photosynthesis*. As to the other misconceptions, Spencer was the only participant who believed students understood that plants respire at night, and Grace and Clint believed the photosynthesis lesson addressed the misconception that glucose is the major product of photosynthesis. It is important to note that most responses from participants did not acknowledge assessing students' knowledge of misconceptions. Shannon and Grace were the only participants that mentioned assessment when discussing student understanding.

Other learning difficulties. Grace demonstrated knowledge of students' learning difficulties throughout the lesson study process and supported the lesson study team in considering these difficulties throughout both cycles of the lesson study. During the first lesson, she understood that students get the terms null and alternative hypotheses backwards, so she tried to "stress the terms as much as possible" (Grace, pre-lesson study interview, 09/04/14). During the first lesson study cycle, she created a list of student difficulties (Email correspondence to lesson study team, 09/03/14) and pointed out student difficulties with understanding life cycles while the team created the lesson for protists (Lesson study meeting six, 10/03/14). Her knowledge of student difficulties during the photosynthesis lesson contributed to the chromatography activity the team implemented in the first iteration of the photosynthesis lesson.

> Grace: I think the hardest part is explaining to them why we care about the Rf value. How are they going to use it?
>
> Shannon: Why do we care about it? Why should they care about it?
>
> Grace: I told them that it can be used in forensic science. A lot of them are forensic science majors.
>
> Shannon: Like with DNA movement, or.
>
> Grace: Or ink.
>
> Shannon: Ink? I had an idea. You can take a marker and a coffee filter and you put a big dot of black marker and then you let the water dissolve—make sure it's a washable marker. Would that help them understand what we're doing as an analogy? Because they're familiar with markers. They're not familiar with pigments. They're familiar with water as a solvent. They're not familiar with acetone.

After this conversation, the team decided to implement a marker chromatography as an "engage" portion of the photosynthesis lessonto help students make connections with substances that are more familiar.

Summary. From the beginning of the lesson study, Shannon was the only participant who provided evidence of understanding the value of being aware of student misconceptions before the planning of the lesson. Shannon guided the other participants to use misconceptions in the literature in order to plan the photosynthesis lesson. Each participant had a different belief about whether the lesson they created addressed each of the misconceptions that was found in the literature. Grace and Shannon were the only participants who mentioned assessment when discussing student understanding. The two misconceptions that participants agreed that students understood included *the majority of a plant's mass comes from soil* and *leaves reflect all green light and do not use green light in photosynthesis.* Grace, being the only participant who had previously taught this course, was the only participant who demonstrated knowledge of other student difficulties and informed the lesson study team of these difficulties throughout the lesson study process.

Knowledge of assessment. Shannon demonstrated knowledge of formative assessment during the pre-lesson study NOS lesson as she went to each table to ask students if they could write a null and alternative hypotheses (Shannon, researcher field notes, 09/29/14). This knowledge of assessment continued during the lesson study meetings as the team discussed the lesson plan that was missing an evaluation component. Shannon discussed with the team a strategy that could be used to relate each activity of the lesson to the appropriate component of the photosynthesis equation. "I was really trying to think. . . . How do we make sure [students] connect [the activities] to the big idea?" (Shannon, lesson study meeting four, 09/05/14). Shannon then explained her idea of connecting certain words from each activity of the lesson to the component of the photosynthesis equation using sticky notes.

When asked about their thoughts regarding the photosynthesis sticky note activity, the other three participants stated that they liked the activity. However, Grace and Spencer did not mention the sticky note activity as a method of assessment. Grace stated, “I’m thinking from the beginning of every lesson, I’m going to try to do something interactive like that” (Grace, post-lesson study interview, 12/02/14). Spencer stated, “I think students really benefitted from that critical thinking and also from having to work in groups to come up with a conclusive answer (Spencer, weekly reflection, 10/16/14). Clint implicitly referred to assessment when he stated, “I liked that we could use [the activity] to gauge the student’s understanding” (Clint, lesson study five, 09/26/14).

After realizing that students were looking at other groups’ placements of their sticky notes during this activity, the lesson study team decided to revise this portion of the lesson in order for each group to have their own poster. Grace mentioned the idea of giving each group a poster at the beginning and end of the lesson to see if anything changed (Grace, lesson study meeting five, 09/26/14). She later decided to have groups “collectively write down everything they know and then do the same thing at the end to see how [students’ knowledge] changes. This might be more fun for them” (Grace, lesson study meeting five, 09/26/14). She later explained that she thought her method was a good way to “gauge how much [students] had learned in lab. . . . it gets them thinking about it so they are ready to absorb more information” (Grace, post-lesson study interview, 12/02/14). This suggested that Grace saw value in utilizing pre-/post-assessment to evaluate students' knowledge change.

When asked how to tell if a student understands, Shannon was the only participant who discussed asking the individual student questions (Shannon, pre-lesson study interview, 09/29/14). The researcher observed Shannon doing this during every observation of her teaching. At the beginning of lesson study, Grace stated, "When [students] are answering questions or even willing to try to answer questions, [then they understand]. Usually, [I look at] how they interact with each other when I let them loose on experiments" (Pre-lesson study interview, 09/04/14). During the observation of the NOS lesson, Grace asked the whole class questions, and the same students answered all of her questions. When asked at the end of the lesson study, Grace stated, "I feel like if I can ask [students] a question in class and they can answer it, they have a grasp on it" (Grace, post-lesson study interview, 12/02/14). During the teaching of the photosynthesis lesson (09/25/14) and the fungi observation, the researcher observed Grace going to individual tables to check for student understanding.

Clint mentioned asking students if they understood, but stated, "You're not going to get many verbal responses from them. I have to determine based on whether I'm getting quizzical looks" (Pre-lesson study interview, 09/02/14). During the pre-lesson study observation, every question Clint asked was directed to the entire class, with the same students answering each time. However, during the post-lesson observation, when students were individually looking at the specimens, Clint traveled to each group to check for student understanding (Clint, researcher field notes, 11/13/14). Spencer stated, "I will see other students going to [students who understand] and they are able to explain it. . . .

Also, I can tell when they have good exam grades" (Spencer, post-lesson study interview, 12/04/14).

Summary. From the beginning of lesson study, Shannon checked for student understanding by asking individual groups/students questions, which continued throughout the semester. Throughout both cycles of lesson study, she continuously asked the team, "How do you know if your students understand?" At the beginning of lesson study, the other three participants did not incorporate formative assessment techniques into their lessons. If they asked questions, the questions were directed to the entire class. However, at the end of the lesson study, both Grace and Clint traveled from group to group to check for student understanding. Shannon and Clint were the only participants who mentioned the sticky note activity was a method that could be used to gauge students' knowledge. Grace mentioned the interactive component of the activity as being beneficial to students, while Spencer discussed the critical thinking component. As mentioned in the previous section over knowledge of student understanding, only Shannon and Grace talked about student assessment when discussing whether students held the four common misconceptions the lesson study team tried to address in their photosynthesis lesson.

Knowledge of instructional strategies. Before lesson study meeting two, Shannon emailed an agenda to the lesson study team that included items that needed to be discussed as they planned the photosynthesis lesson. Item three on the agenda stated:

> Do we need to DO anything different (change the order or complete a different activity) or is it simply HOW we explain or present the material? Telling is not

teaching. How do you know when your students know or don't know?" (Shannon, email to participants, 09/04/14).

During lesson study meeting two, Shannon addressed this item of the agenda by introducing the learning triangle, which claimed students only retain 20% of what they hear. This initiated a conversation with the lesson study team that raised some questions from the other participants. Questions included: how to get students' attention while they are doing experiments, what to do when an experiment goes wrong, and when is an appropriate time the instructor should perform the lecture portion of the lesson? To these questions, Shannon was able to offer suggestions of strategies that were not teacher-centered and helped the instructor to determine whether students were understanding the material.

Shannon: How do we get [students] to retain more down in this lower part of the triangle than at the top?

Clint: Sounds like we should spend less time lecturing and more time doing experiments.

Grace: Maybe just start the experiments and talk to [students] about it as the experiment goes.

Spencer: I kind of thought about that, but once [students] start doing the experiment, it's hard to reel them back in.

Clint: They are like 'follow the recipe. Get through lab.'

Shannon: So the osmosis lab yesterday, [students] did all of the procedures before I explained anything about osmosis and diffusion. . . . I showed them where the sucrose was, and I showed them the procedures. As they are setting it up, [I went] from table to table, because sometimes you can't reign them all in, but if you go to table to table, and it takes a lot of work and energy, and you say 'okay, why are you guys doing that?', and questioning them as you go from table to table, you may have to teach the same thing six times at each table, but some groups are going to get it and some aren't. . . . Are you guys up for trying what we talked about, where we're not lecturing and we're doing, and lecturing as we're doing?

Clint: My only issue with that would be, like when I set up the osmosis bag with the phenylthaline and the sodium hydroxide, I had the student help me tie it and I was pretty sure they didn't tie it, but then I was hoping that they did. And so, the whole jar ended up being pink. So then when I went to explain it, I was like, 'Well, ideally the bag would have just turned pink and then the water would have stayed clear so you could see the sodium hydroxide in the water move into the cell.' And then I was like, 'Well it's all pink. So this is what should have happened.' . . . so they don't see what I want them to see and they have to go back to my explanation. So I guess what I am saying is, for [students] to fully understand, the experiment has to go correctly.

Shannon: Could you have students come up with explanations for that? So for example, [in the chromatography activity], what if one [group's] comes out the right way, and the other one doesn't? Could you say, 'Hey, group 4, check out group 2's. You guys come up with an explanation of why you think [they are] different'? And then, if they still don't get it, you can explain, and then see if they can get it.

Spencer: Yeah, for my last lab, I was like, 'Well, we didn't get the results we wanted. What were some possible sources of error?' They had no idea. They had no idea.

Shannon: But could you have suggested, 'Hey, what about the bag could have been—'

Clint: If you give them two options, they're pretty much 50/50. . . . and they're like, 'That one,' and you're like, 'No, but thank you.'

Shannon: Or you could say, 'No, but why do you think it's no?' They really can think. We just haven't asked them.

Spencer: They got a grade, that's all that matters.

Shannon: They do talk more and participate more when they're comfortable with each other. I did the exercise [on the first day of lab] at the tables, having them find things in common with each other. And so the rest of the lab was a lot more interactive and they all teamed up.

Clint: I did all my lecture at one time and I've heard that some people would lecture and do the experiment, lecture, experiment—

Shannon: Are you aware of the research on attention span?

Clint: No, but I would say it would be around 10-15 minutes.

Grace: Is it 10, 15, 20 max?

Shannon: 20 at undergrad and graduate levels. . . . And they found that even 60 seconds of letting [students] talk to each other about something that was just lectured on is the break [needed] to begin the next 20-minute set. So if you're lecturing about spectrometry, then you say, 'Okay. I need you to talk to your

> groups for 60 seconds about what are we going to do and what questions you have'. . . . now you can ask them questions. Number one, they're going to be more likely to tell you things because they've been able to share their answers so they don't feel afraid that their answer's wrong, because if everybody's wrong at the table, at least there's four wrong people and not just [them]. And now you can actually lecture again or you can have them do something and then bring them back and lecture again. (Lesson study two, 09/05/14)

In the above conversation, Shannon offered several strategies for instructional approaches for teaching. First, Shannon addressed Spencer's question concerning "reeling students back in" after they are performing experiments. Shannon discussed the idea of having students perform the experiments before any discussion has occurred, in which the instructor then goes from group to group to ask questions and offer explanations to what is going on. When Clint brought up his concern of the experiment not going correctly, Shannon offered questioning techniques that addressed this issue and attempted to lead him away from the "correct" answer being the only way that students can learn material.

When Clint mentioned that he did all of his lecture at one time but heard some GTAs lectured, then experimented, lectured, and then experimented, Shannon responded by discussing research that indicated the length of students' attention span is limited, and that successful teachers offer activities to "reset" students' attention. Additionally, she mentioned an activity that she did which engaged the students during the first day of lab. In this activity, Shannon asked each group of four to find three things everyone in the group had in common (Researcher field notes, 08/28/14). She believed that it helped students feel more comfortable with working in groups. After the get-to-know-you activity was introduced to the lesson study team, Grace also tried it with her students, and found the activity to be "tremendously helpful" in engaging students to participate (Grace, written reflection, 09/10/14).

From the above conversation, the lesson study team was introduced to the importance of instructional strategies that offered more than teacher-centered instruction. This conversation led to a variety of strategies that the lesson study team included throughout both cycles of lesson study. The strategies include the 5-E learning cycle, peer tutoring, what you know/what you learned, sticky note activity, collaborative group article reading, and concept mapping. Discussion and implementation of each strategy will be discussed below.

5-E learning cycle. After the second lesson study meeting, Shannon felt confined to the photosynthesis lesson and was trying to think of ways she could "encourage the group to think outside the box and come up with brand new lessons (Shannon, written reflection, 09/11/14). She decided to introduce the 5-E learning cycle (Bybee, 1997) to the other participants because she felt it was a model that would "enable the group to create an entirely new lesson as this lesson study progresses" (Shannon, written reflection, 09/11/14). She stated that both Grace and Clint had mentioned some of the aspects of the learning cycle such as teacher questioning and informally assessing prior knowledge, and also believed "labs are supposed to be hands on and less lecturing" (Shannon, written reflection, 09/11/14). She believed the learning cycle model would "result in moving from a teacher-centered learning environment in [the other participants'] labs as well as get them thinking about how they can question students rather than tell them" (Shannon, written reflection, 09/01/14).

During lesson study meeting three, Shannon introduced the team to the 5-E learning cycle, and the participants agreed to model the photosynthesis lesson in this format. The team decided which activity would be appropriate for each component (i.e., Engage, Explore, Explain, Elaborate, and Evaluate), and Shannon had the team read aloud what teachers and students should be doing during each component of the lesson. The lesson study team used this model for both cycles of lesson study.

Peer tutoring revised into what students know/what students learned. As the lesson study team discussed structuring the photosynthesis lesson into the 5-E model, the group was discussing the "Explain" portion of the lesson. The following conversation occurred, which led to the creation of the peer-tutoring activity in the photosynthesis lesson.

> Spencer: I've always wondered, do we explain at the end of each activity while they're doing the other one? When is a good time to explain?
>
> Clint: Maybe we could have [students] teach each other, because when you have to teach something, you really have to understand the concept. And we could have people that really know it come teach me. If I check them off, then they can go teach somebody else, and then they can certify them.
>
> Shannon: That's kind of neat. Have any of you ever done that in any of your classes?

> Grace: No. I mean, if there's some that understand it and someone else asks me a question, I'll assign someone I know that understands it to explain it. But I haven't done an official 'explain it to me, you explain it to someone else.'
>
> Shannon: This could look really different in each of our lessons, and I think that's okay. I think that would be neat to watch you do something like that. And then we'd be the ones in there watching, how do the students get it? Because we're not watching you at all.
>
> Clint: I guess with that idea, you'd have to limit how much you try to teach them and get them to understand. I'd pick out maybe four or five key things and then have [students] be able to really understand that, and then teach the whole class. Then say, 'From everybody in their group, whoever understands this the best, come up to me' and then I want them to explain it to me. Then I'll have a checklist. Even if I have to coach them a little bit, if I can just go through that and get them to explain their understanding to me. Then once I can certify that, they go back to their group and they have to do the same process. (Lesson study meeting two, 09/05/14)

During the teaching of this portion of the lesson, Clint modified his initial thoughts because he believed peer mentoring would be a better technique for a topic that was less conceptual (Clint, post-lesson study interview, 12/02/14). He instead had the students form collaborative groups based on the topic with which each student felt most comfortable. Groups then discussed the topic and wrote a synopsis of that subject to present to the rest of the class. He stated that he decided to change his initial ideas because sometimes he has an idea of how a lesson is going to look like, but at times he completely changes it based on what he believes works best (Clint, post-lesson study interview, 12/02/14).

When the lesson study team discussed how they thought this lesson went, Shannon stated it was her favorite part of the lesson (Shannon, lesson study meeting five, 09/26/14). “To me, when I write something down, that’s how I remember things. Just writing, so maybe writing this down after learning it helps solidify it a little” (Shannon, post-lesson study interview, 12/09/14). Grace, who was going to teach the next iteration of the photosynthesis lesson, stated:

> I was thinking about doing this, but I think instead of letting [students] choose what they’re comfortable with, I’m just going to assign each table a topic. And if no one knows anything about it, I guess [they’re] going to learn. (Grace, lesson study meeting five, 09/26/14)

Later in the conversation, Grace decided to modify this portion further by saying:

> I was thinking about just having the groups get a piece of paper and collectively write down everything they know and then doing the same thing at the end and see how it changes. This might be more fun for them. (Grace, lesson study meeting five, 09/26/14)

The above scenario described how one participant’s idea of peer tutoring transformed into a collaborative group discussion and presentation to the class. In the revision portion of the lesson, Grace decided to modify the approach and ask students what they knew about photosynthesis in the beginning of the lesson, and then ask again at the end of the lesson.

Both Shannon and Clint had positive statements about this portion of the lesson. Shannon stated:

> I like how [students] put it in different words, so that means that they're actually hearing what you say and processing it, and they're able to articulate it in their own words. . . . I mean are they learning when they just regurgitate and memorize? (Shannon, lesson study meeting six, 10/03/14)

While Clint responded:

> Even when [students] say stuff like, 'pigments reflect green because they don't like it.' The pigments don't have feelings, but even if [students] can just understand it in those terms, that's better than when they can't. (Clint, lesson study meeting six, 10/03/14)

This strategy was originally created by Clint and revised by Grace. The lesson study team's response to the strategy was positive.

Sticky note activity. After deciding to use a 5-E learning cycle for the photosynthesis lesson, the team organized the lesson where each activity was either used to engage, explore, elaborate, or explain. However, at the end of the meeting, there was no plan for evaluation. At the beginning of the next meeting, Shannon stated:

> I was looking at the photosynthesis equation, and it came to me last night, the big picture that we want them to know, is everything that we do in lab, could they put it on this picture right here? You've got these words like pigments. If you went to a group at any point in the lab—and you've got that equation up there—and you said, 'Hey, what are we doing right now? Where does that fit in that equation?' [Students] should be able to tell you. . . . and if they can't do that, then they don't

> understand what they're doing in lab, and they don't understand photosynthesis. (Shannon, lesson study meeting four, 09/20/14)

The group decided to write the equation on chart paper and put it in two locations in the laboratory.

When the team was discussing this portion of the lesson for revision, both Shannon and Clint mentioned students waiting in line to place the sticky notes on the poster. They also mentioned the issue that many groups were looking where other groups placed their sticky notes. Shannon stated, "I saw a student take one [sticky note] and they were going to put it somewhere, but looked at the other people's answers and put it with the other people's answers" (Shannon, lesson study meeting five, 09/26/14). Clint affirmed this by replying:

> If [students] don't understand it from just a lecture setting, then a lot of people just need to work it out by talking it out. So, if we could get them away from the comparing and seeing where their classmates put the sticker, and if we could just get them to focus on –'Okay, but why did you put that there?' Instead of 'Let's get the right answer like the rest of the class.' (Clint, lesson study meeting five, 09/26/14)

Therefore, the team decided to ask each group to write the photosynthesis equation on their own poster and place the sticky notes on this poster throughout the lesson. When Shannon utilized this strategy in her laboratory she said the students placed the sticky notes on their poster throughout the lab, and then she saved 30 minutes at the end of the class to talk about their posters.

> You can get into argumentation. They were arguing, 'Well, I'd put this here.' And another group would say, 'No, I wouldn't.' And I think the difference was they each had their own in front of them. Now, my plan if I hadn't run out of time was to have them visit each other's, go around the room 'How was yours the same or different?' (Shannon, lesson study meeting six, 10/03/14)

In the post-lesson study interview, each participant said they would utilize the sticky note activity next time they taught the photosynthesis lesson. Spencer claimed you could do it for every lesson, but you would have to "think of other ways to do it" (Spencer, post-lesson study interview, 12/04/14). Clint stated:

> I liked that we could use that to gauge the student's understanding. . . . students need to communicate with other students and discuss because the whole exercise is figuring out this goes there because of this. When they discuss it with other students, they can apply their reasoning and compare with the reasoning of others. (Clint, post-lesson study interview, 12/02/14)

In general, each participant saw value in the sticky note activity and stated they would use the activity next time they taught a lesson over photosynthesis.

Concept mapping. As the lesson study team planned the lesson for the second cycle of lesson study, Shannon was discussing a method that she used to understand how protists were related to one another as well as the organisms in other kingdoms.

> So we talked about last time, we want them to learn this stuff. We don't want them to memorize it. We want them to actually assimilate all of this knowledge into understanding, and so we have to come up with ways . . . . to help them understand. I had an idea about a concept map. Because when you come into

> protists, and classify something with all these words and they are all jumbled up, you have to step back and make it make sense for them, so possibly making a concept map to how protists fit into the classification, into the hierarchy. . . . Basically, that's how I made sense of protists. I don't know anything about protists. I read the first two pages (in the laboratory manual), and put it into a map, and I thought, "Hey, it helped me make sense of it, I wonder if it will help students make sense of the big picture here." (Shannon, lesson study meeting seven, 10/27/14).

Shannon then had the participants use the word list that she created in order to construct a group concept map (see Appendix I). They started with the word *algae* in the middle of the board.

> Shannon: Okay, those are just the words I came up with. We can have more words, less words, more structure, less structure, so how can we place these? Where would eukaryotic fit there to hook algae to eukaryotic?
>
> Spencer: Algae are eukaryotic.
>
> Shannon: Okay, you want to add that? Concept maps get messy. So make a line from it and then. . . . so algae are eukaryotic.
>
> Spencer: What about if you did, protists are both eukaryotic and algae.
>
> Shannon: So what words would you use to connect the lines? There is no right or wrong answer to this, that's another thing.
>
> Clint: Protists are all eukaryotic and all eukaryotic algae are protists, but not all protists are algae.

> Shannon: So you can make those little notes to the side. Do you want to add that, Clint? It would be really neat to see what your students come up with. Each pair can be doing this on a piece of paper. Okay, where do fungus-like slime molds fit in?
>
> Grace: Under protists, I guess. (Lesson study meeting seven, 10/27/14)

The participants continued to go through the list of terms to complete their concept map. They decided that students would do the concept maps with a partner as the engagement portion of the lesson. They allowed 20 minutes for the activity.

After reviewing the lesson plan the team created, Grace asked if they should show students an example of a concept map (Lesson study meeting 10, 11/03/14). Shannon suggested demonstrating a three-minute concept map for students who did not have a lot of experience making them. They decided to use the topic of genetics, since that was a topic that students had already covered in a previous lab.

During the teaching of both iterations of this lesson, Shannon and Spencer (the instructors for this lesson) both made comments to students (after they had worked on the concept maps for 20 minutes) that they could make additions to their maps throughout the lesson. At the end of class, each group was to turn in their maps for a quiz grade. As the lesson study team reflected on this lesson during meeting 10, Shannon stated:

> When we got to the end and [students] were looking at specimens, I kept saying, “Okay, are you adding to your concept map,” “Where are you going to put the diatoms on your concept map,” “Where are you going to put economic importance on your concept map?” (Shannon, lesson study 10, 11/03/14)

Shannon and Clint both utilized the concept map during the teaching of the post-lesson over the topic of fungi. However, in the middle of Clint's lesson, he abandoned the strategy, stating that he felt like students were hesitant to do a concept map because there was a great deal of new terminology (Clint, post-lesson study interview, 12/02/14). Clint felt like concept mapping was a good technique, and that "there is a learning curve, but once you get past that, it is helpful" (Clint, post-lesson study interview, 12/02/14).

Grace and Spencer did not use the concept map in their fungus lesson, but Grace believed it was a good exercise that "helped [students] picture that there are many different kinds of protists and [the kingdom] is very diverse" (Grace, post-lesson study interview, 12/02/14). She believed it would be an exercise that could be used at the beginning of other labs. When asked about his thoughts regarding the concept maps, Spencer stated:

> I think there could be a better way to do that. I felt like it was a little rushed, maybe. I would maybe have them do it before the lab, like before they even come in. They would just come in and not have any idea what they were going to talk about that day, and I think it would be helpful if they made a concept map. . . . they weren't bad but [protists] are just so different and [students] had no idea what the protists were and they were just confused. It might be easier to do a concept map for different things. It might have been easier for fungi than the protists, just because the protists are so different. (Spencer, post-lesson study interview, 12/04/14)

However, when asked about the concept map the lesson study team developed together as they were planning the lesson over protists, Spencer stated:

> I hadn't looked at protists since Biology I, so I knew what they were but that was it, and I'm sure things have changed in the six years since I took it. As we went through it, light bulbs clicked on. It was cool. (Spencer, post-lesson study interview, 12/04/14)

The above quote indicated that participating in concept mapping helped Spencer to gain an understanding of the content over protists. However, Spencer felt that he would not have students create a concept map over protists next time he taught this lesson because students were too confused. Similar to Spencer, Clint mentioned the difficulty involved with concept mapping and thought they could be helpful once students had mastered how to create them. This indicated there may need to be further training with GTAs that involves how to create concept maps.

Article engagement activity. During the second cycle of lesson study, Grace initiated a conversation that led to an instructional strategy the group wanted to implement. As the team decided how the second lesson plan was going to unfold, Grace mentioned several interesting ecological benefits for which algae were known. This led to a discussion of incorporating articles within the lesson for students to read and present in order to generate interest in the topic.

> Grace: I'm going to talk about red tide, I think that's dinoflagellates, and that's a big deal, and you can talk about algal blooms and fertilizer runoff from fields.
>
> Shannon: Lake Erie.
>
> Grace: And I'm going to talk about Caragenans because so many people think it is a carcinogen.
>
> Shannon: What is your favorite, Spencer?

Spencer: I don’t have a favorite yet.

Clint: Some people are studying, I think its dinoflagellates again, to make lipids for biofuel. Bioengineering.

Shannon: If each of us could find an article about what we find interesting. . . . and [students] could actually do some reading and discussion on it. Like when [Clint] did six groups of people in photosynthesis, and [students] stood up and reported on it, that didn’t take long at all. So the groups read, we could come up with six of them, and then say something interesting about that, and that could cover [objective] four. (Lesson study meeting seven, 10/27/14)

The participants placed this strategy as the elaboration component in the 5-E lesson plan, and allowed 10 minutes for students to read their article, five minutes to write their summary, and 10 minutes for reporting for the entire group. During the revision of the lesson plan, the group decided to move the activity to the beginning of the lesson as the engage component.

Shannon: As I was teaching this yesterday, I wondered if we should start the entire thing with the articles?

Grace: That’s what I did on Tuesday. I started with that. For each group, I gave them the organism they were talking about so they could see it. . . . Then, they got up in front of the class and had someone do the “Vanna White” thing with the organisms and someone else present what they wrote about. After that, they just passed [the specimens] around, everyone put on gloves and touched everything.

Shannon: That gets them engaged. (Lesson study meeting 10, 11/03/14)

During the post-lesson study observation, both Grace and Spencer used the articles to engage students over the topic of fungi. Grace stated that she liked incorporating the articles into the lesson because "I think in a lot of the undergrad classes, except for speech, they don't have to present stuff. It was a lot of fun and [students] learned some cool stuff" (Grace, post-lesson study interview, 12/02/14). Spencer stated that "students were able to interact with each other and I think that helps get the lab going; that's what I thought about the protist lesson" (Spencer, post-lesson study interview, 12/04/14).

In contrast, Clint stated that he liked the idea of using the articles to get interested in the topic, but:

> I don't think [students] are conditioned or motivated to read. The higher up you get, the more and more you realize that reading is what you do to learn things, but [students] like to be spoon fed. (Clint, post-lesson study interview, 12/02/14)

The article engagement activity was an instructional approach created by all participants in the lesson study team. All participants mentioned the activity as a way to engage students in learning about protists/algae, but Clint felt that students were not motivated to read. He believed that showing a video would be more engaging than having students read articles.

Summary. Shannon first introduced a variety of questioning techniques as participants voiced their concerns about "lecturing while doing." She discussed having students begin experiments without any direction, while the instructor traveled from group to group to question students and offer explanations. Additionally, Shannon discussed methods that allow students to become more comfortable interacting within groups by introducing a get-to-know-you activity. When results from experiments did not go as planned, Shannon offered questioning techniques the participants could use. Shannon introduced the 5-E learning cycle as a strategy to utilize more student-centered instruction during both cycles of lesson study.

In order to guide participants to do more than one large lecture at the beginning of class, Shannon discussed research on student attention span so that the participants would incorporate brief periods of discussion to reset students' attention. Shannon also created the sticky note activity as a method to assess students' knowledge in the photosynthesis lesson. Each participant discussed benefits to this activity and claimed they would utilize the strategy again the next time they taught photosynthesis. Shannon also guided participants to utilize the concept mapping activity, in which all participants saw value, even though Spencer stated he would have students perform the activity on their own outside of class, and Clint abandoned the activity during the lesson over the topic of fungi.

Clint created the peer-tutoring portion of the lesson, which he later modified. This was Shannon's favorite component of the photosynthesis lesson because she believed writing the information after helped "solidify" the learning. Grace modified this strategy further into a *what students know/what students learned* activity to determine how learning changed from the beginning of the lesson to the end. The entire team came up with the idea of the article collaborative group activity in order to initiate student interest in protists/algae. During their post-lesson study observations, both Grace and Spencer utilized the group article activity, while Clint believed a video segment would be a better way to engage students' interests.

Additional themes that occurred. In addition to the five aspects of PCK, the researcher observed themes that occurred during the lesson study cycle. These themes include the length of the post-lesson study lesson and implications of the outside observer notes.

Length of post-lesson study lesson. One theme that occurred throughout lesson study was how the instructional time was being utilized by the GTAs. As the participants began planning the second cycle over the topic of protists/algae, Grace mentioned how students often leave early in the classes that involve a survey of the organisms within a particular kingdom. "If you're not careful with those labs—if you just talk about it and then say, 'Go look at your specimens', [students] take photos and they'll leave. And they're there for maybe half an hour" (Grace, lesson study meeting five, 09/26/14). Shannon also discussed the issue of students not remaining in class for the entire laboratory period while addressing the lesson study team.

> I feel really strongly that [students] are paying a lot of money to sit in these classes, and if we don't do what we know we should to make sure that they know what they do or do not understand before they leave, I feel like they're throwing money in the trash. (Shannon, lesson study meeting six, 10/03/14)

Shannon later mentioned in a reflection about arriving early to the protist/algae lesson and noticing that the GTA who taught before her was no longer in the classroom during the scheduled class time. This GTA was a member of the lesson study team who taught the research lesson from the second cycle of lesson study.

> I got to the room before the previous TA should have been done teaching and they were long gone and none of the specimens were even out. This is someone

> teaching our lesson, which, if done correctly, should have had students in class the entire time being challenged to learn. My students begged to stay after class to keep looking at specimens and ask me questions. What is the difference? 1) I know how to motivate students, 2) I understand the content well and help them know it well, and 3) I care that they learn. (Shannon, written reflection, 10/29/14)

Shannon believed that because students were paying to be in these classes, it was the instructor's responsibility to ensure student understanding of the material. Additionally, Shannon felt that GTAs should utilize the full class time in teaching their lessons.

The researcher noticed there were participants who did not utilize the full two hours and 45 minutes of instructional time. To examine this more closely, the next portion will include the timeframe that each participant used to teach the lesson over the topic of fungi. The first 21 minutes of the beginning of the class was devoted to student evaluation of the GTAs, in which the individual GTA was not present. What follows is a description on the remaining instructional time, approximately 140 minutes, for each participant.

Shannon utilized a different approach than the other participants in that she first gave an overview of fungi. After this instructor-centered approached, she went over the first phyla of fungi and then asked students to view the specimens in the phylum while starting their concept map. Shannon visited each table, answered student questions, and then showed specimens on the overhead microscope as well as PowerPoint slides. She then checked for student understanding of the previous two laboratory periods as she displayed an image on PowerPoint, and asked students to recall the phyla, important characteristics, and economical uses. She continued this approach with the remaining three phyla of fungi. This took one hour and 57 minutes of instructional time. She then told students they could work on their concept maps and continue looking at specimens for the remainder of the time. The first student left five minutes after this statement, with the last three students leaving 19 minutes after this statement. There was three minutes left before the end of class when the last three students left.

Grace first asked groups of students to read articles over each phyla of fungi, and asked each group to present their article. As groups were presenting, Grace recapped the important uses of each phyla. Next, she used an instructor-centered approach to give a brief overview of the fungi kingdom, and then described each phyla of fungi. The article activity and instructor-centered instruction took 50 minutes of instructional time. She then asked students to view the specimens on their own, for the remainder of class. The first student left after 21 minutes of this independent time, with the last student leaving after 32 total minutes of independent viewing time. There was one hour and two minutes remaining of the required class time when the last student left.

Spencer also asked groups to read articles and present to the class. He then used an instructor-centered approach to give a brief overview of fungi and to describe each phyla. These two portions of the lesson took 46 minutes of instructional time. He then asked students to view the specimens on their own for the remainder of class. The first student left after five minutes, with the last student leaving after 28 minutes of independent viewing time. There was one hour and seven minutes remaining of the required class time when the last student left.

Clint used an instructor-centered approach to first describe each phyla of fungi. He then stated that the class was going to perform a concept map together using the key terminology to fungi. During this portion of the lesson, Clint abandoned the concept map, and then explained each term to his students. This overview of fungi and the four phyla took 57 minutes of instructional time. He then asked students to view the specimens on their own for the remainder of the class. The first student left after 45 minutes of independent viewing time. The last student left after one hour of independent viewing time. There was 14 minutes of class time remaining after the last student left.

Most of the students remained in both Shannon's and Clint's classroom for the majority of the required class time. In contrast, Grace and Spencer's students left with over an hour remaining. The time remaining in each participant's class could lead to more questions including both GTA and student motivations.

Outside observer feedback. During the first cycle of lesson study, the lesson study team was still working on edits to the research lesson during the fourth meeting of lesson study. The lesson was to be taught the following week, so there was not enough time for the lesson study members to discuss feedback from the reviewers before the first iteration was taught. When the research lesson was complete, the researcher sent the research lesson to both the biology expert and the biology education expert. The biology education expert sent feedback, which the researcher forwarded via email to the other lesson study members. However, the feedback was not discussed with the lesson study team. The biology expert did not send feedback for the first cycle of lesson study.

Shannon was the only participant who responded to the biology educator's feedback by stating:

> I went through [the biology educator's] comments and our lesson plan and created a photosynthesis PowerPoint. . . . I feel like lesson plans are simply frameworks

> and the teacher brings them to life. Anyone can follow a lesson plan, but a master teacher can take the lesson plan and visualize themselves teaching it before they actually teach, thinking about where students will be confused, what order the information needs to be presented in, questions to guide students to get them thinking, ways to get students to interact with the content. I visualized our lesson today and created this PowerPoint as I did. The PowerPoint is a guide for me and I take great effort to make it something useful to students after the lab. (Shannon, written reflection, 09/20/14)

Shannon applied the biology educator’s feedback in the PowerPoint presentation that she used to teach this lesson. For example, the biology educator suggested the team:

> Put the learning goals at the top of the page and word them in a way that indicates what students should be able to demonstrate or do, i.e., “at the end of this laboratory, students should be able to . . . .” (Biology education expert review, 09/19/14)

Shannon did this in her PowerPoint that she used to guide the instruction of the photosynthesis lesson. For example, the guiding questions in the original lesson plan stated:

- Understand the overall starting materials, products, and importance of photosynthesis and the reactions therein.
- Be able to relate each lab activity to the photosynthesis equation.

In the PowerPoint presentation that Shannon used to teach this lesson, Shannon displayed on a slide after the engage portion of the lesson the learning objectives that stated:

After this lab, students should be able to:

- Clearly state the overall starting materials and products of photosynthesis.
- Describe photosynthesis in regard to the electron transport chain and Calvin cycle.
- Be able to explain how every activity you complete in lab today relates to the photosynthesis equation below.
- Be able to answer the guiding questions for each activity using evidence from lab and information from lecture. (Shannon, photosynthesis PowerPoint, 09/20/14)

In the PowerPoint presentation, Shannon implemented the biology education expert's suggestions by explicitly stating what students should be able to do at the end of the lesson. Shannon forwarded this PowerPoint to the other participants, but none of the participants used the PowerPoint in the teaching of the lesson. In fact, when Clint and Grace taught this lesson while the other participants observed student learning, neither participant displayed or stated learning goals or objectives (Researcher field notes 09/18/14; 09/22/14).

Another suggestion from the biology educator involved the evaluation section of the lesson. He stated, "I know you mention that formative evaluation will occur throughout the lesson, but is there any time of closure activity that you will complete to wrap-up and ensure that students have achieved the set learning objectives?" (Biology education expert review, 09/19/14). To this comment, Shannon added a slide at the end of her PowerPoint presentation that stated, "Go look at the placement of sticky notes on both posters. Do you disagree with any? Be ready to share" (Shannon, photosynthesis PowerPoint, 09/20/14). After the teaching of this lesson, Shannon mentioned how she reserved 30 minutes at the end of the lesson for the class to discuss the sticky note assessment (Lesson study meeting five, 09/26/14). She mentioned the activity allowed her students to participate in argumentation as they offered reasons why they placed a sticky note in a certain location.

For the second cycle of lesson study, the team was able to complete the edits in time to receive and discuss feedback from the outside reviewers. The biology expert, Dr. Sturgeon, stated that he would prefer to discuss his comments in person rather than in written form. Therefore, both Shannon and the researcher met with Dr. Sturgeon in order deliver his feedback to the lesson study team.

In the protist/algae lesson plan, learning objective two stated, “Students should be able to place observed specimens into taxonomical hierarchy (phyla, genus)” (Protist/algae lesson plan, 10/20/14). The biology education expert stated:

> This learning objective is well-stated, but I want to make sure that you are thinking about how it aligns with your assessment. Will students be given a list of phyla and asked to place an observed specimen in that phyla on a quiz (which is how this learning objective reads) OR will they be given a specimen and expected to state/write its Phyla? If so the learning objective should reflect that. (Biology education expert review, 10/20/14)

After reading this comment, Shannon initiated a conversation with the lesson study team:

> Shannon: I think it’s that second one that we are expecting them to do, right? They’ll be given the specimen and expected to state, ‘Write its phyla.’ If so, the learning objectives should reflect that. Students should identify the taxonomic hierarchy of their specimens. Do you guys like that way? Underneath that, would you guys want to list the specific ones that you will be asking? The only reason I say that is that the [biology] expert mentioned in the meeting yesterday that he is

> very specific about what he wants [students] to know, so he's only asking them about cell wall components, energy storage, and accessory pigments of two of them. He's not asking every single one that they're going to look at.
>
> Grace: He is asking for phyla and genera of all of them.
>
> Shannon: He's not asking for genera on some of them.
>
> Grace: Okay.
>
> Shannon: What do you guys think about, 'The students should be able to place their specimens in taxonomic hierarchy of observed specimens that are specifically pointed out in lab.' By that, I mean, obviously, when Dr. Sturgeon teaches this, he emphasizes different things than maybe we will emphasize. But [students] need to be only held accountable for what we specifically emphasize. (Lesson study meeting nine, 10/24/14)

In the above conversation, Shannon mentioned the feedback of the content expert. When addressing the learning objective, Dr. Sturgeon stated:

> My comment there is only some [organisms that should be identified by phyla and genera]. It's almost too much to have [students] memorize microcystis, laminaria and all that stuff, if there is really no value to it. So, I have picked out some that I make mine know because they represent something that I am emphasizing in class. (Biology content expert interview, 10/23/14)

The participants decided to change the learning objective based on both experts' feedback in order to ensure that students did not have to learn the phyla and the genera of each specimen they observed, but only the specimens the instructor emphasized. The new objective stated, "Students should identify the taxonomic hierarchy of observed specimens that are specifically pointed out in lab" (Protist/algae lesson plan revision, 10/24/14).

During the engage portion of the research lesson, the students were to create concept maps over protists. The biology education expert asked the questions, "Do [students] have any training at building concept maps yet? If so, you may want to provide an example or brief training" (Biology education expert review, 10/20/14).

> Grace: So do we need to come up with an example of a concept map?
>
> Shannon: We probably need to come up with like a three-minute example of a concept map. I know you guys maybe don't have a whole lot of experience making them, but could we do something completely unrelated to biology? Like five terms and something in the middle?
>
> Grace: We could just use photosynthesis. Instead of doing that, and they know it.
>
> Shannon: Would it confuse them because photosynthesis is a word in here?
>
> Grace: I don't know. . . . Are we going to give them terms?
>
> Shannon: Yes. We're definitely going to give them terms. Photosynthesis, what is another one that they've—
>
> Spencer: Genetics.
>
> Shannon: What would be five words that they can group some of them higher categories than others for genetics?
>
> Grace: Gregor Mendel, Genes, Alleles.
>
> Spencer: Dominant and recessive.
>
> Grace: Chromosomes.

Shannon: Would genetics be the word in the middle or the top? The big ideas of genetics? We'll have Mendel, genes, alleles, dominant, recessive, and chromosomes. There are six. On the board we could connect, what would be the word connecting genetics to Mendel?

Clint: Father of Genetics.

Shannon: How would genes fit in there? What would be the word that connected it?

Clint: The unit of inheritance.

Shannon: Is there something bigger than genes?

Grace: Chromosomes.

Shannon: How would you connect genetics to chromosomes? What would be the word that connected them?

Grace: DNA.

Clint: Responsible for recombination.

Grace: I think inheritance is in there.

Shannon: So, if you said in a sentence, genetics, inheritance, chromosomes, when you do a concept map, it should flow as a sentence. Genetics, is the study of chromosomes: genetics inheritance chromosomes. Do you see the difference? Like you're trying to explain what it is, in relationship to genetics and chromosomes, so the words should link them in a sentence.

Spencer: It involves chromosomes.

Shannon: Right. Involves might be one.

Clint: The more concise you try to make a statement, the harder it is to—

Shannon: That's why this is really, really tough to get [students] to think about what is the relationship between those. Is genetics the study of chromosomes?

Grace: I would say if you're going that route, it would be the study of inheritance and then under that you would do chromosomes, genes, alleles, et cetera.

Shannon: Do you want to add the word inheritance?

Grace: Well, we talked about inheritance in class.

Shannon: Let's add another word to our concept map—so it's the study of inheritance. Then from there, inheritance is going to link each one. How would you link inheritance and chromosomes?

Grace: I'd say inheritance by chromosomes. Then chromosomes connect genes, alleles.

Shannon: Chromosomes—

Spencer: Have genes. Genes have different—

Shannon: Alleles, which can be dominant or recessive. Your students may actually come up with different words, so this is just an example. The key is getting them to understand those connecting words. How the words are related.

As demonstrated above, Shannon was guiding the lesson study team in the methods of how to correctly construct a concept map by utilizing connecting words. After this conversation, the participants added the genetics example to the research lesson to ensure all students understood how to properly create a concept map.

In the engage portion of the research lesson as mentioned above, there was a statement that said, "While students are constructing these maps, the instructor will be observing groups and listening for student ideas/misconceptions" (Protists/algae lesson plan, 10/20/14). The biology education expert asked the following question related to this statement, “How will you address any misconceptions you hear?” (Biology education expert review, 10/20/14). The following conversation addressed this question from the expert:

> Shannon: I think we should all have in our notes what our [concept maps] look[ed] like as a reference. Then just be able to listen and—what would be a term, let’s say they put photosynthetic, where should they not put that?
>
> Spencer: That shouldn’t be on heterotrophic.
>
> Shannon: So are you guys going to be able to look for that as you go around and how will we address those things? Just say red mark no, or are you going to say, ‘How are you thinking?’
>
> Spencer: I’d be like, ‘Hey, maybe that goes in a different spot.’ Or, ‘Is there a better spot?’
>
> Shannon: Engage them in discussion somehow.
>
> Spencer: Ask them why they put that there in the first place.
>
> Grace: Tell them to Google it.
>
> Clint: That’s the easiest way. Google it, you got your phones. (Lesson study meeting nine, 10/24/14)

After this conversation, the group decided to add the following statement to the research lesson. “If a misconception is identified, the instructor will ask the group to explain the reasoning and determine if there is a better place for the word” (Protist/algae lesson plan revision, 10/24/14).

An additional change the lesson study team made to the research lesson occurred after the content expert mentioned his concern about engaging student interest in protists. He believed the articles would be a good way to do this, but thought the articles came too late in the overall lesson.

> A lot of these are organisms that [students] are going to have a hard time generating an interest in even though I think they're cool. If you were to flip objective four and objective three such that they learn about the ecological and evolutionary significance of these organisms so they have a reason to think they're interesting. (Biology content expert interview, 10/23/14)

Shannon discussed Dr. Sturgeon's comment to the lesson study team, and the team decided to introduce the articles earlier in the lesson. Grace commented, "That would be a nice break after talking with them" (Grace, lesson study meeting nine, 10/24/14).

In summary, the lesson study team did not finish the research lesson plan for the topic of photosynthesis in time to obtain and discuss feedback from the outside observers. Shannon was the only participant who utilized feedback from the biology education expert in her lesson, and the biology content expert did not provide feedback to the lesson study team for the participants to incorporate in their teaching of the photosynthesis lesson. During the second cycle of lesson study, both experts offered feedback that the lesson study team used to make improvements to the protist/algae lesson. In order to properly discuss the feedback given by the experts, there needed to be more time to discuss the changes that were recommended.

What are GTAs' Perceptions of Lesson Study as a Form of Professional Development?

In addition to understanding the aspects of PCK that emerged through participation in lesson study, it was important for the researcher to understand how participants viewed lesson study as a form of professional development. At the end of the lesson study, the researcher asked each participant the same set of questions (see Appendix E) in order to address this line of inquiry. The next section describes each participant's response to 10 questions that capture the GTAs' perceptions of lesson study as a form of professional development.

What is Lesson Study?

At the end of professional development, each participant was asked to define lesson study. Shannon believed that before participating, she thought lesson study involved taking existing lessons and redesigning them. However, after participating in this type of professional development, Shannon felt the existing lessons:

> Weren't really lessons, they were just procedures that students do. There wasn't really much that we could change until we got to the conceptual understanding of what [students] should know. I think lesson study is teachers getting together and talking about what they need to do to change. That may be designing a lesson or it may be finding out what you're not doing in the classroom to get students engaged. (Shannon, post-lesson study interview, 12/09/14)

By comparison, Grace stated that lesson study "is a group of people discussing, tweaking, and hopefully, semi-perfecting a lesson plan with a set of goals in mind" (Grace, post-lesson study interview, 12/02/14). Spencer said, "It is developing an ideal template to go over a certain topic as a group; people teaching the same thing and collaborating to come together and develop a lesson plan" (Spencer, post-lesson study interview, 12/04/14). Finally, Clint believed lesson study was something that could be performed in any field. "Lesson study is meeting with your peers and co-workers to compare experiences and getting different strategies to implement. I think it's a good technique or a good exercise to build better teachers" (Clint, post-lesson study interview, 12/02/14). Each participant had a unique stance on the definition of lesson study, but the common view among all participants involved collaboration with peers. Both Shannon and Clint mentioned collaboration for the purpose of improving teaching.

How Did Collaboration With Peers Help in Your Teaching?

When asked how collaboration with peers helped with the participant's teaching, each participant felt the interactions with the other members of the lesson study team were beneficial. Shannon felt the collaboration with peers gave her more confidence because she viewed her content knowledge as low, but realized "[the GTAs'] content knowledge isn't even where mine is" (Shannon, post-lesson study interview, 12/09/14). Shannon believed that talking with other GTAs about preparing for labs she had never taught "always boosts my confidence about teaching something for the first time" (Shannon, written reflection, 09/01/14). Additionally, Shannon felt that each member of the team brought different strengths to the conversation and believed "we all want to improve our teaching despite the mindset in a biology department that your research is more important than your teaching" (Shannon, written reflection, 09/01/14).

Although Shannon felt lesson study increased her confidence, Grace felt that because she had never been trained in instructional practices or theories in teaching, her conversations with Shannon helped tremendously. “I’ve never heard anything about having the goals set for students, things you want them to learn, and concept maps. Learning all of those things was really good for me” (Grace, post-lesson study interview, 12/02/14).

Like Grace, Spencer believed collaboration was beneficial to his teaching and he attributed the collaborations with peers in helping him be more comfortable in his teaching.

> With lessons I had to do by myself, I wondered if I was doing it right. With collaboration, I knew exactly what we were talking about and what I needed to focus on and how it should go if everything went right. (Spencer, post-lesson study interview, 12/04/14)

Like the other lesson study participants, Clint felt collaborations with peers was beneficial and discussed how each participant of the lesson study team was beneficial in developing his teaching.

> With Grace, who has taught this class before, I can learn what to expect. . . . It’s nice talking with Shannon because [she] has years of teaching experience, pedagogical techniques, and a wealth of knowledge. It was nice talking with Spencer because he is in the same seat as I am, and we got to compare our first-time experiences. (Clint, post-lesson study interview, 12/02/14)

Each member of the lesson study team felt collaborating with their peers was beneficial. Shannon felt collaboration helped with her confidence in the content knowledge, while Grace, Spencer, and Clint felt collaboration was more helpful in planning and executing the lessons.

What Did You Learn About Teaching and Learning?

Each participant was asked what they learned about teaching and learning through the lesson study process. Shannon answered:

> Teachers have to put their work in on the front end but the students are also responsible for putting the work in as well. It's a two-way street. Sometimes, as teachers, we think that if we do more, the students will do more, but I think if we do more effectively, then that gives students a better chance to be more. If we do nothing, students will do nothing. (Shannon, post-lesson study interview, 12/09/14)

Similar to Shannon, Grace believed student success varied with instructors. "Students respond well if you're approachable and they can tell you like teaching and the content" (Grace, post-lesson study interview, 12/02/14). In contrast to both Shannon and Grace, Spencer said that:

> The good students will put in the appropriate amount of work and their grades will reflect it. With the bad students, you can try to help them as much as you want, but if they aren't willing to meet you half-way, nothing is going to happen; they will either drop the course or get a poor grade. Teaching-wise, being prepared is one of the most important things. My goal was to be able to present them with as much relevant information about the topic as I could and be able to answer any pertinent questions they might have. (Spencer, post-lesson study interview, 12/02/14)

Finally, Clint discussed his new awareness for checking for student understanding before the lesson.

> Teaching is about finding out what students know and then adding to that and building off what they already know. . . . In how students learn, you have to deal with students not being comfortable explaining what they don't know. (Clint, post-lesson study interview, 12/02/14)

Each participant's view of the role of the teacher varied to some degree. Shannon, Grace, and Clint had a viewpoint that the teacher's role had an effect on student learning. Spencer, however, felt that the teacher's approach did not influence the student, because if the student did not do their part, no learning will take place.

How Was Lesson Study Influential in Revising Your Teaching?

When asked if lesson study influenced each participant's teaching, Shannon believed that being the leader of the team helped her to be more reflective in her teaching. "I think even in lessons that we weren't doing lesson study with, I was more engaged and focused (Shannon, post-lesson study reflection, 12/09/14). Because Shannon reflected on her teaching throughout the lesson study process, she believed she had revised her teaching by ensuring her learning objectives and assessments were aligned.

> We've got these learning objectives, I'm teaching these participants about learning objectives and I have to break everything down for them. It's like a coach. You have to break it down to the simple fundamentals and then you go out and implement it, thinking about the fundamentals. For lesson study, I was thinking about the fundamentals of teaching all the time. I break it down and think how my assessments are aligned with my learning objectives and how am I stating the learning objectives. Are they attainable for students? Are the learning objectives what the lab coordinator wants us to know, or what *I* want them to

know? I did a lot of that with this lesson study. That is one big difference. It has been something I've slowly been working on but I've never made it this explicit. (Shannon, post-lesson study interview, 12/09/14)

Like Shannon, Grace also mentioned learning objectives when discussing how lesson study influenced her teaching. "Just looking at the lessons differently and approaching [lessons] with goals in mind and definitely with a more conceptual focus" (Grace, post-lesson study interview, 12/02/14). Grace mentioned that because of lesson study she had revised her teaching by being more interactive and approachable to her students. She stated the students wrote that she was approachable in her student reviews. When asked what made her more interactive, she said, "I think I'm more confident as an instructor" (Grace, post-lesson study interview, 12/02/14).

Although Shannon and Grace discussed learning goals when discussing how lesson study influenced their teaching, Spencer mentioned how observing his colleagues was influential to his teaching. "I would try to take some tips and look at what [the GTAs] were doing well and what the students were getting from that. It helped me realize what I needed to focus on" (Spencer, post-lesson study interview, 12/04/14). Spencer stated that he had revised his teaching after lesson study by including more outside resources such as articles and videos. "I realize that the students have a lab manual and if you just teach from that, it's nothing more than they could do at home, so you need to have outside resources" (Spencer, post-lesson study interview, 12/04/14).

Although Spencer mentioned observing other teachers as helping to influence his teaching, Clint discussed how collaborations with his peers influenced his teaching the most. Both Spencer and Clint were not able to go to the weekly laboratory meetings.

Because of this, Clint claimed that lesson study was the only opportunity that he had to communicate with other GTAs. He further stated, "I don't think anyone ever teaches you how to teach, so it's nice to learn from people who have taught before (Clint, post-lesson study interview, 12/02/14). Because of these collaborations with the other participants, Clint stated he was able to revise his teaching to include a different approach to learning by utilizing a variety of instructional strategies that were introduced in lesson study.

> From the first day that I taught until the end of the semester, I focused a lot more on giving students a conceptual understanding rather than just checking off a list of topics they need to talk about. I learned some really good exercises like concept mapping and a lot of pedagogical techniques that I probably wouldn't have had access to had I not undergone this. (Clint, post-lesson study interview, 12/02/14)

Each participant shared a different aspect of lesson study as being influential to revision of his/her teaching. Shannon mentioned the reflective component of lesson study had improved her assessment writing, while Grace talked about establishing learning goals with a more conceptual approach had made her teaching more interactive. Spencer discussed observing his peers teach as being influential in helping him include more outside resources, while Clint talked about the conversations that occurred while collaborating with his peers helped him teach with a more conceptual approach.

What Were Rewarding and Challenging Aspects of Lesson Study?

When asked what was the most rewarding about lesson study, Shannon stated, "My teaching was better this semester" (Shannon, post-lesson study interview, 12/09/14). While Shannon believed her teaching had improved because of lesson study, Grace believed the students enjoyed themselves more this semester than in the past. “Even the [students] that didn’t do well, I think, learned something and they don’t hate biology” (Grace, post-lesson study interview, 12/02/14). Furthermore, Spencer said that he felt more confident in the lesson plans (Spencer, post-lesson study interview, 12/04/14).

When asked about the challenging aspects of lesson study, Shannon mentioned the time commitment as a challenge. “I did a lot of preparation especially with the lessons on the content because I didn’t know as much, for example, about fungi” (Shannon, post-lesson study interview, 12/09/14). Unlike Shannon, Grace did not mention any real challenges of lesson study.

> I guess it was a good challenge to have to think about all of these things and do reflections. I wish I had done it the first semester that I taught….[lesson study provides] some training and some knowledge of teaching that [GTAs] don’t [usually] get. That would have helped a lot. I felt very thrown to the wolves because you’re given the basic outline and you have to make your PowerPoints and come up with your own lesson plan. So if I had done this first and figured out how to think about these lessons, it would have been a lot different. (Grace, post-lesson study interview, 12/02/14)

Similar to Grace, Spencer also did not believe there were any real challenges of lesson study. He felt that he did not contribute as much in the conversation as Shannon or Grace, but he felt participating in lesson study was beneficial during his first semester of teaching because:

> [Lesson study] gave me an idea of how other people teach. I feel like [participating in lesson study] the second [semester] would be beneficial, but after

> that, maybe not as much, because I would be set into what I want to do and what works. (Spencer, post-lesson study interview, 12/04/14)

Like Spencer, Clint also thought participating in lesson study during his first semester was more beneficial than challenging.

> It helped me because I had a lot of questions and, through this, I could get them answered. It helped me to set expectations of what to expect with my classroom and how I was going to teach. It gave me a lot of tools that I needed in order to successfully teach, and it was fun. (Clint, post-lesson study interview, 12/02/14)

Overall, the participants believed lesson study improved their teaching. Shannon's statement was from the viewpoint of her teaching, while Grace's statement was from the viewpoint of her students. Clint believed lesson study gave him more confidence in his teaching. When discussing challenges of lesson study, Shannon mentioned the amount of time that it took to prepare was a challenge, while Spencer stated he did not feel as though he was able to contribute to the conversation as much. Grace, Spencer, and Clint all mentioned that lesson study would be beneficial during the first year as a GTA.

How Did Participants Feel About General Conversations During Lesson Study?

There was no set structure to each lesson study meeting. Each participant understood they had four meetings to create each lesson and one meeting to revise. Throughout this time, there were several conversations that occurred that were not related to the photosynthesis lesson or the protist/algae lesson. However, the conversations involved various aspects of teaching and learning, such as how students performed on quizzes or student difficulties with the labs classes were performing that week. Each participant was asked about whether these general conversations were helpful. Shannon stated:

> It was enlightening, yeah. Not assuming that what you do in your class is what everybody else does and understanding that some things are the same and then some things are very different. We're on these islands where we don't even get to know. We never have the opportunity to talk to each other like we did in these lesson study meetings. Even though we meet weekly [in the regular laboratory meetings], those are not the types of conversations that go on and I'm not sure why. Maybe we're intimidated with the lab leader there, but we don't talk about problems because we don't want anyone to think we have problems in our teaching. So, at least in this environment, it was good, especially for the new guys. (Shannon, post-lesson study interview, 12/09/14)

Like Shannon, Clint also believed the format of lesson study was helpful in discussing issues that occurred during instruction.

> It's nice to be able to compare your experiences and see if this experience was unique to my classroom. With a lot of them or most of them aren't. It's kind of like we're getting the same students and so we're going to have similar experiences. Everybody has a different solution to the problems that arise. If we can get a couple of different options, then I think it's very helpful. (Clint, post-lesson study interview, 12/02/14)

While Shannon and Clint discussed the lesson study format as an opportunity to discuss issues in teaching, Grace mentioned how these general conversations helped her gain a better understanding of how students learn.

> I learned a lot of things that I have never really thought about, even things that might be kind of obvious but I had never sat and thought about…for example, when we talked about the way students learn and absorb the material. Those are things that are kind of intuitive but I just hadn't hashed it out with anybody or heard anyone say it. (Grace, post-lesson study interview, 12/02/14)

While the other participants discussed the beneficial aspects of the conversations about teaching and learning, Spencer mentioned the relaxed atmosphere of the lesson study format. Spencer stated the general discussions that occurred during lesson study "definitely helped because it gives a more relaxed atmosphere instead of being super-focused all the time. It kind of lets your mind wander and connect different areas (Spencer, post-lesson study interview, 12/04/14).

Each participant enjoyed these general conversations that emerged throughout the lesson study process and felt as though it was helpful to talk with other GTAs about general problems that occur in the classroom. Shannon felt that the smaller environment was less threatening than the weekly TA laboratory meetings, while Spencer felt the less-structured design of lesson study was helpful in connecting ideas.

How Did Your Students Respond to the Different Instructional Approaches?

When asked how their students responded to the different instructional approaches that were used throughout lesson study, Shannon and Grace shared positive experiences with their students. Shannon said that her students did not have any problem at all, "because I have already been teaching that way from day one of class" (Shannon, post-lesson study interview, 12/09/14). Grace believed her students "enjoyed it" because the lessons were more interesting.

> In the past and for a lot of the TAs it's just lecturing with a PowerPoint and then letting [students] do whatever activity. The way we structured the lesson plans was a lot more fun for the kids. The lesson study inspired me to do away with PowerPoints. The lesson plans we came up with didn't really rely on a PowerPoint and so, after we did the first one, that's kind of when I quit using the PowerPoints all together. (Grace, post-lesson study interview, 12/02/14)

In contrast to Shannon and Grace's response, Spencer thought it depended on the student. "Some will [understand] it better. Some are more eager to learn" (Spencer, post-lesson study interview, 12/04/14). Like Spencer, Clint also stated that his students had mixed reactions.

> I think a lot of it has to do with expectations that I set, and they didn't necessarily know what they were coming into in the classroom. I think if you implement any of the strategies at the beginning of the semester, then they'll be more effective. That way, they'll know, coming in, how they are going to be taught. (Clint, post-lesson study interview, 12/02/14)

Since Shannon implemented a variety of instructional strategies in her lessons from the first day of class, she felt students responded well with the different approaches utilized throughout lesson study. Grace also implemented strategies early in the semester and felt that students responded well to the strategies. However, Spencer and Clint, who did not introduce these activities from the beginning of the semester, had mixed reactions from their students. Clint stated he felt expectations for these instructional approaches needed to be established earlier in the semester to be more effective.

Were The Goals of Lesson Study Met?

At the beginning of the semester, each participant was asked what they hoped to gain from lesson study. At the end of the semester, participants were asked if their participation in lesson study helped in his/her obtainment of the goal. Each participant had positive responses to this question. Shannon stated that the one thing she hoped to gain by participating in lesson study was “an increase in my content knowledge because I do not feel confident that I understand the fine details and processes described in biology labs at the undergraduate level” (Shannon, written reflection, 09/02/14). At the end of lesson study, Shannon affirmed, “Having to prepare to lead the TAs forced me to dig into the content deeper, so in that respect, yes. However, I was surprised by how much content I really did know based on my conversations with the participants” (Shannon, post-lesson study interview, 12/09/14).

While Shannon discussed increasing content knowledge as her goal, Grace stated that she hoped that discussing lesson plans with peers will “help improve my teaching abilities. I hope that this lesson study changes the way I view lesson plans and the way I present material to students” (Grace, written reflection, 09/03/14). When asked at the end of lesson study if her participation helped in these areas, Grace replied, “Yes, in all of them. It definitely exceeded my expectations” (Grace, post-lesson study interview, 12/02/14).

Similar to Grace, Spencer had hoped to “gain insight as to how a teacher should go about planning to teach a topic and then executing that plan by following it in the classroom setting” (Spencer, written reflection, 09/08/14). When asked if he felt as though his participation helped with these aspects, Spencer replied, “Yes, definitely I think so. [Lesson study] helped me in working with a group like it helped me realize how much planning does go into a lesson. Then, watching other people teach helped as well" (Spencer, post-lesson study interview, 12/04/14).

Clint said that he "hoped to gain insight from other teachers who have taught the course and who have pedagogical training" (Clint, written reflection, 09/02/14). At the end of lesson study, Clint felt talking with Shannon and Grace helped him understand "what to expect, even on the tests like how [students are] going to do, how they're going to study" (Clint, post-lesson study interview, 12/02/14).

Each participant had an expectation of what they hoped lesson study would accomplish for them. After participating in lesson study, each participant believed this expectation was met. Shannon realized she had more content knowledge than she had thought, Grace felt as though her teaching had improved, Spencer felt that he had a better understanding of planning a lesson, and Clint felt as though he has gained insight from experienced others.

Would You Participate in Lesson Study Again?

When asked if they would participate in lesson study again, each participant stated they would. Shannon stated:

> I think that it might be something that could change the biology department. It's pretty easy to do especially if they waive you from your tutoring hours. I would think that maybe you should have, at least, one year of teaching experience before you could participate because, otherwise, you're trying to keep your head above water. (Shannon, post-lesson study interview, 12/09/14)

While Shannon thought this type of professional development could change the biology department, Grace said she would participate every semester:

> There's always something to learn. So, I've been thinking recently, I would like to sit in on more classes that the more experienced educators are teaching because sitting in on the labs where the other TAs taught was very good and I would like to continue doing that. (Grace, post-lesson study interview, 12/02/14)

Unlike Shannon and Grace who had more favorable responses, Spencer's answer was less emphatic. "Yes and no. Yes because I do feel like it was beneficial and helped me out. No because it is a little time consuming. That's the only negative I've found and it's not even that big of a deal" (Spencer, post-lesson study interview, 12/02/14). Unlike Shannon, who believed participants in lesson study should have at least one year of teaching experience, Clint believed lesson study was beneficial as a first semester teacher. However, he discussed how he would like to participate as an experienced teacher in order to get a different perspective.

> It's always nice to get different viewpoints. It feels good to be able to teach somebody and to teach another teacher to teach. So yes, I would participate again. . . . I think there's always room for improvement and room to benefit from. . . . I think it benefits the [GTAs] who are just coming into the practice the most, but I think it's important to participate even after your first semester because the only way that those people were able to help you is that they had taught and shared their experience and knowledge with you. (Clint, post-lesson study interview, 12/02/14)

Overall, each participant believed lesson study was beneficial, and three of the four would definitely participate in lesson study again.

What Are Your Career Goals After Graduate School?

When asked about their career goals after graduate school, two of the four participants stated their goal was to continue to teach in some capacity, while the other two participants mentioned teaching as a possibility. Shannon discussed how she wanted to be involved with teacher preparation at either a university or learning center to "conduct research to continue to explore what makes teachers effective in order to translate that into practice with the primary goal of improving student learning" (Shannon, post-lesson study interview, 12/09/14). Similar to Shannon, Grace also mentioned teaching after graduate school. "I want to teach biology in South America or Asia" (Grace, post-lesson study interview, 12/02/14). Clint mentioned a possibility of teaching after graduate school, but he was not certain at this early stage in his career.

> If I do decide to pursue teaching in some capacity then this will be very helpful to me. If not, I can always apply methodologies that you learned in teaching. Everyone, in some level, is a teacher. Even if I worked for a company, teaching new employees, etc. I think this is applicable. (Clint, post-lesson study interview, 12/02/14)

Even if Clint did not pursue teaching as a career goal, he felt strategies learned in lesson study could be beneficial in many different capacities in other careers. Similar to Clint, Spencer was unsure of his career plans after graduate school.

> They are still kind of up in the air. If a job presented itself, like with the [Tennessee Wildlife Resource Agency] in the fisheries department or something,

> that would be ideal, but also, to continue to do research, maybe a career in academia would be cool. You get to do what you want and study what you want. I thought about that, as well. Money is important, also. (Spencer, post-lesson study interview, 12/04/14)

Spencer mentioned a possible career in academia, but not for the reason of teaching students, but rather to continue his research.

Summary

Each participant believed the collaboration that occurred during lesson study was beneficial in his/her teaching. Additionally, each participant viewed lesson study as influential in their teaching practices for a variety of reasons including reflection, observing peers teach, and establishing learning goals with a more conceptual approach. All participants had revised their teaching as a result of lesson study ranging from curricular aspects to instructional approaches. Participants mentioned more rewarding aspects of lesson study than challenges, with the only challenge mentioned being the amount of time involved. Participants viewed lesson study as a non-threatening and relaxed environment that allowed ideas to organically emerge. The participants who implemented different instructional strategies from the beginning, or early on, believed their students responded positively to the instructional approaches created during the lesson study process. The participants who did not, had mixed reactions from students. Each participant's individual expectations at the beginning of lesson study were met, and each participant said lesson study was a type of professional development that was beneficial to their teaching. Three of the four participants stated they would definitely participate in lesson study again, with the one participant stating he thought lesson study helped his teaching, but was time-consuming.

Chapter Summary

This chapter portrayed the aspects of each participant's PCK as they participated in lesson study. Shannon demonstrated a strong understanding of all aspects of PCK, which were aligned with the framework for science teaching in higher education, *Vision and Change* (AAAS, 2011). She believed more emphasis should be placed on conceptual learning, a belief that emerged in both Grace and Clint during the semester. Throughout both cycles of lesson study, Shannon expressed the importance of establishing learning goals for each lesson, and guided the lesson study team in creating these goals based on common misconceptions and student difficulties. Even though the lesson study team established learning goals for both lesson study cycles, Shannon was the only participant to explicitly state learning goals to her students. At the end of lesson study, all of the participants made instructional changes to the curriculum by using at least one strategy used in lesson study. Additionally, all participants felt as though collaborating with other GTAs in lesson study was beneficial to their teaching. Each participant believed his/her goals for lesson study were met and welcomed participation in lesson study in the future.

CHAPTER V: DISCUSSION

Introduction

This research explored the potential that lesson study holds for advancing graduate teaching assistants' (GTAs') PCK while teaching an introductory biology laboratory course. One purpose of the study was to investigate the components of PCK that emerged while the GTAs participated in lesson study. Another goal of this study was to determine GTAs' perceptions of lesson study as a form of professional development. A brief restatement of the research problem and a review of the methods used in this study are presented first in order to frame the discussion. The chapter ends with a discussion of the results and the implications for science education research and practice.

The Research Problem

This study was conducted to address the issue that many institutions of higher education are experiencing, that of high attrition rates in students majoring in STEM (Atkinson & Mayo, 2011; Seymour & Hewitt, 1997; Strenta et al., 1994). Of the students who change their majors to a non-STEM field, research demonstrates that many highlight the role of the instructor as a primary reason for leaving (Seymour & Hewitt, 1997). STEM faculty, including GTAs, should utilize research-based instructional strategies to improve student learning and retention (Seymour & Hewitt, 1997).

GTAs are responsible for teaching the majority of biology undergraduate laboratory sections in many institutions of higher education (Gardner & Jones, 2011; Miller et al., 2014) despite many having inadequate training in aspects of effective teaching (Golde & Dore, 2001). Many institutions of higher education offer some sort of limited teaching professional development, but these programs are not necessarily meeting the needs of GTAs (BioTAP, 2013; Gardner & Jones, 2011; Prieto & Scheel, 2008; Rushin et al., 1997). This study sought to address this need in a limited capacity by engaging a small group of GTAs in professional development and exploring their emergence of PCK, which has been shown to be critical for effective instruction (Shulman, 1986).

The professional development chosen for this project was lesson study, because it has played a key role in improving student achievement in secondary education in both Japan and the United States (Fernandez & Yoshida, 2004). The features of lesson study, which include research, collaboration, observation, and reflection, are believed to create changes in teachers' knowledge and beliefs (Lewis et al., 2009), which can inform the development of PCK (Magnusson et al., 1999). PCK is an integration of both content knowledge and pedagogical knowledge and involves teachers' understanding of the best ways to help students comprehend the specific subject matter using multiple instructional strategies, examples, and explanations (Shulman, 1986).

Several studies have documented K-12 teachers' participation in a lesson study (Lewis et al., 2009; Perry & Lewis, 2009; Saunders et al., 2009), but few have examined the impacts of this form of professional development at the post-secondary level (Cerbin & Kopp, 2006; Dotger, 2011). This study contributed to the limited amount of research available for professional development models for GTAs as well as the use of this professional development model in post-secondary settings.

Review of Methodology

As a case study, this research used a qualitative approach to describe the components of PCK that emerged through the process of lesson study. A single-case design with multiple units of analysis was utilized. The single case included the group of GTAs, and the embedded units of analysis included the individual participants who were involved in the lesson study team.

Multiple data sources were utilized in order to achieve triangulation, and all data sources were coded by the researcher in two phases. The first phase included the five categories of PCK based on the Magnusson et al. (1999) framework, in which the researcher wrote a summary profile for each participant. In the second phase, a cross-case analysis of the four participants was conducted to determine similarities, differences, and additional themes that arose across participants. A discussion of the results is presented in the following sections and is organized by themes that arose from this research, implications for science education practice, and areas of future research.

Discussion of the Results

The researcher identified two aspects of PCK in which participants demonstrated growth after participation within the lesson study. These aspects included knowledge of instructional practices and conceptions of goals in science teaching, an aspect of orientations toward science teaching. These are discussed along with possible explanations for why growth was demonstrated along these aspects.

Second, the researcher identified occasions when participants failed to implement educational strategies as outlined by the facilitator and as articulated by themselves personally. Relevant data and explanations for this disconnect between intent and practice will be discussed. Finally, the researcher will situate the results of the current study within a related study (Dotger, 2011). This will be completed by highlighting the limitations as stated in the Dotger (2011) study, and discussing how addressing these limitations impacted the current study.

Aspects of PCK that Demonstrated Growth

The data revealed that there were two aspects of PCK in which participants demonstrated growth after participation in lesson study. These aspects included goals of science teaching, which is one of the three components of orientations to science teaching, as identified by Friedrichsen et al. (2010), and knowledge of instructional strategies. A discussion of each aspect follows.

Conceptions of goals of science teaching. A teacher's orientations to science teaching refers to knowledge and beliefs about the goals and purpose for teaching science (Magnusson et al., 1999). These beliefs guide instructional decisions in the classroom including selection of curricular materials, determination of goals and objectives, instructional practices, and assessment of student learning (Borko & Putnam, 1996). Friedrichsen et al. (2010) identified three important aspects of science teaching orientations that shape science teaching beliefs: conceptions of science teaching and learning, conceptions about NOS, and conceptions about the goals of science education. The participants demonstrated growth in their conceptions of goals of science education, but did not demonstrate growth in their conceptions of science teaching and learning or their conceptions about NOS.

Although teachers work together during the professional development to plan and discuss a research lesson, their individual beliefs become visible (Lewis & Hurd, 2011). Shannon believed the amount of reflection she did because of her role as the facilitator in lesson study helped to identify her teaching philosophy as a constructivist. Throughout both cycles of lesson study Shannon guided the participants to incorporate student-centered instructional methods that offered students a more conceptual approach to their learning; a practice highlighted in *Vision and Change* (AAAS, 2011). Both Grace and Clint expressed their goal in teaching had changed to a more conceptual approach. However, Spencer's philosophy toward teaching remained consistent.

Perhaps the change in Grace and Clint's philosophy was due to their beliefs in the role of a teacher. Grace's beliefs of the role of the instructor was to present the information the best way she could, while Clint felt the instructor should "lay down the layers" for students to "foster creativity needed for synthesis of new ideas" (Clint, weekly reflection, 11/03/14). In contrast to the other participants, Spencer felt he should be prepared to present the information and be able to answer questions from students. He felt the role of the instructor was limited, especially if the student did not work outside the class. According to Magnusson et al. (1999), the other constructs of PCK are filtered through their orientations to science teaching. Spencer's belief in the limited nature of the instructor could be the reason he demonstrated the least development of PCK as indicated by the data.

Perhaps the change in goals for science teaching for Grace and Clint was due to motivation behind their teaching. All four participants mentioned wanting a career in academia, but Spencer, who did not change his beliefs in goals in science teaching, was the only participant who did not mention teaching as a career goal. Spencer mentioned a career in academia, but for the reason of continuing his research. This sentiment, that teaching is viewed as a secondary career, is common in the academic setting (Shannon, Twale, & Moore, 1998). Shannon was passionate in her delivery to the lesson study team of current science education research that indicates that students learn best when instruction is student-centered and focused on conceptual understanding. Because Grace and Clint had a desire to teach or possibly teach past graduate school, perhaps they placed more value on Shannon's explanation of the research behind reformed-based teaching strategies. Further questions arise as to how professional development can change GTAs' beliefs if they are not motivated to improve their instruction.

Knowledge of instructional strategies. *Vision and Change* (AAAS, 2011) recommends that instructors shift their focus from a faculty-centered instruction in which facts are given priority, to student-centered instruction focusing on concepts, and it recommends a variety of strategies to achieve these instructional goals. Such strategies include concept mapping (Novak, 1998) and the 5-E learning cycle (Bybee, 1997). Shannon, who entered the lesson study with knowledge of these instructional approaches, guided the lesson study team to implement these strategies into their lessons, which supported the growth of this aspect of PCK within the other participants. In addition to these strategies, the participants were introduced to other student-centered methods including the sticky note activity, what students know/what students learned activity, and the collaborative article engagement activity. Each participant incorporated one of the activities in their post-lesson study observation, and each said he/she would utilize one or more of the above activities the next semester. It is unknown how effective the new strategies were, as this was outside the scope of this study. This would be the next stage of research regarding lesson study with GTAs.

Summary. As the facilitator of lesson study, Shannon felt it was important to guide the other participants to research-based strategies that shifted the focus of learning on the student. Because of this, Shannon stated she reflected a great deal during the lesson study process. This reflection allowed Shannon to establish that she held constructivist views in teaching, which seemed to resonate with both Grace and Clint who both stated their philosophy of teaching shifted to a more conceptual approach to learning. Possible reasons why all participants did not change their goals to teaching science could be due to their beliefs of the role of the instructor and student as well as GTA motivation. Shannon's knowledge of instructional approaches of student-centered instruction was passed to all participants during the process of lesson study, as all participants increased their knowledge of instructional strategies. However, it is still unknown how effective these strategies were in terms of supporting students' understanding.

Disconnect Between Intent and Practice

There were several instances in which the conversations that occurred between participants did not manifest itself in the teaching of the participants' lessons. Examples of this disconnect included establishing learning objectives, implementing concept mapping, and understanding the value of "telling is not teaching." Each of these will be discussed in this section, with an explanation from the literature as to why there may be a disconnect between intent and practice for these particular aspects.

Goals and objectives. *Vision and Change* (AAAS, 2011) suggests that instructors should clearly articulate expected student learning outcomes and follow students' progress in achieving those outcomes; a practice that Shannon conducted from the beginning of the semester. Additionally, while the team planned both lessons, Shannon guided the other participants in establishing learning goals. Clint mentioned the best teachers in his past had "specific learning objectives and activities that directly address these objectives" (Clint, written reflection, 10/29/14). Grace believed that "looking at the lessons differently and approaching [lessons] with goals in mind" was extremely influential in her teaching (Grace, post-lesson study interview, 12/02/14). Despite placing value on establishing learning objectives, none of the participants except Shannon explicitly stated learning objectives to their students while teaching their iteration of the research lesson or during their post-lesson study interview.

Concept mapping. *Vision and Change* (AAAS, 2011) states that once learning goals and assessment strategies have been established, instructors should then choose instructional strategies to help achieve those goals. Concept mapping (Novak, 1998) was one of the recommended strategies listed. Shannon introduced the idea of concept mapping to the lesson study team. After implementing their own concept map as a team in the protist/algae lesson, each participant placed value on utilizing a concept map. Spencer said it helped him to understand protist/algae better since it had been a while since he learned about them. However, when asked if he would use the concept mapping activity the next time he taught this lesson, Spencer expressed the students' difficulty in creating the concept maps, and felt as though there was "a better way to do [the concept map]" (Spencer, post-lesson study interview, 12/04/14). Clint tried to incorporate a concept map with his students during the lesson over the topic of fungi, but abandoned the activity because he felt students were "hesitant because there was a great deal of new terminology" (Clint, post-lesson study interview, 12/02/14). These examples indicated that there was difficulty with implementation of the concept map with the novice participants.

Telling is not teaching. Shannon stated the phrase "telling is not teaching" several times, but after observing the participants teach his/her lesson, Shannon felt as though her efforts were not enough. Despite utilizing a variety of instructional strategies, Shannon felt the participants were still telling students the information they needed to hear, rather than the students determining the answers on their own. This was a sentiment also viewed by the researcher during the post-lesson study observations.

Reason for disconnect between intent and practice. Many traditional professional development programs are ineffective because they are unable to support teachers during the implementation stage of learning (Gulamhussein, 2013). Lesson study provides an opportunity for participants to support one another during the implementation phase. Despite this strength of lesson study, there were a few instances of disconnect between the participants' intent and practice. The following section discusses three possible reasons for the disconnect demonstrated in this study: an awkward implementation phase, the duration of the lesson study, and the inexperience of a majority of the participants.

An awkward implementation phase. The research indicates that teachers struggle when implementing new strategies in the classroom (Joyce & Showers, 2002). While learning a new skill, a teacher must push through the awkward first trials, even when the effectiveness of the student learning may be low. Joyce and Showers (2002) believed that persistence in utilizing new approaches seems to differentiate successful from unsuccessful teachers. Haberman (1995) identified persistence as the first of 15 functions of successful teachers of children in poverty while Wheatley (2002) believed teacher persistence is critical for teaching excellence. Wheatley further stated that persistence is crucial for successful implementation of educational reforms that call for changes in instruction (2002). Therefore, teacher persistence in using new strategies is crucial in order to be effective in student learning.

Student discomfort with change may also encourage the teacher to abandon the new strategy altogether (Joyce & Showers, 2002). When new teaching approaches require students to take greater responsibility for their learning, teachers may also have to persist to work through the student resistance that the new approach often creates (Wheatley, 2002). Both Shannon and Grace implemented research-based instructional strategies from the beginning of the semester, and both felt their students responded well to the strategies that were developed during lesson study. However, both Spencer and Clint, who did not implement research-based instructional strategies from the beginning, stated they had mixed reactions from their students. Furthermore, they both mentioned students having difficulty creating concept maps. For example, while performing the concept map with his students during the post-lesson study observation, Clint abandoned the strategy because he said his students were having difficulty. However, during the photosynthesis lesson, Clint noticed students having difficulty with the sticky note activity and stated that working through this difficulty was how students learn. Perhaps if Clint had continued to let students work through the difficulty in the concept maps and had demonstrated persistence in this strategy rather than abandoning the strategy, he would have felt more comfortable the next time he asked students to create a concept map. It would be interesting to determine participants' perception of concept mapping and similar strategies after they continue to persist through the awkwardness of the new activity in subsequent semesters.

Duration of lesson study. The duration of professional development is related to the depth of teacher change (Shields, Marsh, & Adelman, 1998; Weiss, Montgomery, Ridgway, & Bond, 1998). Several sources indicated that in order for teachers to truly change practices, professional development opportunities should occur over time and be ongoing (Banilower, 2002; French, 1997; Garet, Porter, Desimone, Birman, & Yoon, 2001). According to Darling-Hammond et al. (2009), professional development programs that offered contact hours ranging from 30-100 hours spread over 6-12 months showed a positive and significant effect on student achievement gains. More specifically, professional development programs that offer 49 hours in one year boosted student achievement by approximately 21 percentile points. The authors found that programs that offered 4-14 hours showed no statistically significant effect on student learning. It is important to note that the authors in the above study were not looking at professional development programs that were embedded in context, such as lesson study. The participants in this study participated in discussions for 10 hours, and observations for 8.25 hours for a total of 18.25 hours of total time spent in professional development, which is slightly above the time period of the studies that demonstrated no effect on student learning.

Although the professional development in this study lasted throughout a semester, it would not be considered ongoing. The National Education Association (NEA) believes ongoing professional development should be required throughout the career of educational personnel. In order for professional development to be considered ongoing in this context, it would need to last throughout the educational career of the GTA.

Therefore, in order for more aspects of PCK to emerge, GTAs would need to participate in lesson study for as long as they are teaching undergraduate students.

The inexperience of participants. Three of the four participants in this study had no prior training in research-based instructional strategies. Joyce and Showers (2002) claim that teachers need a deep understanding of theories involved; otherwise, teachers will be unable to utilize the new strategies in meaningful ways. Half of the participants of this study were novice instructors with no previous experience in teaching. After a review of the literature, Kagan (1992) found that novice educators approach the classroom with a "critical lack of knowledge" (p. 142) about students. Novice educators often assume that their students will possess aptitudes, problems, and learning styles similar to their own. As novice educators acquire knowledge of students, they use this information to modify and reconstruct their beliefs. While this occurs, novices tend to focus on their own behaviors rather than those of their students.

During the short duration of this study, it is possible the novice educators were still acquiring knowledge of their students and focusing on their own behaviors rather than those of their students. This could be the reason why Grace's and Clint's goals for teaching changed to a more conceptual approach, but not their practices. They continued to tell students what they needed to know rather than have students discover meaning on their own. Additionally, the idea that the GTAs were focusing on their own behaviors rather than the students' could be the reason more aspects of PCK did not emerge during this study. Perhaps more changes would occur if the study was ongoing and extended over a period of two to four semesters rather than one.

Summary. There were several areas where conversations in lesson study meetings did not translate into practice. Examples of disconnect included explicitly stating learning objectives, difficulties with concept mapping, and the value of telling is not teaching. The literature indicates possible reasons for this disconnect. Instructors should demonstrate persistence as they utilize new teaching strategies despite student resistance and their own hesitation with employing new approaches. Additionally, it appeared that the inexperience of the majority of the participants could have led to disconnect. Novice instructors hold assumptions that all students learn as they learned. As they try to acquire knowledge of their students, much of the focus is placed on their own behaviors rather than those of their students. Finally, the literature indicated that professional development should be ongoing and occur over time in order for teachers to change their practice. Perhaps one semester of lesson study was not enough for the novice instructors to change their focus from their own behaviors to that of their students.

Addressing Limitations in Previous Work

One of the initial rationales for this study was to address the limitations to Dotger's (2011) study that explored the impact of lesson study on GTAs in an Earth Science department. As stated by Dotger (2011) these limitations included all novice participants with no understanding of knowledge of teaching, no formal research plan, and only one cycle of lesson study. The following sections will discuss how the current study addressed each of the limitations of Dotger's study and what, if any, impacts this had on the resulting PCK of participants.

All novice participants with no knowledge of teaching. Dotger's (2011) study included four novice GTAs with no understanding of learning objectives, consideration of student prior knowledge, or alternative instructional strategies. Because of this, Dotger believed that the lesson the team created did not deviate much from the original lesson. The current study addressed this limitation by including a participant who had previously taught this particular course. Grace was helpful in informing the lesson study team of areas of the lessons where students typically had difficulties in their learning.

Additionally, this study incorporated a facilitator who was trained in educational theories and practices as well as many years of classroom instruction. Shannon was helpful in guiding participants to current research in science education as outlined by *Vision and Change* (AAAS, 2011). Because this study included an experienced GTA and a GTA trained in research-based instructional strategies, the lessons the team created deviated from the original lesson, unlike the Dotger (2011) study. Both lessons were formatted in a 5-E format and included research-based instructional strategies to focus student learning. Despite this, Shannon was the main contributor to these ideas and expressed difficulty in getting the novice participants to contribute to the conversations. Spencer, a novice participant, also expressed his lack of participation in the conversations. This seems to indicate that another participant with training in research-based instructional strategies would be beneficial to the team.

No formal research plan. Dotger (2011) indicated the absence of a research plan made it difficult to evaluate the lesson during observations and significantly impacted the outcome. The GTAs in this study were asked to write a research lesson plan for both cycles of lesson study. Ferndandez (2002) suggested that lesson study teams write annotated lesson plans which contain what to do and why/how to do it that way. These plans should include explicit learning goals, rationales for instructional practices, anticipated student responses and questions, and enough detail that teachers can implement the plan as intended.

For the first cycle of lesson study, Shannon created an annotated lesson plan based on conversations that occurred throughout the meetings. This was a huge task for Shannon, so the researcher asked that the lesson study team help Shannon compose the research lesson plan for the second cycle of lesson study. The lesson study team created most of this lesson during meetings seven and eight of lesson study, and each participant had a portion to complete on their own before the lesson was distributed to the outside reviewers.

The literature recommends that the lesson study team make the necessary revisions to the lesson after the re-teaching portion of lesson study to create continuously improving lessons that can guide teachers' implementations of them (Ferndandez, 2002). After the lesson study team made revisions to the lesson, no one volunteered to add the additions to the original plan, so there was no research lesson plan that reflected the changes the participants made to the lessons. Lewis and Hurd (2011) suggested lesson study teams prepare the results of their research in order to share with staff or faculty. For future studies with GTAs, this would be a helpful approach to ensure there is a final product of the research lesson the team created.

In this study, the participants created two research lesson plans. Notable plans helped the participants to articulate their rationale for student learning for each portion of the lesson. Having this plan was crucial in obtaining feedback from the outside researchers as well as guiding the instruction of their students. This was not the case in the Dotger (2011) study as all participants were novice and had never written a lesson plan. In this study, Shannon was the only participant with knowledge of how to write a lesson plan. She wrote the entire first research lesson plan and guided most of the writing of the second research lesson plan. Because of this, it is unclear as to how much the other participants understood about the major components that should be included in a research lesson plan.

One cycle of lesson study. Dotger (2011) indicated that one cycle of lesson study was insufficient to prompt a great deal of change in GTAs' thinking about student learning. Therefore, this study incorporated two cycles of lesson study during a semester. Given the nature of the sequence of the laboratories in this particular course, participants had five weeks to plan, teach, and revise each lesson. During the first cycle of lesson study, participants did not have enough time to create the research lesson plan in order to discuss the feedback from the outside reviewers. Additionally, Shannon wrote the entire research lesson plan on her own time because there was not enough time to do this during four short meetings.

During the second lesson study, the entire team created an outline of the research lesson plan, but only had one meeting to discuss the outside observers' feedback, which was not enough time. There was much to do in such a small period of time, so the researcher believed that two cycles of lesson study during one semester was too much to perform the lesson study effectively. Therefore, addressing this limitation by Dotger (2001) by including two cycles of lesson study in one semester was not effective; one cycle of lesson study during each semester would be more suitable. Due to the literature that states successful professional development should be ongoing, the researcher would suggest offering lesson study for the duration of GTAs' tenure in order for GTAs to gain a full understanding of lesson planning.

Implications for Science Education Practice

Although a single case study cannot provide a sound basis for the practice of lesson study as a form of professional development, the results of this study suggested that lesson study was beneficial for these GTAs in a general biology laboratory course for students majoring in Biology. Each participant felt that lesson study helped revise their teaching, and changes were seen in most of the participants' orientations to science teaching and knowledge of instructional strategies.

Despite these changes in beliefs, many areas of PCK did not show evidence of growth. Therefore, it is suggested that lesson study should be ongoing and GTAs should participate in at least two semesters of lesson study, with a presentation of the research lesson to the other GTAs who teach this course. All participants in this study said they would be willing to participate in one more semester of lesson study, with most of the participants expressing they would welcome ongoing participation in lesson study. The facilitator was beneficial in guiding participants to research-based instructional strategies, but because Shannon was the only participant with this knowledge, it would be interesting to see how two participants with training in educational practices and theories would change the dynamics of lesson study with the novice GTAs.

Because there appeared to be a disconnect between beliefs and practices, perhaps it would be beneficial for GTAs to participate in a science methods course during their first semester of teaching before they participate in lesson study. In this course, GTAs would be introduced to the research of educational theories and practices. This class could also serve as a support for their first semester of teaching, where they could discuss lesson planning, classroom management issues, and challenges during their first semester of teaching. All participants of this study believed conversations that emerged throughout lesson study were helpful in providing support for their teaching. After participation in this course, participants would then be better prepared to participate in lesson study in order to improve specific instructional strategies and methods, as well as their subsequent PCK.

Future Areas of Research

The next step of this research is modifying lesson study so that it provides the support that novice GTAs need to allow for the connection between intent and practice. Additionally, two participants mentioned their confidence in teaching improved because of their participation in lesson study. It would be interesting to measure science teaching self-efficacy of GTAs before and after lesson study to determine if there was a change.

Finally, it became clear at the beginning of the study that most of the participants did not have an understanding of NOS. Friedrichson et al. (2002) suggested a teacher's conceptions of NOS is an aspect of their orientations to science teaching that drives all other instructional decisions in the classroom. NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman et al., 2002).

The first lesson the GTAs taught titled "Nature of Science" focused primarily on the empirical aspect of NOS. Shannon was the only participant who recognized this, while the other participants had not heard the term before. This was similar to a study conducted by Aydeniz and Bilican (2013) that found many of the GTAs lacked an adequate understanding of various aspects of NOS. Whether the participants in this study had a naïve or informed view of NOS was not addressed. However, three of the four participants were not familiar with the term NOS, which indicates that training on improving GTAs' understanding of NOS could be beneficial. Especially since current science education literature suggests that an objective of science teaching should be to help students develop informed conceptions of NOS (Abd-El-Khalick et al., 1998). Therefore, more research on GTAs' understanding of NOS needs to occur to determine how their understanding affects their orientations toward teaching science. Questions to ask would include what is the role that this limited view of NOS played in the limited development of PCK? Might the participants reap greater rewards from participation in lesson study had they been provided with initial opportunities to develop a deeper understanding of NOS?

Chapter Summary

In order for STEM majors to remain in their field in higher education, the quality of instruction in STEM classrooms needs improvement (Seymour & Hewitt, 1997). Many undergraduate students majoring in STEM encounter GTAs during their first years of instruction, making the GTA an impactful instructor during the early years of STEM education. Despite this, many GTAs are not trained in research-based instructional strategies and do not feel adequately prepared to teach. This study established lesson study as a type of professional development that is beneficial to GTAs in developing certain aspects of PCK, a construct that has proven to be important in successful teachers. In this study, all participants believed that lesson study was influential in changing their instruction in the classroom. Most of the participants showed growth in their conceptions of their goals of science education, and all participants showed growth in knowledge of instructional strategies. Despite these changes, there appeared to be a disconnect with participants' beliefs and their practices. Possible reasons for this disconnect could be the duration of lesson study, the novice educators who participated in lesson study, and the unwillingness to persist during the awkward periods of implementing new instructional strategies. In spite of this, the facilitator served as a valuable tool in guiding the participants to research-based instructional strategies in science teaching and learning.

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APPENDICES

APPENDIX A

PRIME PCK Reflection Template

Example: PCK Reflection on **Cell Structures**

Think of a lesson you taught about **cell structures**. Use the matrix below to describe the lesson (Use as many rows as necessary)

Step	What I Will Do	What the Students Will Do	Rationale
1			
2			
3			
4			
5			

1. Why are **cell structures** important in the study of biology?

2. What did you find that your students typically knew about **cell structures** when they come to class?

3. What did students typically struggle with when they were studying **cell structures**?

4. What were the advantages of the teaching strategies you used in this lesson?

5. What alternative teaching strategies did you consider in addition to those suggested in the curriculum?

6. If you made changes to the curriculum, what prompted you to do so?

APPENDIX B

Lesson Observation Log

Title of lesson:

Goals of the lesson:

Observation objectives:

Time	Observation	Significance

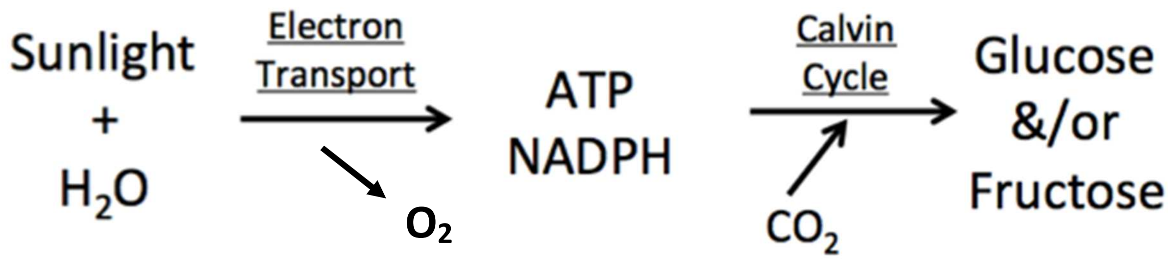
Conclusions:

Further questions raised:

APPENDIX C

Photosynthesis Lesson Plan

BIOL 1111 Photosynthesis Lesson Plan



Exercise 13 Photosynthesis

- Marker Pigments-Analogy for multiple components of plant pigments
- Photosynthetic Pigment Separation (Procedure 13.1)
- Absorption of Light by Chlorophyll (Procedure 8.4)
- CO_2 Uptake During Photosynthesis (Procedure 13. 4)
- Use of Light and Chlorophyll to Produce Starch (Procedure 13.6, 13.7, and 13.8)

- **Guiding Questions (from lecture study guide to be aware of)**
  - What colors of light excite electrons to the highest energy state?
  - What are the starting materials and products of photosynthesis?
    - What is the starting material for the photosynthetic electron transport chain and what product(s) is/are produced?
    - What is the starting material for the Calvin cycle and what product(s) is/are produced?
  - If a plant has green leaves, what do you know about the light that is absorbed by the plant and what do you know about the light that is reflected by the plant?

Learning Goals:

- **Understand the overall starting materials, products, and importance of photosynthesis and the reactions therein.**
- **Be able to relate each lab activity to the photosynthesis equation.**

Engage: instructor is *guiding* students into a discussion amongst themselves.

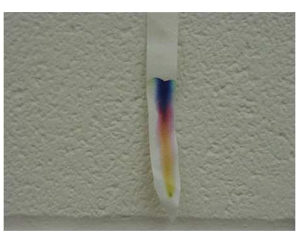
Marker Chromatography Activity

Materials (per table group: One side of table will use the acetone, the other side will use the water)

- 4 pieces of chromatography paper or coffee filter
- One sharpie and one vis a vis black marker
- Acetone
- Water
- (2) 200 mL beakers (or smaller)
- Dowel or pencil
- Tape

Procedure: Students cut the chromatography paper or coffee filter into four 10 cm x 2cm pieces. Fill the beaker with 10-15 ml of water or acetone (one side of table will fill beaker with water, the other side will fill beaker with acetone) Each group of two students should make a dark circle with the vis a vis marker on one sheet of chromatography paper, and a dark circle with the black sharpie on the other sheet of chromatography paper. Make sure the black marker is about halfway up the paper. Each group of two should wrap both papers around the dowel or pencil and tape so that the paper hangs into the cup and just touches the liquid and the black circle is at least 1 cm above the surface of the liquid. Water or acetone should move up the paper and students can observe the colors separating. Each group of two should see the movement from the other side of the table and compare. **(These instructions will be displayed via PowerPoint or verbal instructions from the instructor)**

Below: Black vis a vis in water (sharpie in acetone is not quite as dramatic but water should do nothing to sharpie)



Set up and while they wait (3-5 minutes) have them answer the questions to assess student prior knowledge:

> **"Where does the mass of a plant come from?"** (Use visuals such as seeds and a large branch per the Harvard video to ensure students know what you are asking)

-Have students collaborate at their table to put an answer on the board. This is a chance for students to have fun with discussing; maybe turn it into a competition to keep them involved.

Hopefully the process of photosynthesis has come up in discussion…now ask class

"What do you know about photosynthesis?"

Student answers should provide what they know, misconceptions, and what they don't know. Refer to these ideas throughout the lab. Students can add to or change what is on the board based on experience in the lab. This idea of the mass of a plant coming from CO_2 should be emphasized during procedures 13.4 (uptake of CO_2), 13.6 (starch production)

Exploration: *Instructor guides students through the procedures and helps them understand the role light and pigments play in photosynthesis. Encourage students to explain what they observe to others in their group. Student questions can be written on the board as they arise.*

<u>Photosynthetic Pigment Separation (Procedure 13.1)</u>

- Guiding Question(s):
  - What plant pigments are in spinach extract?
  - Why does the absorption spectrum for the extract not match the absorption spectrum shown for **Chlorophyll a** on page 87? (**discuss in class)**
  - How is the marker activity similar to plant chromatography?

Procedure 13.1: Students work in pairs.

- Students will obtain a strip of chromatography paper from the lab instructor, being sure to handle the paper by its edges so that oil from the fingers does not contaminate the paper.
- Using a fresh spinach leaf and a quarter (or dime), students will roll a line of green pigment onto the chromatography paper approximately 2 cm from the tip of the paper.

- The chromatography strip will then be placed in a test tube containing 2 mL of chromatography solvent (9 parts petroleum ether : 1 part acetone). The chromatography strip will be positioned so that the tip of the strip (but not the stripe of the plant from the coin) is submerged in the solvent.
- The tube will then be placed in a test-tube rack and students will watch as the solvent moves up the paper. The tubes will be capped and undisturbed during solvent movement.
- The chromatography strip will be removed before the solvent front reaches the top of the strip (~5 minutes). Students will mark the position of the solvent front with a pencil and set the strip aside to dry. While drying, students will observe the bands of color, and then draw their results on figure 13.5. They will use their textbook or other materials in lab to identify the different bands of pigments according to their position and color. For example, xanthophylls appear yellow.
- Students will use a ruler to measure the distance from the pigment origin to the solvent front and from the origin to each pigment band. Students will calculate the R_f number for each pigment and record data in table 13.1.

- The instructor should revisit the marker activity while the pigments separate.. Where did the colors from the mark of green pigment come from? Why do we see black and not the other colors in the marker? (absorbance)
- Students fill in figures 13.5 (blank chromatogram) and Table 13.1 (Table of pigments in plants). Could they determine an R_f value for the marker pigments? (discuss)
- In table groups have students answer Question 2 a-e in the lab manual. Instead of giving them the answers have them write the questions they have on the board. If another group can answer the question or help explain let them ☺

  2a. What does a small R_f number tell you about the characteristics of the moving molecules?

  b. Which are more soluble in the chromatography solvent, xanthophylls or chlorophyll a? How do you conclude this?

  c. Would you expect the R_f number of a pigment to change if you altered the composition of the solvent? Why or why not?

  d. If yellow xanthophylls were present in the extract, why did the extract appear green?

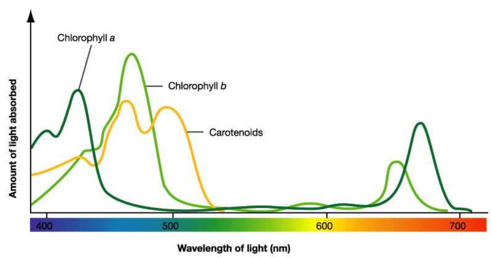
  e. Is it possible to have an R_f number greater than I? Why or why not?

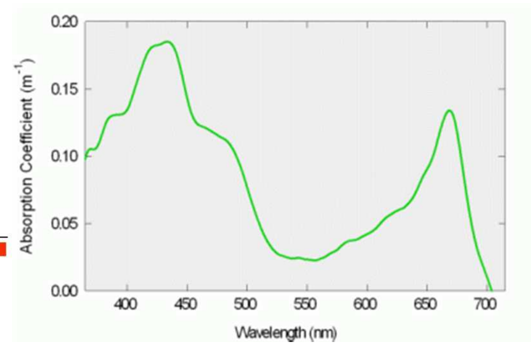
***Determining the Absorption Spectrum of Chlorophyll* (Photosynthesis: Procedure 8.4)**

- Guiding Question(s):
  - What is the function of plant pigments?
  - If a plant has green leaves, what do you know about the light that is absorbed by the plant and what do you know about he light that is reflected by the plant?

Procedure

- The students should already know how to use the specs thanks to the enzyme lab. The blank will already be prepared (80% acetone).
- The instructor will make a spinach slurry by using a mortar and pestle to grind a few spinach leaves in a little acetone. Use 1-2 leaves; the slurry needs to be a light green color. You will dilute the spinach extract with acetone to reach the desired light green color. The instructor will then use the Buckner funnel to filter the slurry. This will be demonstrated in more detail at the pre-lab meeting.
- The students will measure the absorbance of chlorophyll for the following wavelengths:
  - 350 nm, 420 nm, 460 nm, 490 nm, 530 nm, 570 nm, 610 nm, 660 nm, and 700 nm
  - Note: the lever on the bottom left of the spec must be moved from left to right position when the students move from 570 nm to 610 nm.
    - Chlorophyll slurry will be in a small glass cuvette used specifically for the specs (same as enzyme lab)
    - Spec will need to be blanked before ***each*** reading
- The students will graph absorbance vs. wavelength, and will see several peaks. The peaks represent sunlight wavelengths absorbed by the major pigments (chlorphylls a and b, and the carotenoids, seen in the paper chromatography experiment). This is where to revisit the marker analogy and talk about absorbance and reflection.
- Getting students to understand Rf values might mean using something simple like the marker chromatogram as an extra example. The goal isn't to get them to understand what an Rf value is but rather that molecules with different properties (size, polarity, solubility, etc…) travel different distances and have unique Rf values. An Rf value is simply a mathematical number used to help identify unknown molecules. They might understand this better using the black marker as an example. The red pigment always traveled the same distance so we know the same red pigment was in all the markers.
- Why does the absorption spectrum for the extract not match the absorption spectrum shown for **Chlorophyll a** on page 87? Relate to marker analogy and be explicit that we are putting ALL the pigments into the spectrophotometer so we will get a non-discrete spectrum.
  See below.



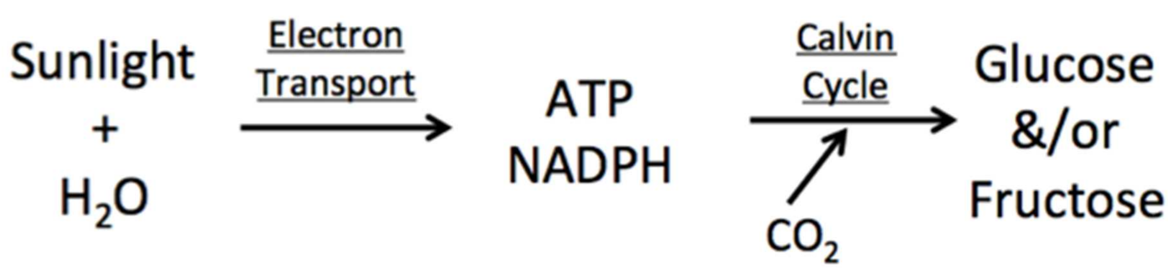


Discrete   Non-discrete

Explanation: ***Discuss the overall photosynthesis equation with students, relating the utility of pigments and light to the function of photosynthesis.***

Use student questions to clarify, allow students to discuss results in groups. This would be time for a **<u>short</u>** PowerPoint or class discussion-<u>use lab examples</u> to highlight chloroplast structure and function and the photosynthesis reaction.* Refer to student work/questions on the board to clarify concepts and fill in gaps in knowledge. Ask questions such as, "Where do the pigments fall in this equation?" Introduce photosynthetic electron transport (light dependent reactions p. 137)

**Check your time and make sure you will be able to get students to complete the activities in time.*



Elaboration: ***Informal evaluation of student understanding (their questions, your interactions with students) guides elaboration.***

We've talked about half of the equation, what other processes encompass photosynthesis? Where does this happen in the cell? What does the plant need? (Even point students back to the where does plant mass come from question).

<u>Procedures 13.4 (Uptake of CO_2), 13.6 (Starch Production), 13.7 (Light), 13.8 (Chlorophyll)</u>

Procedure 13.4

- Guiding Question(s):
  - What happens to phenol red when you blow carbon dioxide into it?
  - What happens to that same solution of phenol red when you leave photosynthesizing leaves in it for a period of time, and why?
  - Where do plants get their mass? (Emphasize this!)

<u>Follow manual directions</u> for **Procedure 13.4** using phenol red (**dilute the stock phenol red with 12 parts water to 1 part P.R**.) and *Elodea*.

Provide per table: two lamps with 100 w bulbs, 4 small beakers, 4 straws. Students will work in pairs. Follow manual instructions, but fill 1 beaker about 2/3 full with phenol red. Using straws students should blow **gently** into the phenol red solution. CAUTION: splashing likely! Blow, do not suck! Pour ½ the phenol red into the second beaker. Select healthy *Elodea* and break into 3-4 pieces (total 10 cm) so that it is covered easily by the phenol red solution in 1 beaker.

***** Special note – This semester we will try something new: While explaining this procedure, you should prepare 2 beakers with the phenol red (do not blow into these) – 1 with just p.r. and one with p.r. and *Elodea.* Ask the students what should happen if you put the beakers in darkness. Put both beakers in a dark spot for about 90 min then pull them out and show that the Elodea beaker turned orange (we hope). Ask the students to explain why.**

Explaining Buffer Solutions-*add if this makes sense in context of your discussions with students. They may ask about the equation in the lab book.*

Biological systems have to maintain a relatively stable internal state. This is called homeostasis. One of the factors affecting homeostasis is pH. To maintain this narrow window of pH ranges the human body uses a carbonate buffer solution. A buffer solution is aqueous (the solvent is water) and it contains a weak acid and its conjugate base or vice versa. When a small amount of acid or base is added to the solution the weak acid or base dissociates and pairs up with the new acid or base. This means that the solution can maintain its pH even if a small amount of strong acid or base is added. It also means that a buffer has a capacity and will stop working after a certain amount of acid or base it added.

Main Points

- A buffer solution is made of water and a weak acid/conjugate or base/ conjugate. Ex H^+/ HCO_3
- A buffer solution maintains a certain pH range based on the weak acid or base used. The range can be at nearly any pH depending on the acid or base.
- Buffer solutions have a capacity which means they work perfectly until too much acid or base is added and then they don't work at all.

<u>DO AS INSTRUCTOR DEMONSTRATION</u>

Still go through the guiding questions. Complete procedure either before or during the lab class to be ready toward the end.

Procedure 13.6

- Guiding Question(s):
  - What is the starting material for the Calvin cycle and what product(s) is/are produced?
  - Where do plants get their mass?

1. Observe starch production during photosynthesis

- Students will remove a leaf from a *Geranium* plant that has been illuminated for several hours.
- Students will immerse the leaf in boiling water for one minute.

- Students will bleach the pigments from the leaf by boiling the leaf in methanol for 3-5 minutes. This part of the procedure must be done in a fume hood. Boiling the leaf will remove pigments so that students can see the color changes of the iodine starch test.
- Students will place the leaf in a petri dish containing a small amount of water, and then add five to eight drops of iodine.
- Students will observe any color change in the leaf and record the color of the leaves after each successive treatment in figure 13.10a

Procedure 13.7

- Guiding Question(s):
  - What is happening in the part of the leaf that was kept in darkness? What didn't it stain with iodine?

2. Observe the requirement of light for photosynthesis

- Students will obtain a *Geranium* leaf that has been half or completely covered with metal foil or thick paper for three or four days.
- Students will repeat the bleaching and staining steps described in Procedure 13.6.
- Students will describe and explain any color change in the leaf and record in Figure 13.10b the color of the leaves after each successive treatment.

Procedure 13.8

- Guiding Question(s):
  - Are all pigments green?
  - Is it completely necessary for a pigment to be green to be useful for photosynthesis?
  - Are pigments themselves necessary for photosynthesis?

3. Observe the requirement of chlorophyll for photosynthesis

- Students will obtain leaves of a variegated *Coleus* plant and a purple-leafed *Coleus* plant and make sketches of their original pigmentations patterns in figure 13.10c, d. Students should be sure to indicate which areas are green, red, green/red, and white.

- Students will extract the pigments and stain for starch according to procedure 13.6. Boiling the leaf in water will remove the water-soluble pigments such as the red cynanins, and boiling the leaf in alcohol will remove chlorophyll. These pigments must be removed for students to see the color changes of the iodine starch test.
- Students will record in figure 13.10c, d the color of the leaves after each successive treatment.

Set up two hot plates on front desk: one for beaker of boiling water, other for beaker of boiling ethanol (not methanol). Do not heat ethanol till ready to use. WATCH ethanol beaker—ethanol will boil away quickly!

Answer question 10 a. b. and record results (sketches) in Fig. 13.10a.

Note: Instead of using a geranium leaf grown in the dark, we attach letter templates to the leaves for 1 week prior to the lab. The starch should accumulate in the region of the leaf exposed to the light (in the shape of a letter**). Do not throw templates away put them on David's desk.**

Evaluation: ***Engage students in final discussion. Review the information on the board-have student questions been answered? Based on time remaining engage students in conversation. Ensure that all quizzes and lab exams focus on the big ideas listed in the learning objectives and guiding questions.***

- Evaluation is ongoing throughout the lesson (this is called formative assessment). Every interaction with student(s) is a chance to assess what they understand or don't understand so you can modify your approach on the spot.
  - How will you ask/phrase questions to determine what students know?
  - What strategies can you use to get students to interact and engage in conversation about what they are doing and how it relates to photosynthesis?

The Photosynthesis Equation-the big idea we want them to walk away with

- The photosynthesis equation from the lecture study guide could be written on the board at the beginning of the lab (after the engage) and throughout the lesson students can add words to describe their experience in the correct location. Adding words would be prompted by the instructor going to a group and asking them to specifically relate what they are doing. You can have a word bank already made up with words like “pigments” “chloroplasts” “chlorophyll a” “starch production” “light dependent” “light independent” etc… and they could put those up on the equation to demonstrate understanding of where the activities they are completing in lab relate to the overall equation and how what they are doing relates to photosynthesis. For example, you could randomly ask a group who is completing exercise 13.6 (starch production) how the activity they are doing connects to the equation. Where does the plant get the carbon to synthesize into starch? They have to demonstrate they understand the connection between what they are doing and what concepts they are using by physically putting a word or phrase onto the equation. If they can’t do that then they don’t understand. Another example-you approach a group and they are blowing into the phenol red. Once they finish the activity ask them to explain to another group 1) why did you blow into the phenol red and 2) what does that have to do with photosynthesis? Have them write the word phenol red on the equation under the CO_2 to show they understand this activity was to show how plants uptake CO_2.
- Common quiz for the following week (all questions relate with learning goals-create one question per learning goal and select 3-4 from these)
    - Where does the mass of a plant come from? Explain your answer using evidence from last week’s lab.
- Common questions on the lab exams
- Give my students a “study materials” sheet with selected guiding questions.

APPENDIX D

Protist/Algae Lesson Plan

Biology 1111: Protists Lesson Plan (The Algae)

Learning Objectives:

1. Students should clearly explain protists in terms of biological diversity (catch all group).
2. Students should identify the taxonomic hierarchy of observed specimens that are specifically pointed out in lab.
3. Students should be able to describe the economical and ecological importance of protists.
4. Students should be able to identify the physical specimen or slide, and identify the correct life history stage.
5. Students should be able to apply correct terminology to the appropriate physical specimen or slide. (See list of terms in Table 1)

Learning Objective 1: Students should clearly explain protists in terms of biological diversity (catch all group).

ENGAGE Concept map p. 271-72 in lab manual **(15 minutes)**

The purpose of this activity is to 1) assess student prior knowledge and 2) help students better understand the big picture in regards to protists (foundational knowledge of protists, specifically algae that will be observed in the lab)

- The instructor will demonstrate to students how to construct a concept map using the term GENETICS, and the following associated terms: Mendel, genes, alleles, dominant, recessive, chromosomes, and inheritance.
- The instructor will provide a list of key words to students (written on the board or projected in a PowerPoint) that are related to protists, specifically algae. These words include, but are not limited to: Eukaryotic, protists, protozoa, fungus-like protists, slime molds, importance, uses, photosynthetic, cellular organization, pigments, heterotroph, autotroph, diversity.
- In pairs, students will use an 11x13 piece of paper and write the word algae in the middle of the paper. They will use the information on pages 271-272 to create a concept map connecting the words provided in a sensible way. Each line connecting words must describe why/how they are connected.
- While students are constructing these maps the instructor will be observing groups and listening for student ideas/misconceptions. If a misconception is identified, the instructor will ask the group to explain the reasoning and determine if there is a better place for the word.
- Students will refer to this concept map during the lab activity and add the specific specimens to the map where appropriate.

- This map will be completed at the end of the lab period and be turned in as their quiz. (the back of the paper will also be used for evaluation, see # 3, observing specimens, below.

Learning Objective 2: Students should be able to place observed specimens into taxonomical hierarchy (phyla, genus).

EXPLAIN: Mnemonic for hierarchy is written on the board: Kids Peddling Crack On Freeways Get Smashed. **(15 minutes).** *The purpose of this exercise is to allow students to understand that there is a taxonomic hierarchy of the specimens that they will be observing.*

- Kingdom, Phylum, Class, Order, Family, Genus, Species
- Students will need to be able to place today's protists in their correct phyla and genus.
- On board: ask students to guess at the hierarchical classification for *Homo sapiens.* It is important to note that groupings are not just terms but "baskets" or "boxes" that get smaller as we zoom down the taxonomic hierarchy. Instructor will show a graphic visual with Kingdom as a large basket all the way down to species…highlighting phylum and genus. The instructor will prompt them with the fact that we are animals, mammals, primates, etc.
    - Kingdom Animalia
    - Phylum Chordata
    - Class Mammalia
    - Order Primates
    - Family Hominidae
    - Genus *Homo*
    - Species *sapiens*
- Ask students to come up with the hierarchical classification for *Pan troglodytes.* Common chimpanzee, same classification down to genus.
- List of genus and species we will be covering in this lesson:
    - Phylum Chlorophyta
        - *Chlamydomonas, spirogyra, cladophora, volvox*
    - Phylum Phaeophyta
        - *Macrocystis, laminaria, sargassum, focus*
    - Phylum Rhodophyta
        - Porphyra, polysiphonia, coralline
    - Phylum Bacillariophyta
        - *Synedra*
    - Phylum Dinozoa
        - *Ceratium, peridinium*

- Phylum Euglenida
  - *Euglena*

<u>Learning Objective 3: Students should be able to describe the economical and ecological importance of protists.</u>

ELABORATE Ecological and Economic importance of Protists (**25 minutes**…10 read, 5 write, 10 report…1-2 minutes each group)
The purpose of this activity is to make the specimens viewed during lab relevant to students and elaborate on the economic and ecological importance of algae.

- Each table group will read one of the topics below and write a one-minute summary of the ecological and economical importance of their group to be read to the class.
- The instructor should be sure to reiterate major points and tie the presentations to the specimens viewed during class (for example, when discussing *Fucus* focus the document camera on the specimen or walk around with it to help students associate the specimen with the information)

<u>Topics for each Table</u>

<u>Organism 1: Fucus (Brown Algae) Commonly called rockweed</u>

- Phylum: Phaeophyta
- Genus: *Fucus*
- Fucoxanthin (like diatoms) gives it a brownish color

<u>Articles:</u>
Functions and Values of Rockweeds
http://www.rockweedcoalition.org/downloads/Functions_and_Values_of_Rockweeds_ME_DEP.pdf

Bladderwrack (a loose term for *Fucus vesiculosus*)
http://www.med.nyu.edu/content?ChunkIID=21591

Ecological Importance

- Primary producers (carbon fixation)
- Fix nutrients (phosphate and nitrate) for grazers
- Remove trace metals from environment/purify water
- Provides habitat for marine invertebrates and insects
- Food source for many invertebrates and fish

Economic Importance

- Health food and nutritional supplements
- Food and cosmetics
- Support habitats for commercial fishery industry (lobster, fish, crustaceans, sea urchins)
- Iodine supplement/heartburn medication

Organism 2: Diatoms

- Phylum Bacillariophyta
- Genera: Many
- Diatomaceous earth is formed from diatom frustules (the cell wall of diatoms)

Articles:
Diatoms Speak Volumes
https://www.calacademy.org/science_now/archive/academy_research/sarah_spaulding.php

Diatoms (Mann) 1918*
https://archive.org/details/jstor-2469318

Heterokontophyta IV (1 paragraph)
http://www.life.umd.edu/labs/delwiche/PSlife/lectures/Heterokonts4-diatom.html

Ecological Importance:

- Base of aquatic food chain
- Monitors water quality
- Gives a timeline for climate change
- Carbon fixation

Ecological Importance

- Diatomaceous earth (cleaning products, pest control, swimming pool filters)

*Point out that this article was written in 1918. However, much of what was written is what we have based studies on, though some was just theoretical at the time of this publication

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Organism 3: Carrageenan (from Rhodophyta)

Articles:

Review of harmful gastrointestinal effects of carrageenan in animal experiments.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1242073/

Food additive carrageenan: Part II: A critical review of carrageenan in vivo safety studies.
http://www.ncbi.nlm.nih.gov/pubmed/24467586

Seaweed extract protects against cervical cancer
http://www.nature.com/news/2006/060713/full/news060710-12.html

Students will read the NCBI article abstracts, and the Nature article. Different points of view on carrageenan.

Importance:
Carrageenan is an extract from red algae used as an emulsifier (stabilizer for processed foods, etc.) in common products such as toothpaste and yogurt. There has been recent debate over the safety of human consumption of carrageenan; some sources claim that it is carcinogenic and causes intestinal inflammation. However, a recent study found carrageenan to be safe overall for consumption, and it has even been found to guard against HPV. Algae are cool!

Fun fact: The seaweed industry provides a wide variety of products that have an estimated total annual value of US$ 5.5-6 billion. Food products for human consumption contribute about US$ 5 billion of this. http://www.fao.org/docrep/006/y4765e/y4765e04.htm

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Organism 4: Red tides (Dinoflagellates)

Articles:

Red tides threatens Gulf of Mexico fish
http://www.natureworldnews.com/articles/8278/20140728/red-tide-threatens-gulf-mexico-fish.htm

Turning back the harmful red tide
http://www.whoi.edu/fileserver.do?id=36124&pt=2&p=28251

Scientists work to predict and prevent algae blooms
http://ocean.si.edu/ocean-news/scientists-work-predict-and-prevent-algae-blooms

Importance:
Red tide is term used to describe a harmful algal bloom caused by marine dinoflagelletes. The event is marked by a rust red color is due to large numbers of the unicellular Karenia brevis. The organism produces a potent neurotoxin and depletes the water of oxygen often killing fishes, marine mammals, and poisoning shellfish. This may have detrimental effects on both commercial fishing and tourism. Scientists are working on better understanding the organisms and the ecosystem to develop a solution.

Organism 5: Kelp

Article:
Ecosystems: Kelp Forests
http://sanctuaries.noaa.gov/about/ecosystems/kelpdesc.html

Sea Otters fight Global Warming
http://www.scientificamerican.com/podcast/episode/sea-otters-fight-global-warming-12-09-14/?print=true

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Organism 6: Sargassum

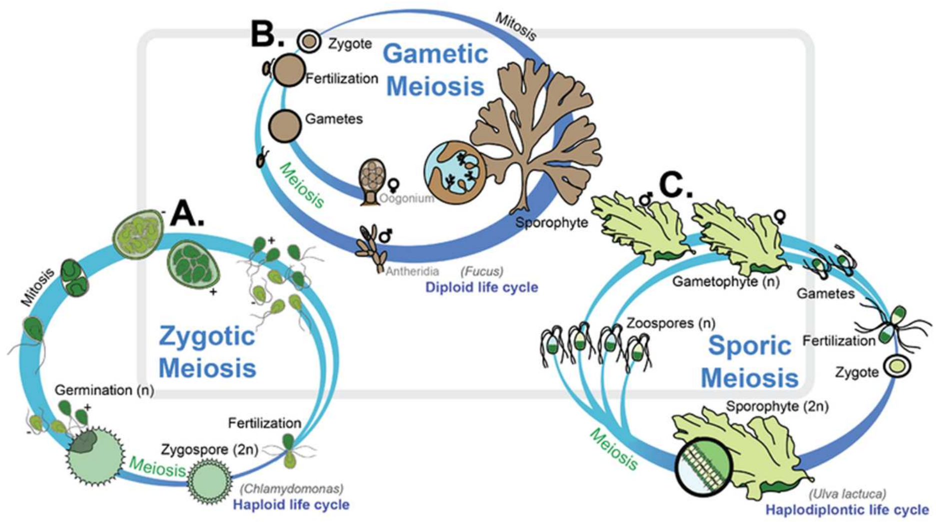
Article:
Where is the Sargasso Sea?
http://oceanservice.noaa.gov/facts/sargassosea.html

Sargassum: A complex island community at sea

http://oceanexplorer.noaa.gov/explorations/03edge/background/sargassum/sargassum.html

Learning Objective 4: Students should be able to identify the physical specimen or slide, including the correct life history stage indicated by a particular physical specimen or slide.

EXPLAIN: - Students will learn 3 life cycles of protists by comparing each cycle with each other. *It is up to individual instructor to either lecture or have students read lab manual and take notes of the different life cycles. Students will fill out life cycle* *worksheet (See Attachment A and B) and note ploidy, where meiosis/mitosis occurs, and where the adult stages are.* **(20 minutes)**



Gametic-

- A multicellular, male or female diploid (2N) adult undergoes meiosis to produce haploid (1N) gametes (egg or sperm)
- The haploid gametes undergo syngamy to form a diploid (2N) zygote… which then undergoes mitosis to become a diploid adult.

Zygotic-

- Uni or multicellular haploid (1N) adult with no discernible sex undergoes mitosis to form haploid gametes (isogamy)
- These haploid (1N) gametes undergo syngamy to form a diploid (2N) zygote
- The diploid zygote undergoes meiosis to form haploid (1N) spores, which can grow into a haploid adult

Sporic-

- A multi diploid (2N) adult, male or female, called a sporophyte, undergoes meiosis to form haploid (1N) spores.
- The haploid spores undergo mitosis to form a multicellular haploid adult (1N), called a gametophyte
- The gametophyte undergoes mitosis to form haploid gametes
- The haploid gametes undergo syngamy to form a diploid zygote (2N) which can then grow into a diploid adult.

Learning Objective 5: Students should be able to apply correct terminology to the appropriate physical specimen or slide. (See list of terms in Table 1)

Table 1: Terms students should know

Gametes	Syngamy	Isogamete
Spore	Zygospore	Zygote
Alternation of generations	Sporophyte	Gametophyte
Ploidy (diploid/haploid)	Oogenia	Antheridia
Concpetacles		

EXPLORE: *Students will observe the specimens in Table 2. Students should make sure they can apply each of the terms in Table 1 to at least one of the organisms in Table 2. The instructor should ensure that students are able to put the appropriate words in the appropriate boxes.* **(30 minutes)**

- Instructor will give students a copy of table 2.
- Students will rotate through stations to complete table as an individual. While students are observing specimens, they will write down key terms that will go with each specimen.
- For a quiz grade at the end of the class, students will need to write at least one key characteristic from each specimen that they observe in class.
- Key focuses for each specimen include the distinguishing characteristics, cell wall components, accessory pigments, and energy storage. (See Attachment C for additional information on each specimen)

Table 2: Specimens students will observe

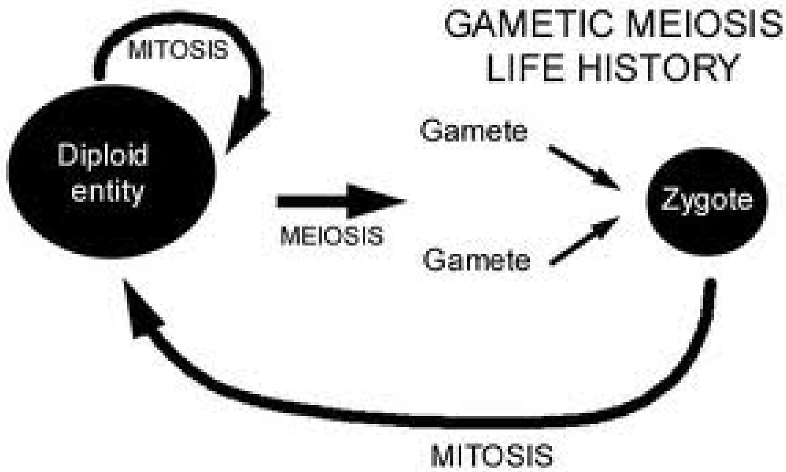
Phylum	Chlorophyta	Phaephyta	Rhodophyta	Bacillariophyta	Dinozoa	Euglenida
Common Name	Green algae	Brown algae	Red algae	Diatoms	Dinoflagellates	Euglenoidds
Genera	Chlamydomonas	Macrocytstis	Porphyra	Synedra	Ceratium	Euglena
	Spirogyra	Laminaria	Corallina	“Diatomaceous Earth”	Peridinium	
	Cladophora	Sargassum	Polysiphonia			
	Volvox	Fucus				

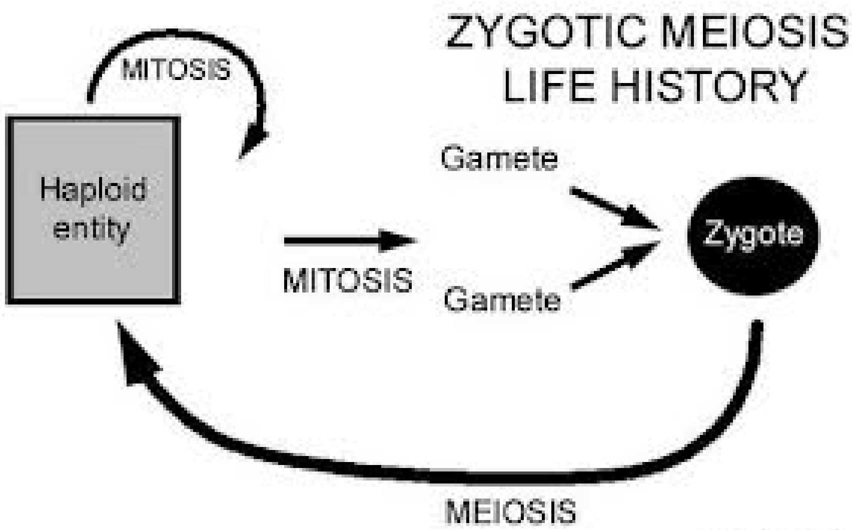
Attachment A: Life History Cycles (Answer Key)

Fucus

Diatoms

synedra





Chlamydomonas

Spirogyra

Volvox

Alternation of generations:

Cladophora

Red algae: porphyra,

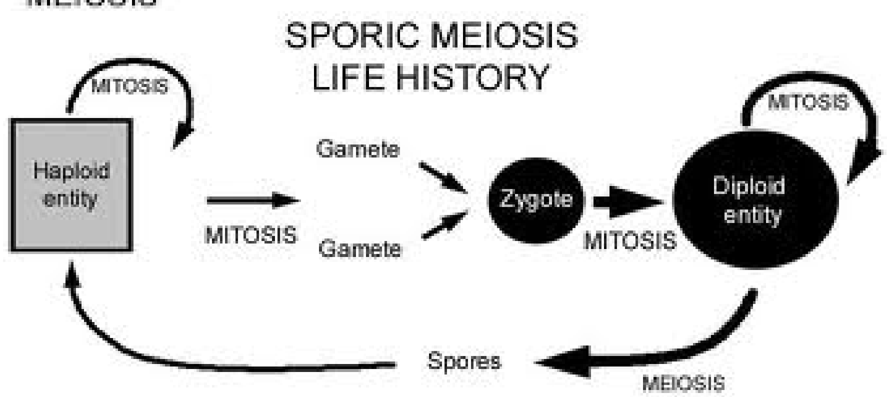
Coralline, polysiphonia

Brown algae

(except fucus):

Macrocystis, sargassum

laminaria



Attachment B: Life History Worksheet for Students

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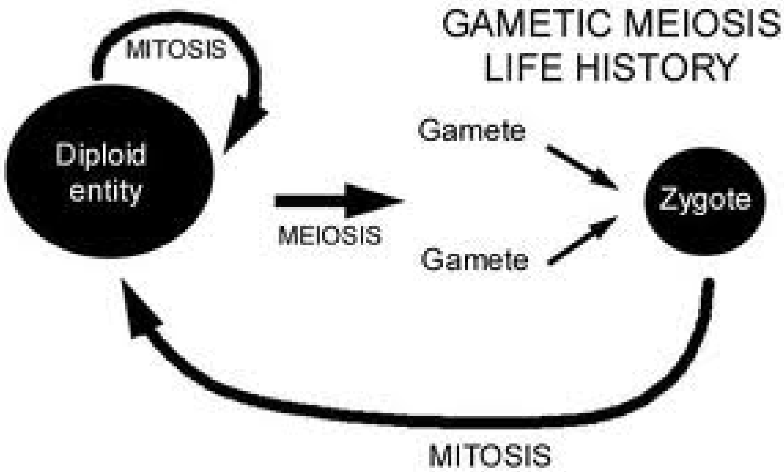

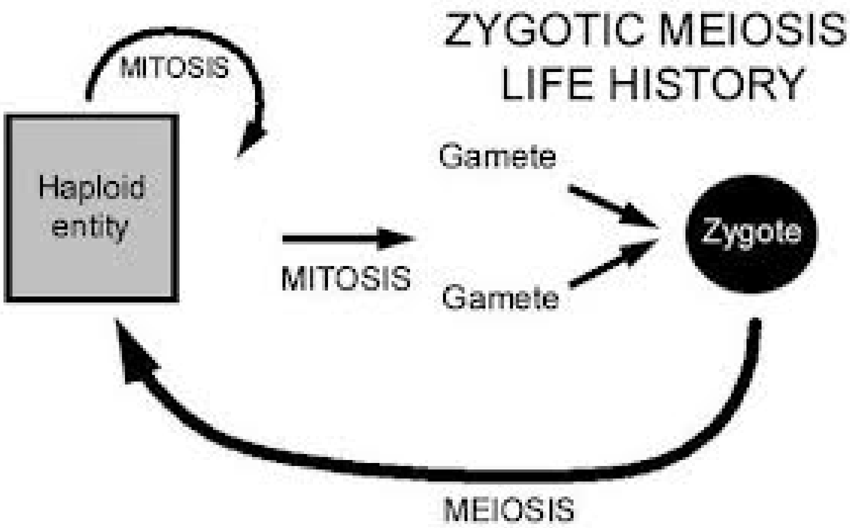

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Alternation of generations:

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Red algae: _________

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Brown algae (except fucus):

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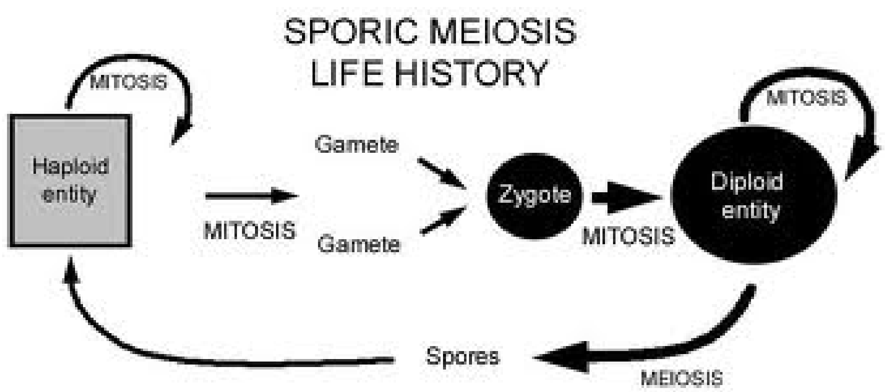


Attachment C: Information about Algae specimens

Phylum Chlorophyta-

- commonly known as green algae
- reproduction varies from fusion of identical cells (isogamy) to fertilization of a large non-motile cell by a smaller motile one (oogamy)
- alternation of generations

Genus *Chlamydomonas*

- good model organism
- small unicellular organism with two flagella

Genus *Spirogyra*

- filamentous green algae of the order Zygnematales
- named for the helical or spiral arrangement of the chloroplasts that is diagnostic of the genus.
- commonly found in freshwater areas, and there are more than 400 species of *Spirogyra* in the world.

Genus *Cladophora*

- reticulated filamentous green algae
- *Cladophora* contains many species that are very hard to tell apart and classify, mainly because of the great variation in their appearances, which is affected by habitat, age and environmental conditions.
- Unlike *Spirogyra* the filaments of *Cladophora* branch and it doesn't undergo conjugation.
- There are two multicellular stages in its life cycle - a haploid gametophyte and a diploid sporophyte - which look highly similar.

Genus *Volvox*

- *Volvox* is the most developed in a series of genera that form spherical colonies. Each mature *Volvox* colony is composed of numerous flagellate cells similar to *Chlamydomonas*, up to 50,000 in total.
- The cells have eyespots, more developed near the anterior, which enable the colony to swim towards light.
- They are known to demonstrate some individuality and working for the good of their colony, acting like one multicellular organism.
- *Volvox* species can be monoecious or dioecious. Male colonies release numerous microgametes, or sperm, while in female colonies single cells enlarge to become oogametes, or eggs.

Phylum Phaephyta

- commonly known as brown algae.
- Structurally complex, multicellular, marine algae.
- Usually grown in cool water.
- Can be anywhere from microscopic to over 100 meters long.

Genus *Laminaria*

- genus of 31 species, all sharing the common name "kelp."
- This economically important genus is characterized by long, leathery laminae and relatively large size.
- The life cycle of the genus involves a diploid generational system.

Genus *Sargassum*

- Species of this genus of algae may grow to a length of several meters.
- They are generally brown or dark green in color and consist of a holdfast, a stipe, and a frond.
- http://en.wikipedia.org/wiki/Oogonia Oogonia and antheridia occur in conceptacles embedded in receptacles on special branches.
- Many have a rough sticky texture, which together with a robust but flexible body, helps it to withstand strong water currents.
- The thick masses of *Sargassum* provide an environment for a distinctive and specialised group of marine animals and plants.

Genus *Fucus*

- genus of brown algae found in the intertidal zones of rocky seashores almost throughout the world.
- After meiosis oogonia and antheridia are produced and released, fertilization follows and the zygote develops directly into the diploid plant.

Phylum Rhodophyta

- Usually live in warm marine waters
- Mostly multicellular
- Habitats for small marine species, helps build Coral Reefs

Genus *Porphyra*

- sporic meiosis
- coldwater seaweed that grows in cold, shallow seawater
- approx. 70 species

Genus *Corallina*

- sporic meiosis
- habitat for small marine animals

Genus *Polysiphonia*

- sporic meiosis
- filamentous and usually well branched, some plants reaching a length of about 30 cm

Phylum Bacillariophyta

- Diatoms are unicellular algae with a golden-brown color.
- Very tiny; however, they occur in large numbers and reproduce rapidly.

- They are a primary producer in the ocean.
- The outer cell wall of a diatom is made of glass (silicon dioxide) which stays intact long after the cell disintegrates.
- These cell walls can accumulate in layers several meters deep to form Diatomaceous Earth.

Genus *Synedra*

- rod-shaped and bilaterally symmetrical.
- cell wall of the algae's diatoms contain overlapping halves that are composed of silica.

Phylum Dinozoa

- -Unicellular
- -Morphologically contain cellulose plates and two flagella found in perpendicular grooves.
- -A red tide is caused by a particular dinoflagellate and can kill massive numbers of fish.
- -Primary producers in oceans, 2^{nd} to diatoms
- -Some are bioluminescent; causes waves to "sparkle"

Genus *Ceratium*

- The most distinguishing characteristic are the arms (also known as horns), the shape and size of which vary from species to species

Genus *Peridium*

- circular or oval-shaped
- range in color from green to yellow or brown
- The cell has a tough outer covering that is divided into two parts

Phylum Euglenida

- Commonly known as euglenoids
- Mostly freshwater unicellular algae
- Cell walls are made mostly of protein, so they are very flexible.
- Motile, contain two flagella

Genus *Euglena*

- genus of single-celled flagellate protists.
- best known and most widely studied member of the class Euglenoidea, a diverse group containing some 54 genera and at least 800 species.
- found in fresh and salt waters. They are often abundant in quiet, inland waters, where they may bloom in numbers sufficient to color the surface of ponds and ditches green (*E. viridis*) or red (*E. sanguinea*).
- reproduce asexually through binary fission, a form of cell division.
- reproduction begins with the mitosis of the cell nucleus, followed by the division of the cell itself.

APPENDIX E

Semi-structured Interview Protocol

1. Tell me about your teaching experience prior to teaching the fall semester of introductory to biology laboratory.

2. I would like to get a general sense of your teaching experience this semester.
    a. What has been the most rewarding aspect? Why has it been rewarding?
    b. What has been the most challenging aspect? Why has it been challenging?

3. In your opinion, what is lesson study?

4. Tell me about how participating in lesson study influenced your teaching practices, if at all?

5. Can you give me an example of how you revised your teaching since you participated in lesson study? If so, will you describe it?

6. Tell me about how your students have responded to the different instructional approaches.

7. What aspects, if any, of lesson study do you think influenced your decisions about teaching?

8. In what ways did collaboration with your peers help you with your teaching, if at all?

9. What have been the most challenging aspects of your participation in lesson study? What have been the most rewarding?

10. What would you change about your experience in lesson study?

11. Would you want to participate in lesson study again? Why or why not?

APPENDIX F

Institutional Review Board Approval

MIDDLE TENNESSEE
STATE UNIVERSITY

8/13/2014

Investigator(s): Sandra Lampley, Dr. Grant Gardner
Department: Math and Science Education
Investigator(s) Email Address: sal2j@mtmail.mtsu.edu; grant.gardner@mtsu.edu

Protocol Title: Exploring Pedagogical Content Knowledge of Graduate Teaching Assistants Through Their Participation in Lesson Study

Protocol Number: #15-024

Dear Investigator(s),

Your study has been designated to be exempt. The exemption is pursuant to 45 CFR 46.101(b)(1) Evaluation/Comparison of Instructional Strategies/ Curricula.

We will contact you annually on the status of your project. If it is completed, we will close it out of our system. You do not need to complete a progress report and you will not need to complete a final report. It is important to note that your study is approved for the life of the project and does not have an expiration date.

The following changes must be reported to the Office of Compliance before they are initiated:

- Adding new subject population
- Adding a new investigator
- Adding new procedures (e.g., new survey; new questions to your survey)
- A change in funding source
- Any change that makes the study no longer eligible for exemption.

The following changes do not need to be reported to the Office of Compliance:

- Editorial or administrative revisions to the consent or other study documents
- Increasing or decreasing the number of subjects from your proposed population

If you encounter any serious unanticipated problems to participants, or if you have any questions as you conduct your research, please do not hesitate to contact us.

Sincerely,

Lauren K. Qualls, Graduate Assistant
Office of Compliance
615-494-8918

APPENDIX G

Terms for Sticky Note Activity

Sticky Notes

- Releases electrons
- Absorption Spectrum
- 400-450nm
- Tree trunk
- Thylakoid membrane
- Stroma
- “Synthesis”
- Absorbance
- Pigments
- Chlorophyll a
- Chlorophyll b
- Carotenoids
- Starch
- Respiration
- Light Dependent Reactions
- Plant Mass (tree trunk, branches, roots, etc…)
- Waste Product
- “Photo”
- Chloroplast
- Phenol red solution
- Sugar
- Splits Water
- Light Independent Reactions
- Spectrophotometer

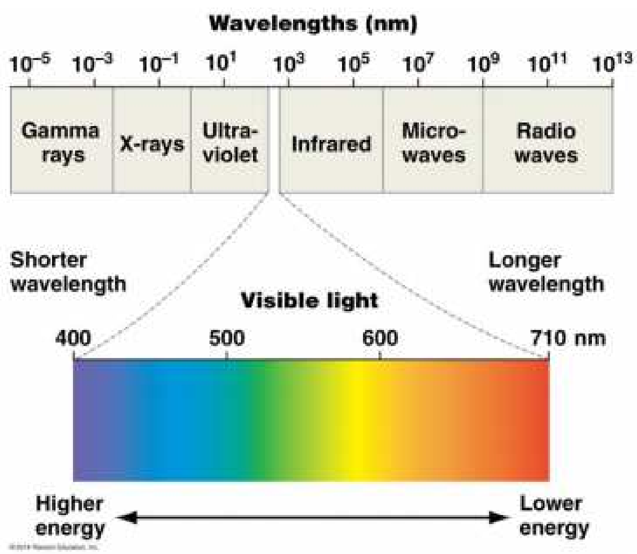
APPENDIX H

Photosynthesis Study Guide Created by Lecture Instructors

Study Guide – Photosynthesis – Chapter 10
Name:____

Photosynthesis is the process of harvesting light energy and carbon dioxide and producing reduced carbon in the form of carbohydrates.

I. Light



The light-capturing reactions of photosynthesis begin with the simple act of sunlight striking chlorophyll. When a photon of light strikes a pigment molecule inside of chlorophyll specific wavelengths are either used or reflected. Sunlight includes white light, which consists of all wavelengths in the visible spectrum at once.

Question: What colors of light excite electrons to the highest energy state?

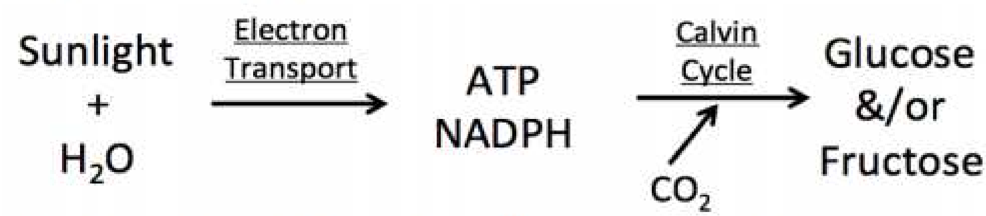
Question: If a plant has green leaves, what do you know about the light that is absorbed by the plant and what do you know about he light that is reflected by the plant?

II. Overview of Photosynthesis

Carbon Dioxide + Water + light → Glucose or Fructose + Oxygen

$$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis can be split into two series of reactions – Photosynthetic Electron Transport and the Calvin Cycle.



Question: What is the starting material for the photosynthetic electron transport chain and what product(s) is/are produced?

Question: What is the starting material for the Calvin cycle and what product(s) is/are produced?

Question: Draw a diagram of a chloroplast and indicate where electron transport and the Calvin cycle reactions occur.

III. Photosynthetic Electron Transport Chain – Light Harvesting

The electron transport chain is responsible for harvesting light and converting it into chemical energy and reducing power – NADPH and ATP

Question: What is the role of photosystem II and photosystem I?

Question: What is the role of plastocyanin (PC)?

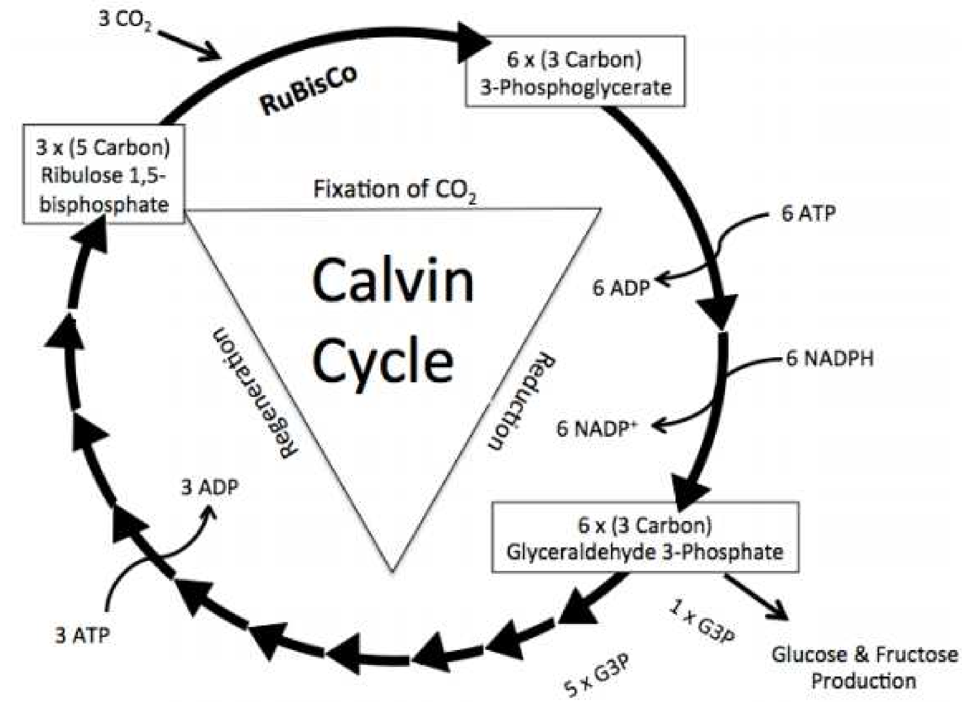
Question: What is the role of ferredoxin and pheophytin?

Question: Which products will be used by the Calvin cycle?

IV. Calvin cycle – carbon fixation

The Calvin cycle is responsible for converting atmospheric CO_2 into a compound that can be used for carbohydrate production.

We can consider the Calvin cycle in three stages – fixation, reduction, and regeneration.



Question: What is carbon fixation?

Question: What molecule goes into the reduction phase and what is the product?

Question: What product(s) from the electron transport chain are used during the reduction stage?

APPENDIX I

Concept Map Word List

<u>Concept Map Words</u>

eukaryotic

protists

protozoa

fungus-like protists

slime molds

importance

uses

photosynthetic

cellular organization

pigments

heterotroph

autotroph

diversity