PROFESSIONAL DEVELOPMENT FOR GENERAL CHEMISTRY LABORATORY TEACHING ASSISTANTS: IMPACT ON TEACHING ASSISTANT BELIEFS, PRACTICES, AND STUDENT OUTCOMES

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by
Lindsay Wheeler
B.S., B.S. Virginia Commonwealth University
M.A., M.T. University of Virginia
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ABSTRACT

The purpose of this mixed methods study was to examine the relationship between TAs and students in an inquiry-based undergraduate general chemistry laboratory. Specifically, the investigation sought to understand how a professional development (PD) to support TAs' implementation of inquiry affected TAs' chemistry content knowledge, teaching beliefs, and teaching confidence, and how these TA characteristics predicted student outcomes. The study also explored TAs' practice to characterize the TA-student interactions. The study took place at a mid-sized, public university in the Mid-Atlantic region. Participants included 14 TAs who taught and their 433 students enrolled in the first semester general chemistry laboratory course. The PD experienced by the TAs was informed by this dissertation's pilot study, situated learning theory, and previous research on PD. The PD occurred during a week-long initial workshop followed by fourteen weekly follow-up meetings. TAs completed pre- and post- PD and end-of-semester (delayed post) surveys that qualitatively and quantitatively assessed their content knowledge, beliefs, and confidence. Six purposefully chosen TAs were interviewed at the beginning and end of the semester to further probe their prior experiences, beliefs, and confidence. Five TAs were observed in the laboratory twice during the semester to characterize their practice. Students completed a multiple choice content assessment on the first and last days of lab (pre- and post- survey, respectively). Quantitative TA data were analyzed using descriptive statistics, non-parametric tests, *t*-

*test*s and correlations. Qualitative survey and interview data and observations were analyzed using analytic induction (Erikson, 1986). Student data were analyzed using *t-test*s, correlations, and hierarchical multiple regression. Qualitative and quantitative data analyses revealed some relationships between the professional development and TAs' content knowledge, beliefs, and confidence. TAs significantly improved their content knowledge from pre- (M=76.02) to delayed-post survey (M=85.20) (p=.01), but no other significant differences existed. Qualitative data suggested TAs held a range of beliefs that were informed by their experiences and were mostly resistant to change. TAs also reported higher confidence in content knowledge than in facilitating student learning. TAs took on similar roles and responsibilities in the laboratory but varied in how they interacted with students. These interactions were informed by TAs' prior and current experiences and affected the level of student engagement in the laboratory. Student content scores significantly improved from pre-survey (M=52.48) to post-survey (M=73.29) (p<.001) with a large effect size (d=1.7). Student demographics and prior experience were the only significant predictors of student post-survey scores. A case-study comparison of 2 TAs suggested TAs' content knowledge, beliefs, and confidence related to their practice, and students' self-reported learning related to their TAs' practice. This study is the first to connect TAs to student outcomes in the undergraduate laboratory context and proposes that a situated PD may positively impact TAs content knowledge, but may not be sufficient to change TAs' beliefs and confidence. Future research will further examine the relationship between PD, TAs, and students through the use of varied assessment instruments and investigate how TAs related to the student learning processes.

DEDICATION

To my amazing husband, Mark Wheeler.

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Thank you to my husband, Mark Wheeler.

For always being my champion and for your encouragement when I didn't think I could get up at 4am one more time.

You are my rock.

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CHAPTER 1: INTRODUCTION

Examining the state of Science, Technology, Engineering, and Mathematics (STEM) education over the past two decades reveals fewer and fewer students are pursuing STEM majors and careers (Fairweather, 2008; National Research Council [NRC], 1996). Researchers suggest the decline of STEM majors may be related to the structure and implementation of undergraduate STEM courses (Fairweather, 2008; Pascarella & Terenzini, 2005). Typical STEM courses use traditional teaching methods (i.e., teacher-centered, passive learning, expository/cookbook laboratories), which lack student engagement in authentic scientific practices. In a review of literature on student attitudes toward science, Osborne, Simon, & Collins (2003) state, “The message presented by school science is that science is somehow disconnected from society and we should simply study it for its own sake” (p. 1062). Further, traditional teaching methods have also been heavily criticized for not providing opportunities for students to think critically (Domin, 1999; German, Haskins, & Auls, 1996). To stress the importance of changing science education, both the National Research Council and the American Chemical Society have charged undergraduate science departments to integrate reform-based practices such as problem-based learning, cooperative learning, and inquiry instruction into the science curriculum to emphasize active learning opportunities for students (Cooper, 2010; NRC, 2000).

Student Outcomes in Undergraduate Science Courses

Empirical studies provide evidence that active learning approaches increase student learning in and attitudes about science (e.g., Basaga, Geban, & Tekkaya, 1994; Pascarella & Terenzini, 2005; Russell & French, 2002; White, 1996). Undergraduate laboratory courses provide a unique opportunity for students to engage in active or "hands on" learning (Bond-Robinson, 2000; Cho, Sohoni, & French, 2010; Herrington & Nakhleh, 2003). Laboratory classes can help students connect scientific concepts (Bond-Robinson & Bernard Rodriques, 2006; Baumgartner, 2007), and can significantly impact student understanding of the nature of science (e.g., Russell & Weaver, 2011).

Undergraduate laboratory classes also offer students the ability to engage in scientific inquiry, which can promote active learning. Inquiry is defined as students drawing justifiable conclusions to answer a research question through the systematic analysis of data (Bell, Smetana & Binns, 2005; Eastwell, 2009). Research demonstrates that students in undergraduate inquiry-based laboratories learn significantly more content (Basaga et al., 1994; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006), increase competence in scientific practices (Brickman, Gormally, Armstrong, & Hallar, 2009; Suits, 2004), and perform significantly better on laboratory skills (Basaga et al., 1994; Suits, 2004) than students in expository or non-inquiry-based laboratory instruction.

Other factors such as student attitudes (e.g., Osborne et al., 2003), student self-efficacy (e.g., Pajaraes, 1996), and student-instructor interactions (e.g., Pascaraella & Terenzini, 2005) also influence student learning in undergraduate science courses. However, studies provide conflicting evidence on how laboratory instruction impacts student attitudes (Chatterjee, Williamson, McCann, & Peck, 2009; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006). Observational data suggest students' interactions and participation in lab may influence their attitudes and learning (Krystyniak & Heikkinen; 2007; Russell & French, 2002). Results suggest that the instructor is an essential component in effective laboratory instruction; yet, none of these studies examine the relationship between instructor and student learning in the laboratory setting.

Teaching Assistants in the Laboratory

Teaching assistants (TAs) are the typical laboratory instructors at large research universities (Luft, Kurdziel, Roehrig, & Turner, 2004). Research on TAs reveals they play an important role in the quality of undergraduate education (e.g Bomotti, 1994; Carroll, 1980; Kendall & Schussler, 2013) and influence the retention of students to major in the sciences (Cho et al., 2010; Baumgartner, 2007), particularly minorities and females (Gardner & Jones, 2011). Existing research investigates TAs' roles (e.g., Bomotti, 1994; Golde & Dore, 2001; Luo, Grady, & Bellows, 2001), beliefs (e.g., Addy & Blanchard, 2010; Luft et al., 2004), and practice (e.g., McGinnis, 1994; Herrington & Nakhleh, 2003). Studies find that TAs' teaching beliefs, self-efficacy, and content knowledge influence their perceptions and practices (Bond-Robinson & Bernard Rodriques, 2006; Osborne et al., 2003; Volkmann & Zgagacz, 2004). For example, a physics TA's belief that instructors should tell students correct answers was a barrier to students' understanding inquiry-based instruction (Volkmann & Zgagacz, 2004). TAs are expected to effectively interact with students in lab using best-teaching practices; yet TAs' own perceptions and practices may not align with these expectations. Thus, one way to help support TAs' instructional practices and subsequently impact students' experiences in laboratory classrooms is through professional development that focuses on TAs' beliefs, self-efficacy, content knowledge, and practice.

Most of the literature on TA training programs is either descriptive (e.g., Birk & Kurtz, 1996; Clark & McLean, 1979; Sharpe, 2000) or evaluative (e.g., Bond-Robinson & Bernard Rodriques, 2006; Marbach-ad et al., 2012; Roehrig, Luft, Kurdziel, & Turner, 2003). The majority of these studies examine TA training programs within an expository laboratory context, which does not emphasize inquiry-based learning. Only a handful of studies focus on TAs in inquiry-based laboratories (e.g., French & Russell, 2002; Volkmann & Zgagacz, 2004). Further, many describe TA preparation as "training," a behaviorist term that implies TAs are passive recipients of information (Bandura, 1977; Jones & Carter, 2007). A "training" approach to professional development fails to align with active learning approaches that have been shown to lead to better student outcomes (e.g., Basaga et al., 1994; Lord & Orkweszewski, 2006). Thus, existing literature provides little insight into effective methods for inquiry-based TA professional development.

In order to identify potential characteristics of effective TA professional development, this dissertation draws from professional development literature for K-12 science teachers. Analysis of numerous TA training and K-12 teacher professional development studies reveals the following characteristics may provide the most effective professional development for TAs: modeling pedagogy and linking instruction to content (e.g., Birk & Kurtz, 1996; Blanchard et al., 2010; Marbach-ad et al., 2012, Rushton, Lotter, & Singer, 2011), TAs acting as students (Lawrenz, Heller, Keith & Heller, 1992; Roehrig et al., 2003), discussion of beliefs (Lotter, Harwood, & Bonner, 2006; Rushton et al., 2011), opportunities for self-reflection of teaching (e.g., Blanchard et al., 2010; Calkins & Kelley, 2005; Luft et al., 2004), linking teaching to learning theory (Lawrenz et al., 1992; Luft et al., 2004), emphasizing the importance of teaching (Jones, 1993; Luft & Hewson, 2014; Shannon, Twale, & Moore, 1998), explicit discussion of expectations and responsibilities (Marbach-ad et al., 2012), grading (Cho et al., 2010; Luft et al., 2004), mentoring (e.g., Calkins & Kelley, 2005; Clark & McLean, 1979; Shannon et al., 1998), and peer or instructor feedback to TAs (e.g., Bond-Robinson, 2000; McGinnis, 1994; Sharpe, 2000; Van Hook, Huziak-Clark, Nurnberger-Haag, & Ballone-Duran, 2009).

Theory-driven Research

A theory-based approach may provide additional insight into TA professional development and laboratory learning. Professional development researchers emphasize the benefits of using a situated learning perspective for professional development efforts (e.g., Borko, 2004; Rosebery & Puttick, 1998; Webster-Wright, 2009). Situated learning theorists suggests that the following components should be utilized for effective learning: engaging participants in a community of practice; providing authentic learning opportunities; utilizing a cognitive apprenticeship model; allowing learners to tell stories; and creating opportunities for reflection (Lave & Wenger, 1991; McLellan, 1996). Using a situated learning framework to design an inquiry-based TA professional development, a novel approach not previously found in the literature, may facilitate changes in TAs’ practice, similar to changes demonstrated in K-12 teachers' practices (Rosebery & Puttick, 1998).

Drawing from social constructivism may provide additional insight into how TAs influence student learning. According to a social constructivist perspective, prior knowledge and social interactions influence the active construction of knowledge (Ferguson, 2007; Tobin, 1993). From this perspective, both TAs' and students' prior experiences and the TA-student interaction shape student learning. However, few, if any, studies of learning in undergraduate science laboratories use a social constructivist-informed approach and no existing studies use a social constructivist lens to understand how changes in TAs may influence student learning. Drawing upon perspectives such as situated learning and social constructivism may provide a more comprehensive understanding of TAs' content knowledge, beliefs, self-efficacy, and practices, and how these may influence student learning.

Statement of the Problem

Analysis of multiple bodies of literature on laboratory instruction reveals two main limitations. First, no studies exist that connect TA preparation and instruction to student learning in laboratory settings. Examining this relationship may lead to ways to optimize student learning within the context of the laboratory. Second, most studies on laboratory instruction do not incorporate theoretical frameworks of learning to understand TA and student learning (e.g., Basaga et al., 1994; Russell & Weaver, 2011). The bodies of literature examining laboratory instruction would benefit from a theory-driven empirical study connecting the role of the TA to student learning.

Purpose

This dissertation used a social constructivist lens to study the relationship between TAs and student learning in a large-enrollment general chemistry laboratory course. This was achieved by implementing and assessing a TA professional development program that utilized an inquiry-based general chemistry curriculum grounded in the K-12 professional development, TA training literature, and a situated learning framework. Changes in TAs' content knowledge, beliefs about teaching, and teaching confidence following the professional development were assessed both qualitatively and quantitatively and related to students' learning in the laboratory. TAs' practices in the laboratory were characterized, and a case study of two TAs compared their beliefs, confidence, and content knowledge to their practice and student learning. The research questions guiding the study were:

1. In what ways, if any, do TAs' content knowledge, beliefs about teaching, and teaching confidence change as a result of TA professional development for an inquiry-based general chemistry lab?
2. How do TAs' prior experience, content knowledge, beliefs about teaching, and teaching confidence relate to student learning in an inquiry-based general chemistry lab?
3. What kinds of instructional practices do TAs use in an inquiry-based general chemistry lab?
4. How do TAs' content knowledge, beliefs about teaching, and teaching confidence relate to their practice, and how does practice relate to student learning?

Significance of the Study

This dissertation makes three main contributions to the research community. First, this dissertation connects the two disparate bodies of literature on student laboratory learning and laboratory TAs through rigorous, theory-driven data collection and analysis to provide a more accurate understanding of student learning in the undergraduate laboratory context. The results of this dissertation refine conceptual frameworks from previous literature on TAs and student learning in the undergraduate laboratory. Refinements to the framework include focusing on TA perceptions of their teaching and highlighting connections among TA professional development, TA characteristics, and TA practice, and ultimately student learning.

Second, this study used situated learning and social constructivist perspectives to understand TA and student outcomes. Situated learning provided a framework for understanding how TA professional development influenced TA characteristics and TA practice, whereas social constructivism allowed for a theoretical understanding of the impact of TAs' characteristics and practice on student learning. Utilization of social constructivism and situated learning lenses is a novel approach that adds to the literature on TA preparation and student outcomes in the laboratory setting.

Third, this dissertation has practical significance for researchers and implementers. The results reveal factors that influenced TAs in this study and suggest ways to promote reform-based TA beliefs, appropriate but high confidence, and student-centered practice. The student demographic variables that affected student content scores and potential aspects of TA practice in the laboratory setting that may relate to student learning can be used to inform course curriculum and professional development modifications that can maximize a variety of learning outcomes in the laboratory. These recommendations have the potential to improve students' perceptions about science and may positively impact students' choice to major in science.

CHAPTER 2: LITERATURE REVIEW

This chapter provides a comprehensive synthesis of the literature on undergraduate laboratory instruction and argues that research in this area needs to use a theoretical lens to examine the relationship between TAs and student outcomes. To begin this chapter, a review of research on undergraduate student learning in science courses provides an overall picture of what students learn and factors that may influence student learning within an undergraduate setting. Second, a closer examination and evaluation of individual research studies directly focused on laboratory courses illustrates the relationship between the laboratory curricula and student learning and reveals gaps in the research. To understand the role of the instructor in the lab context, a separate body of literature on TAs is reviewed. The literature on TAs' role, beliefs, and practice within a laboratory setting suggests the need to support TAs in their instruction. An analysis of the TA training literature follows to help identify effective TA professional development characteristics and identify limitations within the body of TA literature. Finally, this chapter uses a social constructivist framework to propose a model for understanding the relationship between TA professional development, TAs, and student learning based on a synthesis of the multiple bodies of literature.

Undergraduate Student Learning in Science

Two main goals of undergraduate science education are to "prepare students to understand and deal intelligently with modern life" (Chickering & Gamson, 1987, p. 3) and to produce scientifically literate citizens (Leonard, 1997; NRC, 1996) who are lifelong learners (Ketpichainarong, Panijpan & Ruenwongsa, 2010). The National Research Council (1996) suggests scientific literacy is the ability to understand science, technology, engineering, and math (STEM) concepts; apply STEM concepts to everyday life; understand the process of solving science problems; and remain life-long learners of science (p. 15). The development of productive, scientifically literate individuals through undergraduate education can be achieved by maximizing student learning within science and laboratory courses. This section begins with a general review of what undergraduate students can learn, then explores factors that influence student learning. The following section reviews individual studies directly related to learning outcomes in science courses.

What Students Learn in Science Courses

Undergraduate science courses have the potential to provide students with opportunities to actively engage in understanding how science works (Abraham, 2011; Leonard, 1997). When examining the literature on undergraduate student learning, students have the potential to learn facts, concepts, scientific practices, laboratory skills, and nature of science (Abraham, 2011; Leonard, 1997; White, 1996), which can be further categorized as scientific knowledge, science process skills, and nature of science (Abraham, 2011; Lederman & Zeidler, 1987; Leonard, 1997) (Figure 1).

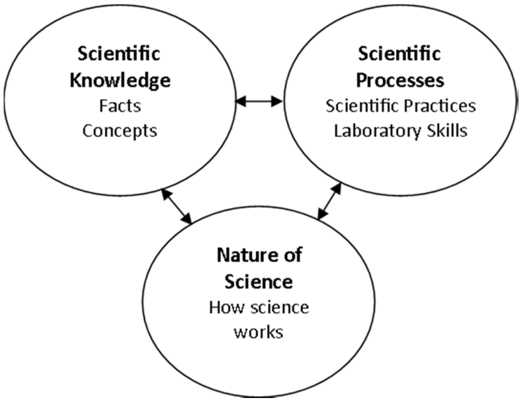

Figure 1. Three Domains of Scientific Understanding. Adapted from "Beyond understanding: Process skills as a context for nature of science instruction," by R. L. Bell, B. Mulvey, & J. L. Maeng, 2012, in M. S. Khine (Ed.), *Advances in the Nature of Science Research: Concepts and Methodologies,* p. 229. Copyright 2007 by Springer.

Gaining *scientific knowledge* requires an understanding of both facts and concepts (Abraham, 2011; Leonard, 1997). Facts, also called propositions (White, 1996) and definitions (Abraham, 2011), are discrete pieces of information that typically emerge from observations (Abraham, 2011; Leonard, 1997). For example, students can observe bubbles and gas emerge when aluminum metal is added to a beaker of hydrochloric acid. Students can also feel the heat released from this reaction. These observations allow students to understand that there is a chemical reaction between aluminum and hydrochloric acid. Combining facts, mental pictures, and experiences (White, 1996) creates a concept, also called an abstract idea (Leonard, 1997) or a general principal (Abraham, 2011). For example, students may further investigate the chemical relationship between metals and acids. This could be achieved by allowing students to develop an experiment to test other metals in hydrochloric acid. These additional investigations provide students the opportunity to combine facts about each metal into a concept relating to trends of metal reactions in acid.

Learning outcomes for laboratory courses also include scientific practices and laboratory skills, called *scientific processes.* Scientific practices are typically more intellectual or cognitive-based, whereas laboratory skills utilize motor skills (White, 1996). For example, when completing the metal/acid experiment, requisite laboratory skills include weighing on a balance and measuring liquid volumes. Scientific practices have become one pillar of the Next General Science Standards in K-12 education (NRC, 2012). The practices students are expected to engage in include: 1) asking questions, 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations, 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating results (NRC, 2012, p. 42).

As an example of how students could engage in these practices, investigating the reactivity of different metals in hydrochloric acid allows students to develop an experiment to test this relationship (i.e. planning an investigation). During the experiment students gather data about metal reactivity (i.e. carry out an investigation) and determine how to organize the gathered data (i.e. analyze and interpret). They may then develop the understanding that metals with certain periodic characteristics react in a particular manner with acid (i.e., construct explanations) and share their results and conclusions with the class (i.e. communicating results).

The final domain on scientific knowledge is an understanding the *nature of science*, an essential learning outcome for science instruction. Nature of science is defined as the “values and assumptions inherent to the development of scientific knowledge" (Lederman & Zeidler, 1987, p. 721); however, it is not enough for students just to experience science to understand how science works. Researchers studying student learning of the nature of science demonstrate that explicit nature of science instruction with opportunities for reflection facilitate accurate and complete nature of science understandings (e.g., Abd-El-Khalick & Lederman, 2000; Bell, Matkins, & Gansneder, 2011). To facilitate instructors teaching explicit nature of science and to aid students in understanding the nature of science, a set of agreed upon nature of science tenets have been developed. These tenets include: 1) science uses multiple methods, 2) scientific knowledge is based upon evidence but is tentative and subject to change with new evidence, 3) creativity, subjectivity, society, and culture play important roles in science, 4) scientific knowledge is gained through both observations and inferences, and 5) scientific laws and theories are complimentary but not interchangeable understandings about science (Bell, Mulvey, & Maeng, 2012). As an example, students could explicitly discuss how their experience investigating metal reactivity emulated some of the nature of science tenets such as subjectivity, knowledge is based upon evidence, and both observations and inferences were required to construct an explanation about metal reactivity. Students could also explain the difference in laws and theories related to metal reactivity and explicitly discuss the differences between them.

In summary, many different types of learning may occur in science classrooms: scientific knowledge, scientific processes, and the nature of science. However, undergraduate science courses typically emphasize just facts rather than conceptual knowledge, process, or the nature of science. The lack of comprehensive learning has implications for how students understand science (Leonard, 1997) and become interested in science (Fairweather, 2008; Pascarella & Terenzini, 2005).

Factors Influencing Student Learning

Research on learning in undergraduate settings suggests there are a variety of factors that affect student learning, which can be categorized as personal characteristics, aspects of instruction, and types of interactions. Further, research reveals additional relationships between these factors (e.g., personal characteristics and instruction), creating a complex picture of student learning. While only interactions will be investigated in the present study, a complete review of factors influencing student learning is warranted. Each of these factors will be examined in the sections below.

Personal characteristics. Reviews of research reveal student attitudes about science and self-efficacy impact student learning (Osborne et al., 2003) (Pajares, 1996; van Dinther, Dochy, & Segers, 2011). When examining the definitions of these two characteristics, student attitude appears to be an overarching construct. Attitudes encompass students' perceptions of their teacher, anxiety about science, value of science, self-esteem, motivation, enjoyment of science, peers/friends/parents attitudes toward science, science achievement, fear of failure, and classroom environment. In a review of the literature on students' attitudes regarding science, Osborne et al. (2003) found most studies agreed there is a moderate relationship between student attitudes and student achievement. The direction of this relationship, however, was unclear. The authors could not conclude if doing well in science classes caused students to enjoy science or if enjoyment of science caused students to do well in science courses.

Research suggests self-efficacy also influences student learning. According to Bandura (1977), self-efficacy is defined as “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (p. 193). Self-efficacy has been significantly positively correlated with student achievement and performance across disciplines and grade levels and is considered an important mediator for student outcomes (Pajares, 1996; van Dinther et al., 2011). However, the strength of relationship between self-efficacy and achievement may be a result of how the constructs are defined and measured, and studies that found no significant relationship may have not appropriately measured self-efficacy (Pajares, 1996). The lack of clarity on how personal characteristics influence student achievement may be due to other factors such as persistence and metacognition as well as the difficulty in accurately and reliably measuring attitudes and self-efficacy (Osborne et al., 2003; Pajares, 1996).

Instructional choices. Studies demonstrate instructional choices such as collaboration, feedback, and active learning relate to student learning (Chickering & Gamson, 1987; Leonard, 1997; Pascarella & Terenzini, 2005; White, 1996). These instructional choices are different than the actual interactions that instructors use to engage students. For example, an instructor may provide opportunities for collaboration between students (i.e., instructional choices) but the instructor takes a passive role in facilitating collaboration in practice (i.e., interactions). Types of interactions are the focus of the next sub-section.

In a review of research studies on undergraduate student learning, opportunities for students to work cooperatively related to students self-reported interpersonal skills

(Pascarella & Terenzini, 2005). A general overview of how to improve undergraduate education suggests incorporating student cooperative learning within courses would help improve student participation and increase their depth of learning (Chickering & Gamson, 1987). Further, prompting and detailed feedback may help students know what and how to improve their learning (Chickering & Gamson, 1987).

Researchers agree student learning improves when instruction incorporates active learning opportunities (e.g., Chickering & Gamson, 1987; Leonard, 1997; White, 1996). Both Leonard (1997) and White (1996) take a theoretical approach to explain the relationship between opportunities for students' active participation and student learning specifically for science courses. They agree that science should be taught the way students learn, so if students learn through active learning approaches, the curriculum should incorporate active learning methods. Providing opportunities for students to gather concrete information allows for the active construction of abstract ideas, which improves learning (Leonard, 1997). The impact of inherently passive laboratory curricula such as cook-book or expository experiments on students' learning scientific practices and nature of science is emphasized by White (1996), "Students will learn anti-science rather than science: that there is a correct answer sanctified by authority. Science will then be perceived as a rigid, unquestionable body of facts rather than as a dynamic, developing interpretation of phenomena" (p. 769). Consequently, from a theoretical perspective instructional choices may not only impact student learning but the overall goal of undergraduate education to produce scientifically literate citizens.

Types of interactions. The types of interactions students have with instructors and peers are another important factor that can influence student learning (Barber, 2012; Komarraju, Musulkin, & Bhattacharya, 2010; Pascarella & Terenzini, 2005). Interactions occur when "individuals engage socially in talk and activity about shared problems or tasks" (Driver, Asoko, Leach, Scott, & Mortimer, 1994, p. 7), and interactions are essential for students to understand scientific knowledge, process, and nature of science (Driver et al., 1994). However, few studies assess how interactions between students and instructors influence student learning.

Some studies provide evidence that student-instructor interactions relate to student achievement. In a study of 292 first year students enrolled in a psychology course, Komarraju et al. (2010) assessed student perceptions of student-faculty interactions using a 40-question Likert survey. The authors found a significant positive correlation between instructor approachability and student GPA (β=.19). In other words, feeling comfortable to approach instructors in order to interact with them may foster student achievement.

Other studies investigate student-student interactions. Peer interactions, typically occurring through collaborative or cooperative learning opportunities within courses, relate to increases in students' social skills (Pascarella & Terenzini, 2005) and impact integration of learning (Barber, 2012). Further, analysis of interview data suggest in the absence of instructor interaction, students rely on peer interactions for guidance and construction of knowledge (Barber, 2012).

Relationship between factors. Research shows student learning may be affected by students' personal characteristics, the course curriculum, and the interactions a student experiences (e.g., Barber, 2012; Komarraju et al., 2010; Osborne et al., 2003; Pajares, 1996; van Dinther et al., 2011;). Analyzing the various bodies of literature on student learning reveals these factors may also influence each other. In fact, the interplay of these factors is the focus of much of the research (Chicerking & Gamson, 1987; Komarraju et al., 2010; Osborne et al., 2003; van Dinther et al., 2011; White, 1996). The research studying the relationship between personal characteristics, curriculum, and interactions is examined below.

Personal characteristics and instructional choices. The research literature indicates instructional choices influence student attitudes, self-efficacy, and motivation (Osborne et al., 2003; van Dinther et al., 2011; White, 1996). Strategies positively impacting students' personal characteristics include making content relevant, engaging students, and using multiple methods of instruction (Osborne et al., 2003). Conversely, first year science course with no opportunities for discussion, collaboration or critical thinking can alienate students (Tobias, 1990). In a review of the higher education self-efficacy literature, van Dinther et al. (2011) identified that 80% of intervention studies showed a significant relationship between the intervention and self-efficacy. These interventions included the use of modeling and mastery of content, which implies that these instructional changes may positively influence self-efficacy. However, studies with treatment and control conditions found less favorable outcomes related to self-efficacy. One study cited in this review indicated no significant differences in students' self-efficacy between students who had cooperative learning experiences to those that did not (Rittschof & Griffin, 2001, as cited in van Dinther et al., 2011).

In a less systematic review of the literature on laboratory instruction and student learning, White (1996) cited a handful of studies from the 1980s and 1990s that showed conflicting results about the relationship between student motivation and the instructional approaches. Some studies illustrated laboratory instruction improved student motivation, whereas other research implied laboratory courses decreased student motivation. However, the context of these studies was not described, so differences in the curricula among studies included in the review is unclear.

Personal characteristics and types of interactions. Studies agree that interactions between faculty and students impact students' attitudes, self-efficacy, and motivation (e.g., Chicerking & Gamson, 1987; Komarraju et al., 2010; Sundberg, Dini, & Li, 1994; van Dinther et al., 2011). Quality interactions positively influence attitudes and occur when teachers are enthusiastic, approachable, and know content (Osborne et al., 2003). Conversely, negative interactions by patronizing instructors negatively affect students' attitudes about science (Tobias, 1990). Thus, instructors' content knowledge, attitude, and self-efficacy may be important in the types of interactions they engage in with students.

Interactions between students and faculty both in and out of the classroom can impact student motivation and participation in a course (Chickering & Gamson, 1987). Empirical data supports the claim that student-faculty interactions may impact motivation and self-efficacy (Komarraju et al., 2010; Pajares, 1996). In a review of self-efficacy research, positive feedback from an instructor appeared to positively impact student self-efficacy Pajares (1996). A study of 242 undergraduate students revealed a significant positive correlation between student perceptions of their interactions with faculty and self-efficacy and between student perceptions of faculty interactions and motivation (Komarraju et al., 2010). Further, there was a significant negative correlation between perceptions of student-faculty interactions and amotivation. Using step-wise multiple regression, Komarraju et al. (2010) identified the interaction characteristics that predicted self-efficacy, motivation, and amotivation. Whether the professor was respectful, approachable, and available outside of class were the most consistent predictors of these outcome variables.

Types of interactions and instructional choices. Research on undergraduate education indicate instructors typically teach the way they were taught (e.g., Bond-Robinson, 2000; Sharpe, 2000; Hammrich, 2001; Leonard, 1997; Luft et al., 2004; Dotger, 2011), which implies a disconnect may exist between reform-based curricula and instructors. For example, an instructor may continue to use didactic approaches even after professional development emphasizing active learning because that is the way that they were taught the material. Despite empirical data emphasizing the importance of both the method of instruction and instructor interactions on student learning, no general undergraduate studies analyze this relationship in the laboratory setting.

In summary, a variety of factors and relationships between factors appear to influence undergraduate student learning (Figure 2). The research on undergraduate students focuses on how instructional choices influences students' personal characteristics, and how these personal characteristics relate to student learning (e.g., Osborne et al., 2003; Pajares, 1996; van Dinther et al., 2011). Literature reviews, empirical research, and theoretical articles appear to agree that student learning is improved when the instruction emphasizes active learning opportunities for students (e.g., Chickering & Gamson, 1987; Leonard, 1997; White, 1996).

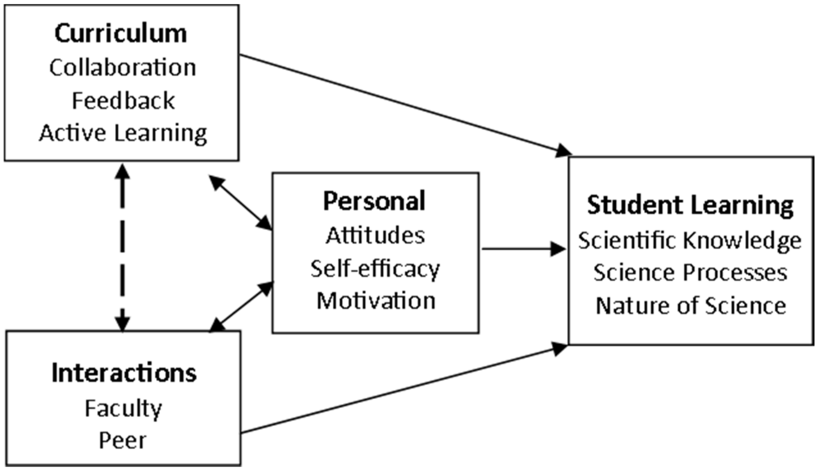

Figure 2. A Pictorial Representation of How Researchers Examine Factors Influencing Undergraduate Student Learning. The arrows indicate how those characteristics are related to each other and student learning. --- indicates a relationship not studied.

However, researchers and theorists state there is actually a misalignment between learning and teaching at the university level (e.g., Chickering & Gamson, 1987; Hofstein & Lunetta, 2004), and more specifically within science courses (e.g., Abraham et al., 1997; Leonard, 1997; Osborne et al., 2003). Examining research on laboratory instruction revealed professors' instructional practices failed to align with their stated goals for the course (Abraham, 2011). For example, if the goal of the laboratory is for students to learn the nature of science, then inquiry-based labs, rather than verification labs, should be utilized (Russell & Weaver, 2011). In fact, when identifying the state of chemistry labs in the United States, 91% (n=203) of responding universities reported students still followed step-by-step instructions in general chemistry labs (Abraham et al., 1997). In a more recent study, analysis of laboratory manuals across seven content areas (n=386) indicated 92% of the experiments provided students step-by-step instructions for collecting and analyzing data (Bruck, Bretz, & Towns, 2009). A review of the research on laboratory courses is warranted in order to further examine the relationship between instructional methods and student learning.

Undergraduate Science Laboratory Instruction

Research on undergraduate science laboratories focuses on student attitudes, learning, and/or interactions in lab (e.g., Chatterjee, et al., 2009; Lord & Orkwiszewski, 2006; Xu & Talanquer, 2012). A synthesis of this body of literature may provide a better understanding of differences in student learning in the laboratory. However, two main challenges exist. First, researchers fail to agree on the terms used to describe different types of laboratory instructional methods (e.g., Domin, 1999; Bruck et al., 2009), making it difficult to compare across studies. Second, many of the studies on student learning in the laboratory have significant methodological issues (e.g., Luckie, Maleszeweski, Loznack, & Khra, 2004; Spiro & Knisely, 2008), creating confusion on effective and ineffective laboratory instructional methods. This section attempts to provide a detailed critique and synthesis of this body of literature. In order to do so, laboratory instructional methods are first defined. Next, the rigor and limitations of the research studies is discussed in order to justify the focus on a select few number of studies for review. A review of the remaining rigorous studies examining the relationship between the types of laboratory curriculum on student outcomes follows. This section concludes with an overall critique of this body of literature and how this dissertation aims to fill the gaps in the research.

Defining Laboratory Instructional Methods

Different approaches to undergraduate laboratory course curricula include expository, inquiry, problem-based, project-based, and discovery (Domin, 1999; Prince & Felder, 2006). However, with the exception of expository instruction, there is not a consensus on how to define these terms, which has led to contention between researchers (e.g., Eastwell, 2009; Hmelo-Silver, Duncan & Chinn, 2007; Kirschner, Sweller, & Clark, 2006). For example, Domin (1999) uses discovery learning and guided inquiry synonymously, whereas Prince and Felder (2006) define discovery learning as students discovering concepts on their own. These researchers not only accuse one another of conflating terms, they also argue about how to structure instruction and what methods are most appropriate for students at different grade levels (e.g., Eastwell, 2009). For example, some science faculty believe that guided inquiry is most appropriate for undergraduate students (Brown, Abell, Demir, & Schmidt, 2006), and some researchers contend open inquiry is not appropriate for beginning undergraduates (Eastwell, 2009). Clearly, the laboratory research literature does not utilize consistent terms for different laboratory instructional methods nor do they agree on which methods to use. In order to review the literature on laboratory courses and student outcomes, these instructional methods need to be more clearly defined.

For this study, inquiry is defined as students drawing justifiable conclusions to answer a research question through the systematic analysis of data (Bell et al., 2005;

Eastwell, 2009). In inquiry instruction students are actively involved in learning through the analysis of data and drawing conclusions from that data. Inquiry is also very broad instructional method that can be incorporated into a project-based or problem-based curriculum, (e.g., Sterling & Frazier, 2010) and inquiry can be structured in a variety of ways to help support student learning (e.g., Blanchard et al., 2010). The studies examined below may be within a project-based or problem-based context, but since inquiry is incorporated into each of these approaches, the studies reviewed will focus on the inquiry structure.

Inquiry-based instruction ranges from highly structured and guided approaches (confirmatory) to less guided approaches (open). Using a framework developed by Herron (1971) and modified by Bell et al. (2005), there are four different methods to structure inquiry: confirmatory, structured, guided, and open inquiry. Some authors contend that confirmatory inquiry is not inquiry and would fall under expository; however, in confirmatory inquiry students remain actively involved in the analysis and conclusion portions of the laboratory. Conversely, in expository instruction students are either told how to analyze the data or are not required to analyze the data (i.e., write down values and do calculations). For clarity, Table 1 provides the definitions of different instructional methods that frame this literature review and dissertation.

Table 1

Framework Used to Define Laboratory Instructional Methods

Term	Definition	Reference(s)
Expository	Students verifying a concept using a given method for collecting and analyzing data	Bruck et al. (2009); Domin (1999)
Confirmatory Inquiry	Students are using a ***given procedure*** and have to determine how to analyze the data to reach the ***expected*** conclusion	Bell, et al. (2005)
Structured Inquiry	Students are provided a research question and the procedure and have to analyze the data to draw their ***own*** conclusions	Bell et al. (2005)
Guided Inquiry	Students are provided a research question but have to ***develop the method*** of answering the question by drawing their ***own conclusions***	Bell et al. (2005)
Open Inquiry	Students come up with ***their own question and method*** and draw their ***own conclusions***	Bell et al. (2005); Bruck et al. (2009)
Problem-based	A complex, ill-structured problem students solve over time	Hmelo-Silver (2004); Prince & Felder (2006)
Project-based	Students are given a problem with a driving question they have to solve, producing a product at the end	Blumenfeld et al. (1991); Hmelo-Silver (2004); Prince & Felder (2006)
Discovery	Students discover concepts on their own	Prince & Felder (2006)

The definition of the instructional methods outlined in this conceptual framework will be used when discussing the research on laboratory instruction and student outcomes. However, this poses a challenge as researchers may not incorporate similar descriptions of their laboratory instructional method(s), making it difficult to characterize across studies. For example, in expository, confirmatory inquiry, and structured inquiry students receive a procedure, so if the authors do not describe the data analysis process it is difficult to differentiate between the three. For the purposes of this literature review, confirmatory inquiry will not be used to describe inquiry in any study since it cannot be differentiated from traditional laboratory instruction. Researchers using the terms cookbook, traditional, or verification to describe the curriculum will be categorized as expository instruction. Studies describing inquiry instruction where students are given a procedure but do not know the outcome will be categorized as structured inquiry.

Undergraduate Laboratories and Student Outcomes

A search of the literature on undergraduate laboratory instruction reveals research assessing student outcomes such as content knowledge (e.g., Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006), scientific practices (e.g., Krystyniak & Heikkinen, 2007; Xu & Talanquer, 2012), laboratory skills (e.g., Suits, 2004), and the nature of science (Russell & Weaver, 2011). Analysis of these studies suggests researchers used varied levels of methodological rigor to assess student outcomes. Since this review compares studies across the body of literature, clear and detailed information about the course curriculum and methods are warranted in order to draw any conclusions about the relationship between science laboratory instruction and student outcomes. The first section reviews literature that contains critical flaws and provides justification for exclusion of these studies in the analysis. The following section examines the identified rigorous studies to characterize the relationship between laboratory instruction and student outcomes. Finally, this section concludes with a discussion of the gaps and limitations of this body of literature and how this dissertation aims to fill these gaps.

Flawed undergraduate laboratory studies. Of the twenty-two identified research studies relating to undergraduate laboratory instruction and student outcomes, nearly half of these studies contain one or more critical issues that limit the validity of reported results. These flaws included lack of instrument validity (Basey & Francis, 2011; Basey, Sacket, & Robinson, 2008, Bryant, 2006; Berg, Bergendahl, Lundberg, & Tibell, 2003; Domin, 2007; Luckie et al., 2004; Rissing & Cogan, 2009; Spiro & Knisely, 2008; Sundberg & Moncada, 1994), comparison of groups across years/instructors without ensuring group similarities (Basey & Francis, 2011; Berg et al., 2003; Domin, 2007; Luckie et al., 2004; Rissing & Cogan, 2009), no information on analysis of qualitative data (Domin, 2007; Ketpichainarong et al., 2010; Poock, Burke, Greenbowe, & Hand, 2007; Sundberg & Moncada, 1994), inherent bias in data due to structure of the study (Berg et al., 2003; Jackman Mollenberg & Brabson, 1987; Luckie et al., 2004; Poock et al, 2007; Rissing & Cogan, 2009; Spiro & Knisely, 2008), and clear misconceptions of authors on educational theory (Bryant, 2006; Rissing & Cogan, 2009; Spiro & Knisely, 2008) (Table 2).

Table 2
Overview of Flaws within Studies Identified as Lacking Rigor

Studies	Validity	Cross-Comparison	Data Analysis	Bias	Misconceptions
Basey & Francis (2011)	x	x			
Basey et al. (2008)	x				
Berg et al. (2003)	x	x		x	
Bryant (2006)	x				x
Domin (2007)	x	x	x		
Jackman et al. (1987)				x	
Ketpichainarong et al. (2010)			x		
Luckie et al. (2004)	x	x		x	
Poock et al. (2007)			x	x	
Rissing & Cogan (2009)	x	x		x	x
Spiro & Knisely (2008)	x			x	x
Sundberg & Moncada (1994)	x		x		

The most prevalent methodological issue found in these flawed studies centered on validity, resulting in a misalignment between the measurement instrument and assessed construct. For example, Basey et al. (2008) had biology laboratory students identify their favorite and least favorite labs, which the authors used to determine student attitude toward science. The lack of validity of their instrument and the misalignment between their construct and data limits the ability to draw conclusions about the study. Another major flaw found in many of the studies was the comparison of students in different lab settings, with different instructors, and across different years without providing evidence that the students in each group were from the same overall student population. For example, Luckie et al. (2004) used voluntary end-of-semester course ratings and content exams for students in two different types of biology labs during two different semesters. The authors concluded that students with the open inquiry laboratory experience had more positive attitudes about lab than students in expository labs, yet they provided no evidence of group similarity. Further, since students positively rated the course in a voluntary end-of-semester evaluation, the results may be biased by students who felt strongly about the curriculum. Lack of information about data analysis was another limitation in the flawed studies. This was more prevalent with qualitative data sources than quantitative; typically authors failed to provide information on how interviews and open-ended questions were analyzed and coded (e.g., Domin, 2007).

The methodological approach or the format of the study itself presented issues of bias in some of these studies. For example, in an expository general chemistry lab students were randomly assigned to complete a single lab using three different instructional approaches: traditional, computer simulation, and guided inquiry (Jackman et al., 1987). Students completed a pre/post content-based assessment, and the authors determined there were no significant differences in students' post-content scores between the traditional and guided inquiry instruction when controlling for pre-test. Since students in this study typically completed expository labs, students had to perform unfamiliar tasks such as developing a procedure in the inquiry lab setting. Time learning inquiry-based tasks may have limited students' content learning, making a content knowledge assessment for students in their first inquiry-based laboratory experience inappropriate.

Finally, some researchers appeared to have clear misconceptions about science education and best educational practices. For example, in a study of pre-service middle school science teachers in a physics laboratory, Bryant (2006) assessed teachers' content understanding within a guided inquiry setting. However, the author explicitly stated the instructor provided no guidance during the laboratory and observed that the pre-service teachers were unsuccessful in lab. Educational researchers suggest providing support for students during instruction, especially within an inquiry context, is an effective pedagogical strategy (e.g., Eastwell, 2009). Therefore, the clear misconception of the author about effective pedagogical practice calls into question the validity of their conclusions.

Rigorous undergraduate laboratory studies. A small set of studies examining learning in undergraduate laboratory settings provide more reliable results on the relationship between laboratory curricula and student outcomes. These studies appeared to be much more rigorous in that they utilized valid instruments, provided appropriate and detailed analysis methods, justified and provided evidence for the comparison of groups across different instructors and semesters, and made relevant and reasonable claims based on their data. For example, in a study of 119 students in an introductory biology course, Hall and McCurdy (1990) used pre/post assessments to determine students' biology content, logical thinking, and attitudes in expository and structured inquiry laboratories. The instruments used by the authors had been examined by a panel of experts, piloted, and/or previously validated. They also provided alpha reliability values to indicate the consistency of the instrument to measure the stated constructs. Further, authors utilized Piaget's developmental levels (i.e., concrete, transitional, and formal) to create the foundation for a logical thinking assessment. Data analysis in this study included an ANCOVA to provide a statistical comparison of post-survey scores while controlling for pre-test scores.

General information about overall characteristics of the ten rigorous studies on laboratory instruction and student outcomes can be found in Table 3. Only two content areas appear to be the focus of this body of research; biology and chemistry. With the exception of one biochemistry course, the remaining studies examine either introductory biology laboratories or general chemistry laboratories. Four of the ten studies utilized solely quantitative measures (Basaga et al., 1994; Chatterjee et al., 2009; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006), four used mixed methods (Brickman et al., 2009; Krystyniak & Heikkinen, 2007; Russell & French, 2002), and two studies utilized only qualitative methods (Russell & Weaver, 2011; Xu & Talanquer, 2012).

Three of the studies observed laboratory instruction (Krystyniak & Heikkinen, 2007; Russell & French, 2002; Xu & Talanquer, 2012). None of the studies in Table 2 provided this observational evidence to triangulate self-reported data, another indication of the lack of rigor in those studies.

When examining these ten rigorous studies, the most prevalent student outcomes assessed included content, attitudes, and scientific practices. Two studies assessed laboratory skills, only one study assessed nature of science, and one study assessed self-efficacy and scientific literacy. The majority of studies compared student outcomes in treatment and control conditions (i.e., inquiry and expository), and the remaining three studies examined student outcomes in one laboratory course incorporating differing levels of inquiry. Five of the seven treatment/control studies used a guided inquiry approach to support students in the laboratory, one study used structured inquiry, and one study incorporated open inquiry.

Table 3

Overview of Rigorous Studies Examining Student Outcomes in Science Laboratory Courses

Authors	Lab Course	Data Sources	Outcome Measures	Instructional Method
Basaga et al. (1994)	Biochem (n=85)	Pre/post survey	Content, Lab skills	Expository vs. Guided
Brickman et al. (2009)	Intro Bio (n=1300)	Pre/post survey, interviews	Scientific practices, Self-efficacy, Scientific literacy	Expository vs. Guided
Chatterjee et al. (2009)	Gen Chem (n=332)	Post-survey	Attitudes	Structured and Guided within course
Hall & McCurdy (1990)	Intro Bio (n=119)	Pre/post survey	Content, Attitude	Expository vs. Structured
Krystyniak & Heikkinen (2007)	Gen Chem (n=24)	Lab transcriptions	Scientific practices	Levels scaffolded within course
Lord & Orkwiszewski (2006)	Intro. Bio (n=200)	Pre/post-survey	Content, Attitude	Expository vs. Guided
Russell & French (2002)	Intro Bio (n=145)	Pre/post-survey, interviews, Lab observations	Content, Attitude	Expository vs. Guided
Russell & Weaver (2011)	Gen Chem (n=19)	Pre-survey, pre/post interviews	Nature of Science	Expository vs. Open
Suits (2004)	Gen Chem (n=110)	Student documents, Lab exam obs.	Scientific practices, Lab skills	Expository vs. Guided
Xu & Talanquer (2012)	Gen Chem (n=24)	Lab observations	Scientific practices	All levels within course

Note. Terms used to define inquiry mirror terms used in Table 1 and are not necessarily the exact term used to define inquiry within the study. Biochem = Biochemistry laboratory, Intro Bio = Introductory Biology laboratory, Gen Chem = General Chemistry laboratory

Organizing these ten studies by outcome measures reveals general trends (Table 4). All three pre/post survey studies comparing laboratory instructional approaches provide evidence that students learned significantly more content in inquiry-based laboratories than students in expository laboratories when controlling for pre-test scores (Basaga et al., 1994; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006). These results were found in biology labs in both structured and guided inquiry settings, which imply that the process of analyzing data rather than developing an experiment may lead to a better understanding of biology concepts. Observational data from Russell and French (2002) may provide more insight into differences in students' content understanding between inquiry and expository labs. The authors found students who actively participated in more open inquiry experiments tended to have higher changes in content scores. There was no evidence of analysis of data within the laboratory setting; students may have analyzed data outside of lab. Thus, interacting with the environment within the laboratory (experimental) and outside of laboratory (data analysis) may help students better learn scientific knowledge.

Two studies examining student laboratory skills determined students in inquiry laboratories had significantly better laboratory skills than students in expository labs (Basaga et al., 1994; Suits, 2004). These results were consistent across a pre/post assessment (Basaga et al., 1994) and an authentic laboratory assessment (Suits, 2004). Since only one study examined students' understanding of nature of science (Russell & Weaver, 2011), and only one study examined self-efficacy and literacy (Brickman et al., 2009), no conclusions can be drawn across studies.

Table 4

Laboratory Research Studies Organized by Student Outcome Measures

Outcome	Study	Results
Content	*Basaga et al. (1994)*	Significantly higher inquiry post-content scores
	Hall & McCurdy (1990)	Significantly higher inquiry post-content scores
	Lord & Orkwiszewski (2006)	Significantly higher inquiry post-content scores
	Russell & French (2002)	Active participation in inquiry lab related to improved content scores
Scientific Practices	*Brickman et al. (2009)*	Significantly higher post-scientific practice scores
	Krystyniak & Heikkinen (2007)	Shift from procedural to data analysis interactions in lab
	Suits (2004)	Longer and better discussions in inquiry lab report
	Xu & Talanquer (2012)	Shift from students asking questions to discussing ideas in lab
Skills	*Basaga et al. (1994)*	Significantly higher post-lab skills scores
	Suits (2004)	Significantly higher lab skill exam scores
Nature of Science	*Russell & Weaver (2011)*	Improved nature of science understanding
Self-efficacy	Brickman et al. (2009)	Significantly higher gains in self-efficacy for control
Scientific Literacy	*Brickman et al. (2009)*	Significantly higher inquiry post-semester literacy scores
Attitudes	Chatterjee et al. (2009)	Preferred structured over guided inquiry
	Hall & McCurdy (1990)	No significant differences on post-attitude scores
	Lord & Orkwiszewski (2006)	Significant pre/post change in attitude
	Russell & French (2002)	Positive attitude change related to active participation in inquiry experiment

Note. Studies *italicized* revealed inquiry was positively related to student outcomes.

Results appear to be mixed for pre/post survey studies assessing student attitudes (Chatterjee et al., 2009; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006). In an assessment of 332 students in a general chemistry course with both structured and guided labs, Chatterjee et al. (2009) found students' preferred structured inquiry compared to guided inquiry. Hall and McCurdy (1990) studied 119 students in either an expository or structured inquiry introductory biology labs and found no significant differences in students' attitudes toward the two methods of instruction when controlling for pre-semester scores. And yet in another study, students had significant positive changes in their attitudes about their experience in a guided inquiry introductory biology course (n=100) whereas students in the expository version of the course had no significant improvement in their attitudes (n=100) (Lord & Orkwiszewski, 2006). Qualitative data on student attitudes may help explain the conflicting results. Students appeared to have more positive attitudes toward expository laboratories because they were less difficult and took less time (Hall & McCurdy, 1990), and students had less positive attitudes toward inquiry laboratories because they were confusing (Lord & Orkwiszewski, 2006). The inability for some students to connect concrete and abstract thought may be one reason for the negative attitudes toward an instructional method such as inquiry. To help promote abstract thinking, students should be provided concrete experiences and opportunities for social interactions to support this transition (Hall & McCurdy, 1990). After examining students' self-efficacy, Brickman et al. (2009) concluded, "Inquiry instruction is often met with resistance from students as they are challenged to approach scientific problems at a higher level" (p. 16). Thus, the role of the laboratory instructor may be an essential component to help support and encourage students to engage in more challenging curricula.

In summary, a plethora of research on student learning in undergraduate laboratory courses exists; however, less than half of these studies are based on rigorous research. Only ten studies were characterized as rigorous (e.g., valid instrumentation, detailed data analysis, reasonable evidenced- based conclusions) and used reliable student outcome measures. Studies examining biology and chemistry undergraduate laboratories found students in inquiry-based labs learned more content, scientific practices, and laboratory skills than students in expository laboratory settings. Observational data from multiple studies suggest inquiry shifts how students interact with other individuals, which may be one reason for the significant differences in these three studies' student outcomes. Investigations provided conflicting results on how inquiry and expository laboratory instruction influenced students' attitudes. Qualitative data imply some students prefer more structured laboratory experiences as they are less challenging and more straightforward. Researchers agree effective instruction is one way to provide students support and improve the learning experience in science laboratories.

Implications for Research on Student Outcomes in Laboratory Courses

Analysis of the literature on undergraduate laboratory instruction and student outcomes reveals two main areas for further research. First, interactions play an important role in student learning (e.g., Basaga et al., 1994; Pascarella & Terenzini, 2005; Prince & Felder, 2006), but only a few studies assess instructor-student interactions within the laboratory setting. To understand this essential instructor role in the laboratory and how that influences student learning, studies should include classroom observations of practice. Yet only three of the 10 studies reviewed in this chapter utilize observations to understand student learning in these settings (Krystyniak & Heikkinen, 2007; Russell & French, 2002; Xu & Talanquer, 2012). In fact, only a single study examined the relationship between instructor interactions and student learning (Komarraju et al., 2010); however, data was self-report and focused on general undergraduate education.

Second, none of the reviewed studies effectively integrated a theoretical framework to understand student learning in the laboratory. Of the 10 reviewed studies, over half included no discussion of learning theory (Basaga et al., 1994; Brickman et al., 2009; Krystyniak & Heikkinen, 2007; Lord & Orkwiszewski, 2006; Russell & French, 2002; Suits, 2004) or perfunctorily mentioned learning theories (Chatterjee et al., 2009; Hall & McCurdy, 1990; Russell & Weaver, 2011). Of the three studies that mentioned theory, the authors used constructivism (Chatterjee et al., 2009), Piaget's development levels (Hall & McCurdy, 1990), and situated cognition (Russell & Weaver, 2011) to justify the curriculum and student outcomes being measured. For example, according to Russell and Weaver (2011), one component of situated cognition is an authentic context. The authors believe the laboratory setting provides an authentic context for which to measure students' understanding of nature of science. None of the studies employed a theoretical framework to drive the data collection, analysis, or discussion of the results, which is a limitation of the research.

Only one study on student outcomes in laboratories utilized a theoretical lens to inform the study (Xu & Talanquer, 2012). Xu and Talanquer (2012) used a sociocultural perspective to understand students' interactions within a group laboratory setting. They integrated three components of a specific sociocultural framework (Kumpulainen, & Mutanen, 1999) into their qualitative data analysis and results to make meaning of students' functional processes, cognitive processes, and social processes in the laboratory. Yet the authors' data consisted of only running records of live observations. This does not align with the multiple data sources used by Kumpulainen & Mutanen (1999) to understand student interactions from a sociocultural perspective. While Xu and Talanquer's (2012) results may provide an accurate depiction of the types of interactions observed in inquiry-based general chemistry laboratories, it is unlikely they provided a complete picture of student learning within the study.

In summary, examining the role of the laboratory instructor and using a theoretical perspective to inform research are essential to fully understand student learning. However, the majority of studies on laboratory instruction focuses on the course curriculum or interactions between students and do not effectively integrate theory and research. This dissertation aims to fill these gaps by studying instructor-student interactions in a guided inquiry general chemistry laboratory course using a constructivist methodology, discussed in depth in later sections. Within large enrollment laboratory courses such as the one serving as the context of this study, TA's are often the instructors (Luft et al., 2004). The following section reviews a separate body of literature focused on TAs in laboratory science courses.

Teaching Assistants in Undergraduate Science Labs

Since the 1970s, graduate students have been utilized at large research universities to teach undergraduate science labs or recitations sections (e.g., Cho et al., 2010; Lawrenz et al., 1992; Luft et al., 2004). TAs have been described as the “first line of defense for instruction” (Nicklow, Marikunte, & Chevalier; 2007, p. 89) and the “bridge between faculty and students” (Dotger, 2011, p. 158). The instructional quality of courses may influence students’ decision to major in science (Fairweather, 2008; Pascarella & Terenzini, 2005), making TAs an essential component of quality undergraduate education (e.g., Bomotti, 1994; Carroll, 1980; Kendall & Schussler, 2013).

When reviewing the TA literature, almost all of the studies examine TAs’ teaching within expository laboratory courses and examine TAs’ beliefs and practice (e.g., Addy & Blanchard, 2010; Luft et al., 2004). This is in stark contrast to the literature on student learning in the lab, which emphasizes implementation of inquiry-based laboratory curricula (e.g., Basaga et al., 1994; Russell & Weaver, 2011). Clearly, the two bodies of literature are disconnected and would benefit from studies that address both student learning and TA implementation in the same laboratory setting. Despite the lack of research on TAs in inquiry laboratory settings, the studies discussed below still provide insight on the TA’s role and instructional practice. The research examining TAs within an inquiry-based laboratory context is highlighted, and observed differences between inquiry and non-inquiry results are discussed.

TA Role

The role of TAs can be categorized into four main types: task-based roles, content-based roles, affective-based roles, and instruction-based roles. *Task-based roles* relate to the types of courses the TAs teach and the responsibilities of the teaching assignment. *Content-based roles* include what the TA teaches, and the *affective-based roles* characterize how caring a TA is toward students. *Instruction-based roles* encompass how the TA supports student learning in the course. The majority of this body of research focuses on the TAs' instruction-based role and the dichotomy between a traditional instruction-based role and a more reform-based instructional role (e.g., Addy & Blanchard, 2010; French & Russell, 2002). Characteristics of the traditional role include teacher-centered instruction, teacher-as-information-giver, or teacher-as-disseminator of information, whereas the reform-based role can be characterized as student-centered and is used synonymously in the literature with active student learning, teacher-as-guide, or teacher-facilitator (Anderson, 2002). Studies on TAs' role indicate a disconnect between TA expectations, beliefs, or understandings of their role and how they actually implement this role (Addy & Blanchard, 2010; Volkmann & Zgagacz, 2004). These differences may be explained by TAs' previous experience and confidence, discussed in detail below.

Task-based roles. Task-based roles of TAs are typically as an instructor for lecture courses, discussion/review sessions, or laboratory courses (Bomotti, 1994; Calkins & Kelley, 2005; Golde & Dore; 2001; Jones, 1993; Luo et al., 2001; McGinnis, 1994; Sharpe, 2000). These studies state one main role of TAs, regardless of the type of course, is grading. TAs can be responsible for approximately 75% of grading for a course (Calkins & Kelley, 2005), and some TAs take on the additional role of developing quizzes/tests for students (Luft et al., 2004).

Specifically within a laboratory setting, TAs have additional responsibilities such as giving pre-lab lectures, knowing lab procedures, ensuring student safety, getting out equipment/materials, teaching lab techniques, and holding office hours (Calkins & Kelley, 2005; Cho et al., 2010; Herrington & Nakhleh, 2003; Roehrig et al., 2003). TAs in science also have to balance their role as teacher, student, and researcher (Gardner & Jones, 2011), which can be challenging as most science departments focus on research rather than teaching (Addy & Blanchard, 2010; Bond-Robinson, 2000; Dotger, 2011; Dudley, 2009; Shannon et al., 1998).

Content-based roles. TAs' content-based roles focus on what the TA teaches to students. The characteristics include: knowing the content, explaining the content, relating lecture concepts and abstract concepts to labs, and helping improve students' process skills (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodriques, 2006; Cho et al., 2010; Luft et al., 2004). In one survey study, 54 engineering TAs, 165 engineering students, and 18 engineering faculty agreed the most important factors for effective TA teaching were effectively communicating and explaining content (Cho et al., 2010).

The remaining studies on TAs' roles indicate TAs understand their content-based role, but it may not be reflected in their practice. Luft et al. (2004) observed 17 TAs in biology, physics, and chemistry laboratories to assess how TAs interacted with students.

The authors concluded that while the TAs explained the content, the majority of the interactions between the TA and student were procedural in nature. Similarly, Bond-Robinson and Bernard Rodriques (2006) observed 14 TAs in general chemistry, organic chemistry, and analytical chemistry labs using a validated observation protocol called the instructor's assessment instrument (ITAT). The observations indicated the majority of TAs' support for students was focused on procedure and managerial tasks rather than integrating conceptual knowledge. Conversely, in a study of 8 TAs taking a teaching seminar and teaching introductory biology lab, Addy and Blanchard (2010) observed TAs using the Reformed Teacher Observation Protocol (RTOP). They found TAs were most proficient at knowing their content and explaining their content rather than implementing reform-based practice. These four studies illustrate that one important expectation for TAs is to help students understand content and concepts; however, many times TAs' actual practice is more focused on procedure than content.

Affective-based roles. Three studies on TAs in science laboratory courses discuss TAs' affective roles (Herrington & Nakhleh, 2003; Sandi-Urena, Cooper, & Gatlin, 2011; Wheeler, Maeng & Whitworth, 2014). In a study of TA effectiveness Herrington and Nakhleh (2003) surveyed ~500 students and 14 TAs in an introductory chemistry course. Both students and TAs indicated respect for students, being helpful, approachable, caring, and enthusiastic were important in the TAs role as an effective instructor. Results also suggested the most important TA role was based on what the TA taught rather than the affective role. When interviewing 13 inexperienced TAs in a cooperative project-based general chemistry course, Sandi-Urena et al. (2011) identified two additional affective characteristics TAs perceived as part of their role; motivators and encouragers. Like the TAs in Herrington and Nakhleh (2003), these TAs also perceived their roles as mostly content-based, despite the reform-based curriculum. In this dissertation's pilot study, five of the six interviewed TAs emphasized the importance of their affective role in a guided inquiry general chemistry laboratory (Wheeler et al., 2014). The affective characteristics identified included motivating students, helping students feel comfortable in lab, and helping students enjoy chemistry. Based on these three studies, the affective role may not be the most important expected or perceived TA role when compared to the content-based role for expository instruction. However, the relative importance of different roles may shift when the curriculum is inquiry-based.

Instruction-based roles. The majority of research on TAs' role examines their understanding, beliefs, and practices of how to support student learning. Some of the teaching techniques expected of TAs in laboratories include: using questioning strategies, providing students feedback, helping students engage in scientific practices, effectively communicating content, assessing student prior knowledge and understanding, using formative assessment, being a facilitator, and understanding student misconceptions and difficulties (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodriques, 2006; French & Russell, 2002; Hammrich, 2001; Luo et al., 2001; Wheeler et al., 2014). However, the research differs on whether TAs understand or can effectively implement this instruction-based role, even after training or teaching laboratories. Further, the research reveals beliefs about teaching may influence TAs' understanding and practice (Addy & Blanchard, 2010; Sandi-Urena & Gatlin, 2013; Wheeler et al., 2014).

A handful of studies examine TAs' understanding of pedagogical approaches to teaching (French & Russell, 2002; Hammrich, 2001; Herrington & Nakhleh, 2003; Luo et al., 2001). The majority of the results are mixed; some TAs understand best-practices such as facilitation and questioning, whereas other TAs continue to see their instruction-based role as information provider. In a survey of 304 science TAs about their perceptions of the TA role, Luo et al. (2001) found that equal percentage of TAs identified their role as facilitator and as disseminator of information. Even more encouraging, the majority of TAs teaching a general chemistry course understood their role as a guide rather than question answerer; however, the TAs in the study all had prior teaching experience (Herrington & Nakhleh, 2003). Most science TAs are first year graduate students with no previous teaching experience (e.g., Nurrenbern, Mickiewicz, & Francisco, 1999; Shannon et al., 1998; Sharpe, 2000), so it is likely these results cannot be generalized to all science TAs.

TAs who teach in inquiry-based laboratory courses still struggle to understand their instructional role (French & Russell, 2002; Hammrich, 2001; Wheeler et al., 2014). In a biology laboratory using an open-inquiry approach, 12 experienced TAs and 15 inexperienced TAs were surveyed on their perceptions of their role (French & Russell, 2002). The experienced TAs understood their role as facilitator whereas the inexperienced TAs, who were not in charge of labs but provided support to experienced TAs, perceived their role as disseminator of information. The inexperienced TAs also felt their role was to help students with content, whereas experienced TAs believed their role was to help students understand the process of science. These results indicate that teaching in a reform-based course may help TAs better understand their pedagogical role; however, the authors did not discuss post-survey data on inexperienced TAs perceptions of their role after helping with the course.

In an interview-based study on TA pedagogical perceptions, Hammrich (2001) found that 10 TAs teaching a conceptual change biology laboratory course also perceived their instructional role as disseminating content to students. However, post-interview data indicated TAs in general better understood their role to be facilitators of students' active learning in the course. Another finding of this study implied TAs' perceived role in assessing students was relegated to tests and quizzes, a perception that did not change over the course of the study. As grading is one of the primary task-based roles of TAs (Calkins & Kelley, 2005), this finding is not surprising. Of concern is the fact that these TAs did not understand formative assessment and how it could be used to gauge student understanding. In this dissertation's pilot study, survey and interview data of 13 TAs in a guided inquiry general chemistry laboratory context revealed TAs improved their understanding of their role as facilitator over the course of the semester (Wheeler et al., 2014). Further, by the end of the semester more than half the TAs understood their role as helping students act like scientists, which may have implications for students learning about science.

Overall, the research indicates TAs have conflicting teacher-centered and student-centered views on their instructional role in lab, across a variety of subject areas as well as in expository and inquiry-based curricula. Thus, TAs teaching science courses may not understand the characteristics of being an effective TA as it relates to instruction.

Volkmann and Zgagacz (2004) conclude this may be a result of the TA's beliefs. Many studies on TA beliefs agree that TAs believe there is one right answer in science and thus their role is to tell students information (e.g., Gardner & Jones, 2011; Luft, et al., 2004; Luo et al., 2001; Nurrenbern et al., 1999; Volkmann & Zgagacz, 2004). These beliefs and perceptions about their role may influence how they interact with students in the lab.

TA Practice

Similar to TAs' perception of their content-based role, there appears to be a disconnect between TAs' instructional views and practice (Addy & Blanchard, 2010; Volkmann & Zgagacz, 2004). Addy and Blanchard (2010) assessed TAs' beliefs about teaching using the Teacher Beliefs Instrument (TBI) and compared the results to the TAs' actual practice using the RTOP. Interview data suggested in general these TAs believed their role as "transitional," where the TA acts as a guide to students in lab. Three TAs had "traditional" beliefs about teaching, defined as TA as information-giver (p. 1059). Despite differences in understandings, TAs in this study did not implement practices aligned with their beliefs. It was noted that "none of the TAs encouraged students to seek alternative ways to interpret evidence" (p. 1064). Overall TA's had the lowest RTOP scores on providing students support with communicating ideas, divergent thinking, and using student talk to dictate the direction of discussions. The authors believe the low scores in these areas were a result of the expository curriculum of the biology course. It is possible TAs in inquiry-based curricula might have more opportunities to emphasize communication, divergent thinking, and student talk; however, there is no evidence that the TAs were prohibited from engaging in these interactions with students. An alternate explanation for these results is that TAs beliefs influence practice.

Volkmann and Zgagacz (2004) also studied beliefs and practice using phenomenological study to follow one physics TA teaching an inquiry-based physics course for elementary education students. The researcher provided the TA with intense mentorship and opportunities to extensively discuss her beliefs and practice. Initially the TA believed her role was to disseminate information to students and that students learned by working hard. In the middle of the study the TA changed some of her practice and graded based on the quality of students' evidenced-based explanations rather than for correctness. The author indicated this change was not evident in the TAs beliefs at this point. By the end of the study the TA had modified her beliefs to be more student-centered; however, she struggled to find ways of implementing her reformed beliefs, such as the use of questioning to guide students. While this study only focused on one TA in physics, the details of how this TA changed over the course of a semester is revealing. This TA appeared to modify her practice before changing her beliefs. However, even with the intense support, the TA still struggled to align her beliefs and practices.

These two studies on TA beliefs imply that TA's beliefs and the type of curriculum may influence their practice. This is aligned with the K-12 literature which also indicates science teachers' beliefs influence their practice (e.g., Anderson, 2002; Blanchard et al., 2010; Kazempour, 2009) and many times teachers beliefs are not aligned with practice (e.g., Brown & Melar, 2006; Wee, Shepardson, Fast, & Harbor, 2007). A large body of science education literature also cites teacher beliefs are difficult to change (e.g., Kagan, 1992; Kane, Sandretto, & Heath, 2002). However, these two TA studies show changing TAs' beliefs is possible, and one method of doing so may be by changing their practice. Alignment of beliefs and practice may be facilitated by implementing an inquiry-based curriculum and providing intense mentorship. While intense mentorship over the course of a year is impractical when implementing large-enrollment laboratory courses, it is possible to incorporate characteristics of the mentorship described by Volkmann and Zgagacz (2004) into a larger-scale professional development for TAs.

In summary, the expectation of TAs is to manage a multitude of task-based, content-based, affect-based, and instruction-based responsibilities. TAs are also expected to know and implement a variety of tasks and teaching methods in the courses they teach. These expectations tend to be in contrast to the practice of TAs, as TAs perceive their role to be more focused on content and grading. This dichotomy between perceptions and practice is likely influenced by beliefs, which tended to be a mix of disseminator and facilitator. Even when TAs' beliefs changed from traditional to reform-based, TAs in the reviewed studies struggled to fully implement these changed beliefs into practice.

Factors that Influence TA Practice

The body of literature on TAs also indicates previous teaching experience (French & Russell, 2002; McGinnis, 1994) and confidence (Bond-Robinson & Bernard Rodriques, 2006; Cho et al., 2010; Kendall & Shussler, 2013; Luft et al., 2004) influences TAs' beliefs, perceptions, and practices. Two studies found that TAs' previous teaching experience influenced their beliefs and practice. In a case study of three TAs in two different science education courses, McGinnis (1994) interviewed and observed these TAs about their attitudes and behaviors. He concluded that the TAs with differing previous teaching experience also differed in their attitudes about teaching. The two TAs with no prior teaching experience tended to accept their role for the course and complied with the instructor's teaching beliefs and practice. The TA with previous K-12 and post-secondary teaching experience also accepted his role; however, he questioned his instructors teaching methods more. This TA also took on additional roles and responsibilities in the course. French & Russell (2002) found conflicting results to this study. As described above, TAs with previous inquiry-based teaching experience complied and agreed with the inquiry-based instruction, whereas TAs with no experienced had conflicting views on inquiry-based teaching methods.

When comparing the TAs in these two studies, it is clear their backgrounds and roles differed. The three TAs studied in McGinnis (1994) were graduate students in science education, and the previous experience of the experienced TA included K-12 teaching. The TAs also worked directly with a professor in a methods course and took on more of an observation role rather than an instructor role. The experienced TAs examined in French and Russell (2002) had previous experience teaching the same course as was the focus of the article, which may have influenced their beliefs differently than would previous teaching experience in a different course. Further, these science TAs were the sole instructor present in a laboratory course, which is much different than the task-based role of the science education TAs. Therefore, the conflicting results from these two studies may be due to the types of TAs assessed, rather than their previous experience.

To complicate the relationship between experience and practice, Bond-Robinson and Bernard Rodriques (2006) determined that prior experience was not a significant factor of TA performance at the end of the semester. The researchers used ITAT observation instrument to measure TA performance and compared TAs' scores based upon prior experience. However, the ITAT instrument scores frequency and quality interactions on the same Likert scale value. In other words, a frequent, low-quality TA-student interaction would be scored the same as an infrequent, high-quality TA-student interaction. The combination of quality and frequency into one construct makes the results difficult to interpret and may be inaccurately representing TA practice.

Similar to studies on previous teaching experience, studies assessing TAs' confidence in teaching provide conflicting results. In a nation-wide survey of 1410 TAs at 27 universities in multiple disciplines, Golde and Dore (2001) found TAs were comfortable and confident about their teaching responsibilities. The TAs surveyed in this study were at least third year graduate students, which is not representative of the TAs used in the present study. Baumgartner (2007) surveyed 19 Zoology TAs and also found TAs with more confidence felt more comfortable in their teaching role. Conversely, a self-report survey study found overconfident TAs overestimated their teaching abilities (Cho et al., 2010). Yet another study concluded that TAs with no confidence were limited in their ability to effectively teach (Bond-Robinson & Bernard Rodriques, 2006). The only characteristics these studies have in common are the data related to confidence is self-reported. Confidence in teaching is one component of self-efficacy and can be challenging to measure (Pajares, 1996), so the lack of consensus in these studies may be due to the differences in measuring confidence as a component of self-efficacy.

As seen in Figure 3, the TA's role is complex and may be influenced by several factors. Based on what course the TA instructs (i.e., task-based role), TAs are expected to have different content-based and instruction-based responsibilities, which they must understand and be able to implement in a science classroom or laboratory. TAs' beliefs, confidence, and prior experience may influence their teaching role, and most TAs perceive their content-based role as superseding their other TA roles. The affective role is a component of the TA role that does not seem to be as important to TAs as the other roles, and there is no evidence of any relationship between the affective role and other TA roles. TAs perception of their role may influence their practice, or TA practice may influence their perceptions of their role. Further, TAs are typically graduate students and have to deal with non-teaching concerns such as research and course-work (Gardner & Jones, 2011), financial support (Cho et al. 2010; Krockover, 1980; Sandi-Urena & Gatlin, 2013) and surviving graduate school (Nickolow et al., 2007). TAs have also voiced their concern over the demanding nature of graduate school (Sandi-Urena et al., 2011).

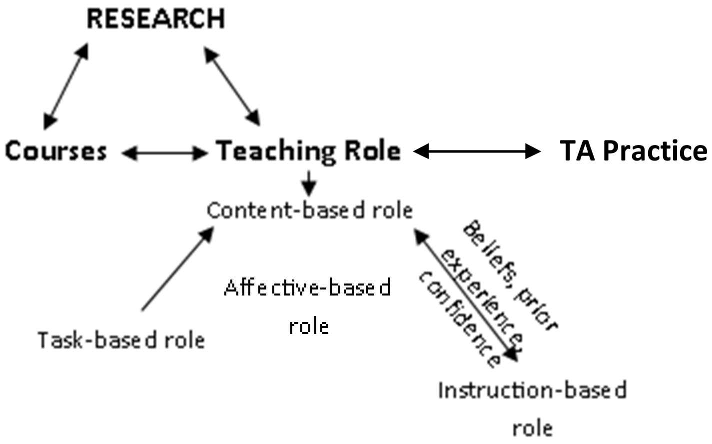

Figure 3. Relationship Between TA's Role and Factors Influencing That Role.

While TAs teach courses and interact with students, one responsibility they are typically not charged with is curriculum development (Addy & Blanchard, 2010; Bond-Robinson, 2000; Calkins & Kelley, 2005; Luft et al., 2004). Thus, TAs have the obligations of a tenure-track faculty member (i.e., teaching and research), but not the power that position holds. As a result, TAs are a marginalized population of teachers who typically are "overworked, underpaid, and generally underappreciated" (Bomotti, 1994, p. 383).

There exists a clear dichotomy between TA expectations and TA perceptions as well as TA responsibilities and TA power. This misalignment may negatively impact TAs' beliefs, confidence, and practice. Further, many researchers agree laboratory TAs implementing inquiry-based curricula should be supported in their teaching through professional development (Brickman et al., 2009; Jackman et al., 1987; Krystyniak & Heikkinen, 2007). A salient quote from Brickman et al. (2009) illustrates the importance of TA professional development, "Adopting an inquiry-based laboratory curriculum requires a substantial investment not only in curriculum development but also in new training for instructors to facilitate the shift in instructional practices" (p. 16). Therefore, TAs should be provided professional development in order to help support their instruction, which may impact TAs practice, and possibly student outcomes.

Professional Development for TAs

TAs are responsible for teaching the majority of undergraduates in science courses at large research universities, yet these TAs typically enter graduate school with no teaching experience (e.g., Hammrich, 2001; Krockover, 1980; Nurrenbern et al., 1999; Sharpe, 2000). Many TAs plan to become faculty after graduate school (Bomotti, 1994), and being a TA is typically the only teaching experience they have prior to becoming faculty (Addy & Blanchard, 2010; Cho et al., 2010). Most current faculty have very traditional beliefs about teaching (Luft et al., 2004), which research finds most prevalent in science courses (Abraham, 1997). In order to break the cycle of didactic, traditional teaching methods by faculty, researchers call for TA training to prepare TAs to teach science utilizing best teaching practices (e.g., Calkins & Kelley, 2005; Gardner & Jones, 2011; Trautmann & Krasny, 2006) that include student-centered, active learning opportunities. Shifting from traditional teaching methods to more student-centered instruction may also positively influence students' attitudes (Lord & Orkwiszewsi, 2006), content knowledge (Basaga et al., 1994; Hall & McCurdy, 1900; Lord & Orkwiszewski, 2006; Russell & French, 2002), scientific practice (Brickman et al., 2009; Krystyniak & Heikkinen, 2003; Suits, 2004; Xu & Talanquer, 2012), and laboratory skills (Basaga et al., 1994; Suits, 2004). This in turn may help improve quality undergraduate education, entice students to major in science, and produce scientifically literate citizens.

The TA training research includes articles describing TA training programs (e.g., Birk & Kurtz, 1996; Clark & McLean, 1979; Sharpe, 2000) and studies examining the effectiveness of TA training programs (e.g., Bond-Robinson & Bernard Rodriques, 2006; Marbach-ad et al., 2012; Roehrig et al., 2003). With the exception of a handful of studies focused on TAs in inquiry-based laboratories (e.g., French & Russell, 2002; Volkmann & Zgagacz, 2004), the remaining studies examine TA training for expository laboratories and/or science instruction. Thus, there is still a call for undergraduate science curriculum reform (Cooper, 2010), further research on TAs and TA programs (e.g., Hammrich, 2001; Gardner & Jones, 2011), and the use of K-12 professional development literature to develop effective TA training programs (Luft et al., 2004). In this section, the characteristics of effective K-12 professional development are first outlined to provide a context for examining the literature on TA training. Next, details on the current state of TA training are discussed. Analysis of the TA training literature in light of the K-12 professional development literature follows, and the section concludes with implications for TA professional development.

Characteristics of Effective K-12 Professional Development

In order to better understand how to change TAs' perceptions and practice, researchers suggest using the extensive literature on professional development for K-12 teachers (Luft et al., 2004). K-12 professional development literature provides evidence of a relationship between professional development, changes in teacher learning and beliefs, teacher practice, and student outcomes (Desimone, 2009). The literature also empirically identifies fundamental professional development characteristics that help promote these changes, which include: content, coherency, collective participation, best-practices, and sustained support (Desimone, 2009; Guskey & Yoon, 2009; Loucks-Horsley & Matsumoto, 1999; Loucks-Horsley, Stiles, Mundry, Love & Hewson, 2009; Luft & Hewson, 2014). These characteristics are not specific to science education and can span different types of professional development, thus they may also be applicable to professional development of TAs.

Professional development focused on *content* should incorporate clear content objectives for what the teacher should know (Luft & Hewson, 2014) as well as how the teacher should teach the content, also identified as pedagogical content knowledge (Desimone, 2009, Guskey & Yoon, 2009, Loucks-Horsley & Matusmoto, 1999). A *coherent* professional development program addresses the context of teaching (Desimone, 2009; Luft & Hewson, 2014) and should be aligned with local or national standards. In science education this may take the form of integrating reform-based practices such as the essential features of inquiry (NRC, 2000) or characteristics of scientific practices (NRC, 2012). Desimone (2009) also includes the alignment of teacher beliefs with the professional development as *coherency*. For example, a coherent professional development would incorporate student-centered practices for teachers with student-centered beliefs. However, as indicated above, teacher beliefs may not align with reform-based practice, making this type of coherency difficult to incorporate into professional development.

The term *collective participation* refers to whether groups of teachers in the same school or content area are involved in the professional development (Desimone, 2009;

Loucks-Horsley & Matsumoto, 1999; Luft & Hewson, 2014). Collective participation provides opportunities for dialogue and collaboration between teachers of similar disciplines, which may improve teacher knowledge and confidence (Luft & Hewson, 2014). Professional development should also include *best-practices* for teachers (Desimone, 2009; Guskey & Yoon, 1999), such as active learning or discipline specific practices like inquiry or problem-based learning in science education. This characteristic overlaps with both the content and coherent components of effective professional development, which is understandable given the breadth of literature on professional development. Finally, *sustained support* describes the type of follow-up support provided to teachers after the professional development. This can be characterized as helping teachers reflect on practice, providing teachers feedback on practice (Desimone, 2009; Louckys-Horsley & Matsumoto, 1999), and offering teachers individualized support over time (Guskey & Yoon, 2009; Luft & Hewson, 2014).

Researchers disagree on whether *duration* is an essential characteristic of effective professional development. Most researchers agree there is no threshold of time associated with the effectiveness of a professional development program but that one day workshops are ineffective in promoting teacher change (Loucks-Horsley & Matsumoto, 1999). Some reviews of professional development literature indicate professional development should be at least 20 hours (Desimone, 2009) whereas others indicate 30 hours (Guskey & Yoon, 2009). However, Guskey and Yoon (2009) state that "simply providing more time for professional development yields no benefit if that time is not used wisely" (p. 497). Due to the contended nature of duration as an essential feature of effective professional development, it will be excluded from the list of characteristics. Thus, five characteristics of effective professional development will be used to critique the characteristics of TA training programs detailed in the next section.

Despite the extensive research on K-12 professional development in science education, only a five studies were identified as assessing the effectiveness of inquiry-based professional development for science teachers (Blanchard et al., 2010; Lotter et al., 2006; Luft, 2001; Rushton et al., 2011; Van Hook et al., 2009). These studies utilized the literature on effective K-12 professional development to create inquiry-based professional development for science teachers. All five inquiry-based professional development programs embedded science *content*. As an example, Lotter et al. (2006) had teachers participate in biology and earth science-based inquiry lessons during follow-up sessions. One program focused specifically on embedding content into the inquiry-based instruction of the professional development in order to help teachers value inquiry as a method to teach chemistry concepts (Rusthon et al., 2011). Similarly, all five studies used the five essential features of inquiry, part of the national science education standards, illustrating the *coherence* of these programs. None of the studies focused on *collective participation* for the participants; however, all of the participants in the studies worked collaboratively during the professional development. Since these professional development programs were inquiry-based, all of the studies incorporated *best practices*. Best practices specific to inquiry instruction are elaborated in the following paragraph. Finally, the majority of the inquiry-based professional development programs incorporated *sustained support* through follow-up meetings during the school year (Lotter et al., 2006; Luft, 2001; Van Hook et al., 2009). During these follow-up meetings teachers had opportunities to discuss their inquiry-based practices with a group (Lotter et al., 2006; Luft, 2001; Van Hook et al., 2009), reflect on their practice (Luft, 2001; Van Hook et al., 2009), observe other teachers implementing inquiry (Luft, 2001), further experience inquiry-based activities (Lotter et al., 2006), and get feedback on their teaching (Luft, 2001).

These inquiry-based professional development studies also identify additional components that may improve teacher effectiveness in implementing inquiry in science classrooms. Providing teachers the opportunity to experience authentic science research (Blanchard et al., 2010; Lotter at al., 2006) is a specific method of incorporating *content* into the professional development. Developing inquiry-based lessons (Blanchard et al., 2010; Lotter et al., 2007; Luft, 2001; Rushton et al., 2011; Van Hook et al., 2009), practicing inquiry with students (Blanchard et al., 2010; Lotter et al., 2006; Luft, 2001; Rushton et al., 2011), and incorporating modeling of inquiry-based practices (Blanchard et al., 2010; Lotter et al., 2006; Rushton et al., 2011; Van Hook et al., 2009) are additional characteristics of *best-practices* utilized in inquiry-based professional development. One component not included in the characteristics of effective professional development is addressing teaching beliefs during inquiry-based professional development (Lotter et al., 2006; Luft, 2001). As indicated above, teacher beliefs tend to not align with reform-based practice such as inquiry, so addressing teachers' beliefs during professional development may improve the effectiveness of inquiry professional development.

In summary, rigorous development, implementation, and assessment of K-12 professional development programs results in identification of professional development characteristics that promote changes in teachers' beliefs and practices. Conversely, the literature on TAs mostly describes TA training or provides anecdotal evidence for effective TA training (e.g., Birk & Kurtz, 1996; Clark & McLean, 1976; Hammrich, 1996; Krockover, 1980; Lawrenz et al., 1992; Nicklow et al., 2007; Sharpe, 2000). Only a handful of studies thoroughly describe and examine the impact of TA training on TAs' beliefs and practice (e.g., Addy & Blanchard, 2010; Luft et al. 2004). Thus, using K-12 professional development literature to analyze TA training literature may provide insight into effective TA training characteristics.

Analysis of TA Training Characteristics

TA training can be categorized into three types of programs: general university-wide orientation programs, course-specific TA training programs, and teaching seminars. General orientation programs span multiple disciplines and focus on university policies and procedures that science TAs find unhelpful (Luft et al., 2004). Teaching seminars are typically voluntary courses TAs can take to help prepare them to become better science teachers, and many are not focused on the immediate TA teaching assignment (e.g., Baumgartner, 2007; Clark & McLean, 1979). Training programs are usually specific to subject area or department and help TAs better understand their current teaching assignment.

Analysis of the TA teaching literature reveals there is much overlap between studies in what components should be included in TA training. These characteristics can be grouped into six categories: practical course details (e.g., Cho et al., 2010; Clark & McClean, 1979; Herrington & Nakhleh, 2003; Roehrig et al., 2003), mentoring (e.g., Hampton & Reiser, 2004; Jones, 1993; Luo et al., 2001; Shannon et al., 1998), feedback/reflection (e.g., Bernard Rodriques & Bond-Robinson, 2006; Bomotti, 1994; Kendall & Shussler, 2013; Sharpe, 2000), pedagogy (e.g., Lawrenz et al., 1992; Luft et al., 2004; Roehrig et al., 2003), modeling (e.g., Birk & Kurtz, 1996; Cho et al., 2010; Hammrich, 2001), and teaching culture (e.g., Jones, 1993; Luft et al., 2004; Marbach-ad et al., 2012; Shannon et al., 1998). The details on how each component is carried out vary slightly by department, course, and implementer; however, there is an overall consensus about what to include in TA training. These six components will be defined and discussed within the context of K-12 professional development (Table 5).

Table 5
Alignment of TA Training Components with K-12 Professional Development Characteristics

TA training component	Characteristics of Effective K-12 Professional Development				
	content	coherency	collective participation	best-practices	sustained support
Practical details		x			x
Mentoring					x
Feedback/reflection					x
Pedagogy	x			x	
Modeling	x			x	
Teaching Culture			x		

The *practical details* about the course aid TAs in understanding their role in the course and help TAs support students in the course. Weekly TA meeting are recommended in order to address the following week's instruction/lab (Nurrenbern et al., 1999; Roehrig et al., 2003; Sandi-Urena et al., 2011). Some of the suggested topics to discuss include: procedures (Bernard Rodriques & Bond-Robinson, 2006; Herrington & Nakhleh, 2003; Krockover, 1980; Luft et al., 2004; Roehrig et al., 2003), grading (Cho et al., 2010; Lawrenz et al., 1992; Luft et al., 2004; Marbach-ad et al., 2012), content (Hammrich, 2001; Herrington & Nakhleh, 2003), practical topics (Baumgartner, 2007; Lawrenz et al., 1992), problems/issues (Clark & McLean, 1979), responsibilities (Marbach-ad et al., 2012), and safety (Herrington & Nakhleh, 2003). The K-12 professional development literature indicates that professional development should be coherent and provide sustained support (Desimone, 2009; Luft & Hewson, 2014). Thus, effective TA training should incorporate weekly meetings for support, and the practical details should align with the department and university policies. One practical detail not addressed in the K-12 professional development literature is grading. Since grading is one main role of TAs (Calkins & Kelley, 2005), it is expected that this would be an essential characteristics of TA training.

Mentoring appears to be another TA training component that supports TAs' instruction, which can be defined as one-on-one support from a more experienced instructor on teaching and learning (Schraw, Crippen, & Hartley, 2006). The majority of authors who discuss mentorship indicate the most important factor is the mentor should have knowledge, experience, and beliefs aligned with best teaching practices (Clark & McLean, 1979; Luo et al., 2001; Shannon et al., 1998). Shannon et al. (1998) states that faculty who do not practice good teaching are not good mentors. Faculty typically do not have student-centered beliefs or practices (Luft et al., 2004) nor are they provided support on how to be an effective mentor (Calkins & Kelley, 2005). This makes effective mentoring a challenge for TA training programs. Thus, if TA training programs are to be successful it may be important to provide professional development to TAs and to also teach faculty best-practices and how to effectively mentor.

According to the TA literature, other characteristics of effective mentoring include: prolonged mentorship (Jones, 1993), clear mentorship expectations (Calkins & Kelley, 2005), involved and supportive mentor (Carroll, 1980; Cho et al., 2010), and a mentor reflective of mentorship and practice (Calkins & Kelley, 2005). Some ways the mentor can be supportive of TAs are by providing explicit instruction on teaching practices (Bond-Robinson & Bernard Rodriques, 2006; Hampton & Reiser, 2004), giving constructive feedback (Bernard Rodriques & Bond-Robinson, 2006; Luo et al., 2001; Nurrenbern et al., 1999), and modeling best practice (Roehrig, et al., 2003). Science faculty members typically mentor, but some studies indicate mentors could also be an experienced TA (Carroll, 1980; Lawrenz et al., 1992; Luft et al., 2004). Mentoring in the K-12 professional development literature is an intense, sustained relationship between mentor and mentee that has been shown to effectively support new teachers in their instruction (e.g., Loucks-Horsley et al., 2009; Ingersoll & Strong, 2011). This suggests professional development for TAs, who typically have limited, if any, teaching experience, may be need to incorporate mentoring to provide effective, ongoing support.

In addition to mentor feedback, TA training program articles suggest *feedback* can also come from peers (Bond-Robinson, 2000; Lawrenz et al., 1992; Luft et al., 2004; McGinnis, 1994; Roehrig et al., 2003; Sharpe, 2000), students (Hampton & Reiser, 2004; Kendall & Shussler, 2013; Krockover, 1980; Shannon et al., 1998), or non-mentoring faculty (Krockover, 1980; Nurrenbern et al., 1999; Shannon et al., 1998). Feedback should be constructive and critical in order to be helpful to TAs (Bomotti, 1994; McGinnis, 1994). Feedback can also be formative (Bernard Rodriques & Bond-Robinson, 2006; Nurrenbern et al., 1999) or summative in nature. Summative feedback may be in the form of a final performance grade for teaching (Bond-Robinson, 2000), or as an end-of-semester student evaluation score (Davis & Kring, 2001; Hampton & Reiser, 2004; Luft et al., 2004; Marbach-ad, 2012). While student evaluation scores have been used to provide TA feedback and assess TA effectiveness, some studies suggest student evaluations are not a valid measure, as students' grades may influence their evaluation of TA effectiveness (Kendall & Shussler, 2013; Luft et al., 2004; Roehrig et al., 2003). For example, a TA who challenges their students to critically think and gives lower grades may not be rated as effectively compared to a TA who makes the course easy and gives high grades to students. The use of feedback as a method of assessing TAs to help them improve instruction should be used appropriately and deliberately.

According to the K-12 professional development literature, feedback could be characterized as sustained support for TAs. However, neither the K-12 professional development literature nor the inquiry-based professional development literature discuss the use of student evaluations as feedback. This supports the researchers who disagree with this practice for TAs. One inquiry-based professional development study reported feedback is helpful to support teachers' implementation of inquiry (Van Hook et al., 2009). In this study, the teachers co-planned and co-taught inquiry-based lessons with science graduate students. The authors determined that feedback and support from the graduate students helped teachers feel more confident in incorporating inquiry into their practice. However, the majority of the inquiry-based studies found that self-reflection was more important and more effective in changing teacher practice than feedback (Blanchard et al., 2010; Lotter et al., 2006; Rushton et al., 2011).

Self-reflection also appears throughout the TA literature (e.g., Calkins & Kelley, 2005; Clark & McLean, 1979; Luft et al., 2004; Marbach-ad et al., 2012) and can be defined as a process of "establishing distance to ourselves and our practice" to learn about teaching practices (Bengsston, 1995). For TAs, self-reflection can be promoted by watching videos of their own teaching (Bernard Rodriques & Bond-Robinson, 2006; Kendall & Shussler, 2013; Roehrig et al., 2003), identifying their own strengths and weaknesses in teaching (Kendall & Shussler, 2013), completing learning logs (Sharpe, 2000), and developing a philosophy of teaching (Nurrenberg et al., 1999; Sharpe, 2000). Some teachers in inquiry-based professional development reflected on their practice by completing reflective journals (Blanchard et al., 2010; Lotter et al., 2006) whereas others reflected on videotaped lessons of their practice (Rusthon et al., 2011) or informally reflected on their practice (Van Hook et al., 2009). This similarity between TA training and inquiry-based professional development programs supports the use of self-reflection as a potentially effective method of improving TA instruction.

The incorporation of different teaching methods in TA training typically provides the only support TAs receive before becoming instructors themselves (Addy & Blanchard, 2010; Cho et al., 2010), making *pedagogy* an essential TA training component. Incorporation of pedagogy, or simply how to teach (Shulman, 1986, p. 6), aligns with the best-practices characteristic of effective K-12 professional development. Some TA studies discuss the use of different approaches to teach TAs pedagogy, whereas others discuss the use of different types of pedagogy taught through these approaches. For example, a TA training program might teach TAs about inquiry-based practices (pedagogy taught) using modeling (approach to teaching pedagogy). The three most prominent approaches to training TAs in pedagogy are through the use of microteaching (Clark & McLean, 1979; Kendall & Shussler, 2013; Luft et al., 2004; Luo et al., 2001; Shannon et al., 1998; Sharpe, 2000), holding discussions about teaching (Bond-Robinson, 2000; Jones, 1993; Luft et al., 2004; Marbach-ad et al., 2012; Roehrig et al., 2003), and teaching about learning theories (Calkins & Kelley, 2005; Clark & McLean, 1979; Roehrig et al., 2003; Sharpe, 2000).

These specific characteristics mirror the inquiry-based professional development literature. Only one study used micro-teaching during the professional development (Van Hook et al., 2009). Since the teachers in the professional development literature are in-service teachers, practice teaching, rather than micro-teaching, prevailed in the inquiry-based literature. Some of the K-12 professional development programs required teachers to implement inquiry-based lessons developed during the professional development into their classroom (Blanchard et al., 2010; Lotter et al., 2006; Luft, 2001) or practice with students prior to entering their own classroom (Rushton et al., 2011). Discussions about teaching during workshops and follow-up sessions were evident in all inquiry-based professional development studies. One inquiry-based professional development study found teachers with more experience with learning theories were more apt to change their practice (Blanchard et al., 2010). Thus they recommend, similar to some of the TA training articles, that learning theory be incorporated into inquiry-based professional development. Since TAs have little experience with teaching and education, it may be even more important to incorporate learning theories into TA professional development.

Other pedagogical approaches identified in the TA literature include: reading articles about teaching (Lawrenz et al., 1992; Luft et al., 2004), using case studies about teaching scenarios (Shannon et al., 1998), attending workshops (Nurrenbern et al., 1999), and utilizing explicit instruction (Bernard Rodriques & Bond-Robinson, 2006; Lawrenz et al., 1992; Roehrig et al., 2003). Some authors suggest TA interest should drive topics and discussions (Bond-Robinson, 2000; Nicklow et al., 2007); however, TAs typically have no teaching experience or understanding of pedagogy prior to TA training (e.g., Hammrich, 2001; Sharpe, 2000). TA training based solely on TA interest would not be effective as TAs may not know what they do not know. Most researchers studying TAs disagree with Bond-Robinson (2000) and Nicklow et al. (2007) and believe the topics and pedagogical approaches included in TA training should be based in the science education literature (Addy & Blanchard, 2010; Baumgartner, 2007; Hammrich, 1996) or K-12 professional development (Luft et al., 2004).

In the TA literature, the most frequently discussed pedagogical approach focuses on inquiry-based instruction (French & Russell, 2002; Hammrich, 1996; Hammrich, 2001; Luft et al., 2004; Roehrig et al., 2003). Researchers state that reform-based practices have the potential make labs an even more positive learning environment (Herrington & Nakhleh, 2003) and help promote students' scientific literacy (Hammrich, 2001). This view is supported by the literature on how inquiry-based laboratory instruction influences student learning (e.g., Chatterjee et al., 2009; Hall & McCurdy, 1990). However, few differences exist between TA training for teaching inquiry-based courses (e.g., French & Russell, 2002) compared to TA training for teaching expository courses (e.g., Addy & Blanchard, 2010).

The review of inquiry-based professional development literature reveals teacher beliefs should be incorporated into TA training. When examining teacher beliefs and implementation of inquiry, Rushton et al. (2011) concluded that in order to see changes in teachers' beliefs, teachers must be forced to see their teacher-centered behaviors as a problem rather than explain it away because of student abilities. Lotter et al. (2006) found that "only when teachers' conceptions aligned with the professional development goals or the teachers were dissatisfied with their current instruction were changes made to their practice" (p. 1341). As the research shows, TAs can also have teacher-centered views about teaching, and addressing these beliefs may result in dissatisfied TAs. If they are dissatisfied with their teaching, it is possible TAs will be more open to changing their practice. Lotter et al. (2006) recommends teachers reflect not only on their practice but on how their beliefs align with their practice. Thus understanding, acknowledging, and reflecting on TA beliefs about teaching comprises an essential component to TA training in inquiry-based instruction.

Other pedagogies identified as an important component of TA training include teaching TAs how to lecture (Clark & McLean, 1979), use questioning strategies (Clark & McLean, 1979; Lawrenz et al., 1992), identify student misconceptions (Hammrich, 1996; Hammrich, 2001; Lawrenz et al., 1992), incorporate discourse or cooperative learning (Bond-Robinson, 2000; Hammrich, 1996; Lawrenz et al., 1992), and improve pedagogical content knowledge (Hammrich, 1996). The literature on K-12 professional development and inquiry-based professional development focuses on supporting teachers' pedagogical content knowledge in their teaching as a characteristic of best-practices. Conversely, the incorporation of lecturing is clearly absent from the K-12 professional development and inquiry-based professional development literature. These differences in the literature relate to differences in science faculties' beliefs about teaching compared to science education faculties' beliefs about teaching. Involving science education experts in TA training may help align the pedagogical approaches taught to TAs within reform-based practice.

One pedagogical approach that merits further discussion is the use of *modeling* in TA training. Modeling can be described as learners observing or engaging in appropriate practices facilitated by an expert (Birk & Kurtz, 2996). Many of the studies on TA training recommend modeling to help support TAs. This modeling can be in the form of the instructor modeling best practices (Birk & Kurtz, 1996; Hammrich, 2001; Lawrenz et al., 1992; Marbach-ad et al., 2012; Roehrig et al., 2003), TAs completing labs as students (Lawrenz et al., 1992; Roehrig et al., 2003), or TAs experiencing pedagogical approaches such as cooperative learning (Birk & Kurtz, 1996; Cho et al., 2010; Hammrich, 2001; Lawrenz et al., 1992; Marbach-ad et al, 2012). Best practices can also be modeled for TAs in actual courses (Baumgartner, 2007; Roehrig et al., 2003) or through the use of videotapes of experienced TAs from previous years (Lawrenz et al., 1992; Shannon et al., 1998).

Modeling could be characterized as a best-practices method of instruction in professional development; however, it is not considered its own characteristic in the general K-12 professional development literature. Modeling does appear to be a component of many of the inquiry-based professional development studies and is also identified by teachers as an effective component of professional development (Blanchard et al., 2010; Rushton et al., 2011). During a two-week inquiry-based professional development, the implementers in Rushton et al. (2011) modeled how to explicitly link content to an inquiry-based lesson, impacting teachers' beliefs and understandings. Teachers improved their understanding of inquiry and realized they had not been actually implementing inquiry in their classroom. Some teachers realized inquiry was "an effective and efficient way to teach in-depth content" (p. 36) once implementers modeled how to integrate content into inquiry-based instruction. Therefore modeling can be a powerful method of making teachers question their own practice and beliefs, which may help further facilitate changes in practice. Research on TAs roles revealed TAs take on a content-based role in their teaching and perceive this role to be most important. Conversely, many TAs beliefs are not aligned with inquiry-based instruction. Therefore, modeling inquiry while incorporating content may facilitate changes in TAs similar to those seen in teachers. This type of modeling should be incorporated into TA professional development in order to improve TAs' use of student-centered pedagogy.

There are clearly many ideas about how to make TA training most effective. However, the literature suggests one primary factor that can be a barrier to TA understanding and practice is their beliefs (Addy & Blanchard, 2010; Volkmann & Zgagacz, 2004). Further, external factors such as faculty perception may influence beliefs. One component of TA training that continues to present itself in the literature is the *culture* surrounding TA training (e.g., Calkins & Kelley, 2005; Jones, 1993; Luft et al., 2004; Nicklow et al., 2007; Shannon et al., 1998). Luft and Hewson (2014) also suggest that culture may have more influence on teacher change than professional development. In order for TA training to be effective, the graduate school culture must emphasize and value teaching, which is typically not the case since faculty do not value teaching or training in teaching (Shannon et al., 1998). A poignant quote from a TA illustrates their understanding of how faculty perceives their importance, “TAs are important because they allow the research agenda to move forward” (Luft et al., 2004, p. 222).

A handful of studies indicate the need to change the teaching culture for TAs at research universities. Many of the recommendations focused on the faculty culture and recommend TAs and faculty collaborate on teaching (Calkins & Kelley, 2005), TAs assess faculty support of TAs (Jones, 1993; Luft et al., 2004), and TA training involve faculty and department chairs (Marbach-ad et al., 2012; Shannon et al., 1998). The remaining recommendations for changing the culture about teaching suggest treating TAs as professionals (McGinnis, 1994; Sharpe, 2000), helping TAs build a community of practice (Bond-Robinson, 2000; Sharpe, 2000), and making TA training mandatory

(Nicklow et al., 2007). Building a community of practice is also important for effective professional development (Luft & Hewson, 2014). By shifting the culture around TA training to emphasize the importance of TAs, more effort may be put in to providing quality TA professional development. TAs may also feel less overwhelmed with their multiple roles and responsibilities and be able to focus on teaching. This more global change may influence TAs' beliefs and practice about teaching to take on a more facilitative role in the laboratory.

Implications for TA Professional Development

Three main conclusions can be drawn from analysis of the TA training literature. First, clear similarities and differences exist between characteristics of effective professional development for K-12 teachers and TA training that can inform the creation of an effective TA professional development program. Evidence from K-12 and inquiry-based professional development suggests the following should be incorporated into TA training: modeling pedagogy and linking instruction to content, discussing beliefs, providing opportunities for self-reflection of teaching, incorporating learning theory, and emphasizing the importance of teaching. The differences between K-12 professional development and TA training support the exclusion of some components from the TA training literature that are likely not effective. These include utilizing student evaluations as a measure of TA effectiveness and teaching non-reform-based pedagogy (e.g., lecturing). Differences in TAs' and teachers' experiences and training imply there are some components that are not always incorporated into effective K-12 PD but should be for TA training. These include explicit discussion of expectations and responsibilities, grading, mentoring, and feedback.

Second, similar to research on student learning in undergraduate laboratories, studies on TAs and TA training often do not integrate a theoretical framework to drive their research. Only a handful of the studies appear to use any theory as a basis for informing their study (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodriques, 2006; Calkins & Kelley, 2005; Dotger, 2011; Hampton & Reiser, 2004; McGinnis, 1994; Luft et al., 2004; Sandi-Urena et al., 2011). Two studies discuss using a constructivist theoretical framework (Bond-Robinson & Bernard Rodriques, 2006; Luft et al., 2004), and other studies utilize frameworks such as Nespor's theory on beliefs and practice (Addy & Blanchard, 2010), Nyquist's model for TA development (Calkins & Kelley, 2005), situated cognition (Dotger, 2011), Gagne's theory of instruction (Hampton & Reiser, 2004), symbolic interactionism (McGinnis, 1994), and Baxter Magolda's Epistemological Reflection Model (Sandi-Urena et al., 2011). However, only three studies fully integrate their framework into the study or add to the body of literature about their theory (Addy & Blanchard, 2010; Calkins & Kelley, 2005; Sandi-Urena et al., 2011). Interestingly, authors who effectively integrated theoretical frameworks in their other research do not do so in their work on TAs (e.g., Bond Robinson, 2000; Luft et al., 2004; Roehrig et al. 2003). The lack of addition to or emphasis on theory-driven research within the TA literature is a limitation of this body of research.

Third, researchers continually utilize "training" to describe the support provided to TAs in their instruction (e.g., Bernard Rodriques & Bond-Robinson, 2006; Roehrig et al., 2003; Shannon et al., 1998). "Training" has a behaviorist connotation and implies TAs passively receive information on how to be a TA. This is in stark contrast to the active approaches emphasized as effective methods for improving student learning (e.g., Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006). A dichotomy clearly exists between research-based science education practices and TA preparation, which has implications for this field of study.

From a cognitive behaviorist perspective on "training" there is a linear relationship between a treatment (i.e. training), perceptions (i.e., beliefs), and behavior (i.e., instruction) (Bandura, 1977; Jones & Carter, 2007), which fails to take into account socially mediating factors that may influence TA beliefs, understandings, and practice. The lack of consensus on whether beliefs change practice, practice changes beliefs, or the process is iterative are evidenced in the literature on TA beliefs and practices (e.g., Blanchard et al., 2010; Sandi-Urena & Gatlin, 2013; Volkmann & Zgagacz, 2004). In fact, the lack of theoretical frameworks to drive research on TAs and TA training may be one reason for the use of "training" to describe TA professional development and is a clear limitation across most of these studies.

The lack of theory-driven research and use of behavioristic approaches to support TAs can be resolve by aligning TA "training" with the active learning approaches emphasized in the laboratory courses TAs teach. From this perspective, this dissertation proposes a model explaining the relationship between TA training (now termed professional development), TA perceptions, and TA practice in an iterative, rather than linear, process influenced by a variety of factors (Figure 4). While all studies examining factors influencing TA practice focus on teaching beliefs, confidence – one component of self-efficacy - is an important factor to consider, and has rarely been measured for TAs in undergraduate laboratories (e.g., DeChenne, Enochs, & Needham, 2012). Another important aspect of this model is follow-up support to help promote changes in perceptions which may in turn influence their practice. Aligning TA expectations to reform-based instructional approaches may improve student learning more than just changing the curriculum.

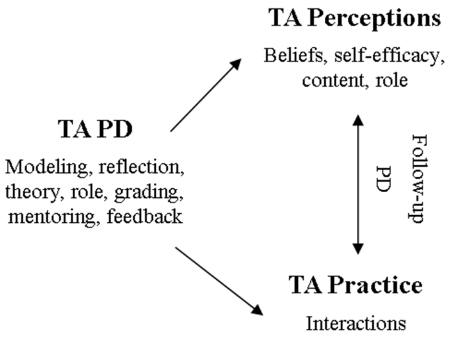

Figure 4. Interactive Relationship between TA Perceptions and TA Practice Following Effective Professional Development with Follow-up Support.

A Framework Explaining the TA-student Relationship in Laboratory Instruction

Two distinct bodies of literature examine undergraduate laboratory instruction; one focused on the curriculum and student learning, the other focused on the role of the TA in instruction. Neither set of research accounts for the other when examining outcomes, a clear gap in the literature. Further, very few of these studies produce rigorous, theory-driven research aligned with how individuals learn. This section outlines the learning process using a constructivist perspective, and then develops a more appropriate model of learning in the laboratory that takes into account social constructivist theory.

How Individuals Learn

Researchers on undergraduate laboratory instruction generally agree that individuals learn best through active participation in the construction of knowledge, also called constructivism (Abraham, 2011; Barber, 2012; Hofstein & Lunetta, 2004; Leonard, 1997; White 1996). A constructivist perspective has two main components that influence an individual's meaning making process: interactions with the surroundings and prior experiences (Ferguson, 2007; Tobin, 1993). First, learning occurs when individuals make meaning from interactions with objects, other individuals, context, or culture. Second, prior experiences shape an individual's construction of knowledge. An individual must use their prior experiences to make sense of their interactions, and the knowledge gained from these interactions continues to be tested and revised based upon new experiences. Previous experiences continually influence the way individuals construct and gain knowledge. Thus, each individual has their own model of reality based upon the interplay between personal experience and interactions (Ferguson, 2007; Tobin, 1993). Further, constructivist views exist on a continuum from personal constructivism to social constructivism. Personal constructivism focuses on the individual construction of knowledge, whereas social constructivism incorporates the social context of the classroom as a factor in the construction of knowledge (Driver et al., 1994; Ferguson, 2007). Within a personal constructivist framework, interactions are typically with objects in which the individual interacts, whereas interactions between people mediate learning in social constructivist framework (Ferguson, 2007).

Research on learning in undergraduate laboratory settings uses a variety of constructivist frameworks (Figure 5). For example, Abraham (2011) draws heavily from Piaget and Cook (1952) and describes student learning as a process of assimilation, accommodation, and organization. During assimilation, students interact with their environment and connect new experiences with old experiences. During accommodation, learners make new meaning by integrating new experiences with prior experiences (Piaget & Cook, 1952). Finally, in the organization step of learning, students apply their new knowledge to other situations. A similar process of student learning in the laboratory setting occurs where students have concrete, hands-on experiences (assimilation), renegotiate their understanding as new experiences occur (accommodation), and extrapolate these experiences (organization) (Leonard, 1997). Operating from a grounded theory approach, Barber (2012) describes learning as making connections between ideas, applying those ideas, and then synthesizing a new concept.

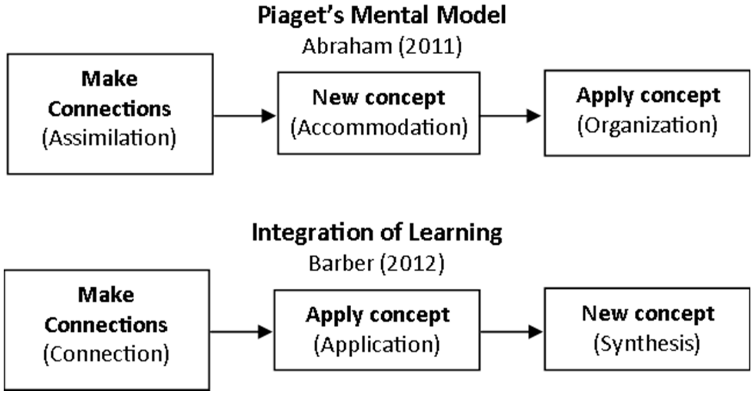

Figure 5. Comparison of Two Constructivist Approaches to the Process of Learning for Undergraduate Students.

Piaget’s Mental Model and the Integration of Learning model provide insight into how students learn in lab settings from a constructivist perspective. For example, using Piaget’s model students may make connections (i.e., assimilation) while observing a phenomena in lab, and through analysis of data develop a new concept (i.e., accommodation). This new concept can then be applied to a new laboratory experiment (i.e., organization). In Barber’s model of learning integration, students might do research prior to lab to develop a hypothesis (connection) and perform experiments in lab to confirm or disconfirm their hypothesis (application). The conclusions based on the research and experiment create a new conceptual understanding (synthesis).

However, there are two shortcomings with applying either model to learning through laboratory work. First, the empirical research on student learning within the laboratory setting and a social constructivist framework emphasize the importance of social (e.g., student-student, teacher-student) interactions (e.g., Basaga et al., 1994; Brickman et al., 2009; Driver et al., 1994; Ferguson, 2007; Prince & Felder, 2006). Neither Piaget’s Mental Model nor the Integration of Learning model take into account these social interactions that aid in the construction of knowledge. Second, when students create and apply knowledge, that knowledge is used to make connections to new knowledge (Ferguson, 2007; Tobin, 1993). Thus, the process of learning is not linear, as purported by Piaget’s Mental Model (Abraham, 2011) or Integration of Learning (Barber, 2012). A more cyclical representation of the learning process takes into account both the prior experience and social interaction components of social constructivism (Figure 6).

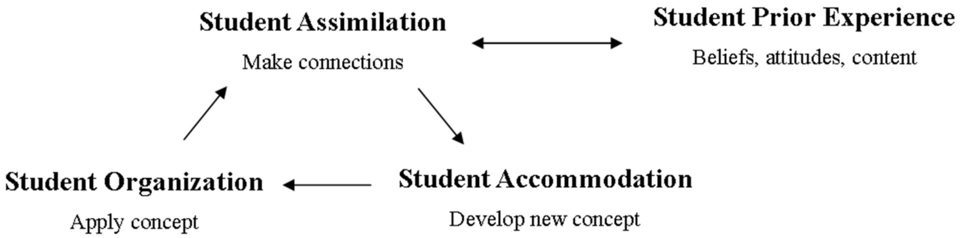

Figure 6. Cyclical learning process aligned with social constructivist theory. Developed based on Piaget's Mental Model.

Relationship between TAs and Students in Laboratories

This chapter argues the need for examining the relationship between TAs and student learning within the context of an inquiry-based laboratory course for undergraduates. To review, a plethora of research exists on student learning in science courses (e.g., Abraham, 2011; Barber et al., 2012; Chatterjee et al., 2009; Russell & Weaver, 2011), TA beliefs and practice (e.g., Addy & Blanchard, 2010; Volkmann & Zgagacz, 2004), and TA training (e.g., Marbach-ad et al., 2012; Roehrig et al., 2003). However, few rigorous studies exist examining either student learning or the role of the TA in the laboratory. The majority of these studies have methodological errors (e.g., Basey & Francis, 2011; Bond Robinson, 200; Domin, 2007), do not align with active learning strategies (Birk & Kurtz, 1996; Shannon et al., 1998), or do not use learning theory to inform their research (e.g., Basaga et al., 1994; Nicklow et al., 2007; Suits, 2004). More importantly, the TA and student learning bodies of literature are completely separate, despite the researchers' emphasis on integrating the two (e.g., Pascarella & Terenzini, 2005; Prince & Felder, 2006). Researchers have yet to examine the relationship between TA preparation, TA perceptions, TA practice, and student learning in the laboratory setting. Further, no research in either body of literature on undergraduate laboratory instruction effectively integrates a theoretical perspective into their research.

Empirically examining this relationship is essential for two reasons. First, the number of undergraduate science majors continues to decline, which can be attributed, in part, to the disconnect between science and science teaching (Fairweather, 2008; NRC, 1996) and between science teaching and science learning (Osborne et al., 2003; White, 1996). Prime contexts for engaging students in active learning opportunities to understand scientific knowledge, science processes, and the nature of science include science laboratory courses. Understanding the TAs' role and how that relates to students' understandings may help create an optimal laboratory learning environment.

Second, research may reveal TAs do not play any role in student learning. If this is the case, then the relationship between TA professional development and TA practice should be re-examined. There would be no reason to provide TAs with professional development if their beliefs and practices do not matter. The focus of the literature would be on developing an effective curriculum rather than on fidelity of implementation. If TAs with differing characteristics are related to student outcomes but not to their actual practice, then further investigation of the relationship between beliefs and practice should be examined.

Before beginning researching examining the relationship between TAs and student learning, both a theoretical and research-based understanding should exist. This can only be achieved through creating a conceptual model synthesized from the varied bodies of research-based literature, including this dissertation's pilot study, and grounded in a theoretical framework (Figure 7). The model presented here is based on an inquiry-based curricular context and utilizes a constructivist lens to understand TA and student learning. From a research perspective, inquiry-based laboratories have the potential to encourage facilitative TA practice (French & Russell, 2002) and enhance student learning (e.g., Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006). The TA professional development components emphasized in this model derive from comparison of TA training research to literature on effective K-12 professional development characteristics. Studies examining TA perceptions and practice suggest TA training, TAs' beliefs, self-efficacy, content understanding, and perception of their role influence their practice (e.g., Addy & Blanchard, 2010; Osborne et al., 2003).

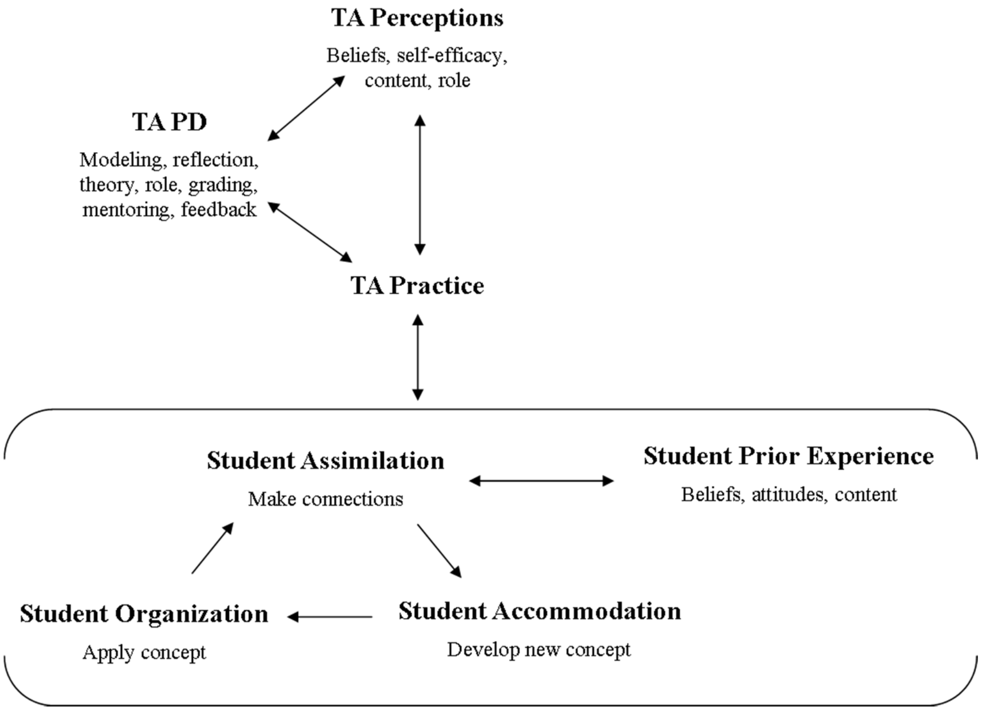

Figure 7. Proposed Literature-based Framework for Understanding the Relationship between TAs and Student Learning. All arrows indicate interactions.

From a theoretical perspective, social constructivism suggests both social interactions and prior experiences are important in learning (Ferguson, 2007; Tobin, 1993). The conceptual model proposes the interactions between the TA and student inform student learning, and prior experience and knowledge play a role in the construction of new knowledge for both the TA and student. For the TA, prior experiences include the TA professional development and prior knowledge includes TA perceptions. Prior experiences and knowledge for students stem from students' personal characteristics, including their beliefs, attitudes, and content knowledge. Further, new knowledge and experiences continue to shape learners' beliefs and interactions. For example the interaction between students and TAs may influence TAs' perceptions, which then may modify how TAs interact with students in the future. This modification process can be facilitated through reflection, feedback, and discussions within the follow-up professional development.

In conclusion, this study aims to understand the relationship between TA professional development, TA perceptions, and student learning within an inquiry-based general chemistry laboratory. Since this study is the first of its kind, it was essential to choose a type of learning that is straightforward to measure. Previous laboratory instruction research reveals content knowledge is the student outcome that provides the most consistent results across studies (Basaga et al., 1994; Hall & McCurdy, 1990; Lord & Orkwiszewski, 2006; Russell & French, 2002), thus students' chemistry content knowledge was assessed in this dissertation. Further, examination of TA practice provided insight into the relationship between TA perceptions and practices as well as characterized the types of TA-student interactions evidenced in an inquiry-based laboratory setting. The following chapter details the methodology used to asses these relationships.

CHAPTER 3: METHODS

The purpose of this study was to build upon this dissertation’s pilot study to assess changes in general chemistry laboratory TAs’ content knowledge, beliefs, and confidence following professional development and to determine if these TA characteristics predict student outcomes. Further, observations characterized TAs’ practice and purposefully selected TAs were compared using cross-case analysis to provide an in-depth understanding of differences in general chemistry lab TAs’ instruction. The research questions guiding this study included:

1. In what ways, if any, do TAs’ content knowledge, beliefs about teaching, and teaching confidence change as a result of TA professional development for an inquiry-based general chemistry lab?
2. How do TAs’ prior experience, content knowledge, beliefs about teaching, and teaching confidence relate to student learning in an inquiry-based general chemistry lab?
3. What kinds of instructional practices do TAs use in an inquiry-based general chemistry lab?
4. How do TAs’ content knowledge, beliefs about teaching, and teaching confidence relate to their practice, and how does practice relate to student learning?

This chapter begins by outlining the theoretical lens framing the study and then discusses the methodological approaches aligning theory and data collection/analysis. Next, the course curriculum and the professional development are outlined to provide context for the study. Then, general characteristics about the TA and student participants are presented. This chapter concludes with details about the data collection and analysis. Table 6 provides an overview of the data collection and analysis as aligned with the research questions.

Social Constructivism and Situated Learning Theory

Social constructivism was the overarching theoretical framework that drove this dissertation study, and situated learning was specifically used to understand TAs' construction of knowledge within the TA professional development. Chapter 2 of this dissertation details how students learn within the constructivist approach, so this section begins by outlining situated learning theory. This includes details on how situated learning fits within the larger social constructivist framework and explains the association between TA professional development components and situated learning theory. The alignment of the theoretical framework within the studies' context are included in the following sections.

Table 6

Overview of Data Sources and Data Analysis Aligned with Research Questions

Research Question	Construct	Qualitative		Quantitative	
		Data source	Data analysis	Data source	Data analysis
TA characteristic changes from PD	Content	---	---	pre/post/delayed post TA survey	descriptives, non-parametric, *t-test*, correlation
	Beliefs	pre/post/delayed post TA survey, post/delayed post TA interviews	analytic induction	pre/post/delayed post TA survey	descriptives, non-parametric, *t-test*, correlation
	Confidence	post/delayed post TA interviews	analytic induction	pre/post/delayed post TA survey	descriptives, non-parametric, *t-test*, correlation
TA characteristics and student outcomes		---	---	pre/post/delayed post TA survey pre/post student survey	*t-test*, correlation, hierarchical multiple regression
TA practice		videotaped observations	analytic induction	---	---
TA characteristics and practice		pre/post/delayed post TA surveys, post/delayed post TA interviews, pre/post student surveys, open-ended post student survey, videotaped observations	mixed methods cross case analysis	---	---

Situated learning theory is based on a constructivist epistemology where learners construct knowledge through connecting prior experience to current active participation within a *community of practice* (Lave & Wenger, 1991; McLellan, 1996). According to Lave and Wenger (1991), a community of practice includes both newcomers and old-timers. Old-timers are defined as experts or masters, and the newcomers enter into the community of practice through legitimate peripheral participation. Newcomers' participation in the community of practice increases as they transition from novice to expert. Engagement in the community of practice provides learners multiple opportunities to practice their skills, an essential component of becoming an expert (McLellan, 1996). The transformation process, or learning the concepts and skills of experts, occurs when novices experience authentic learning opportunities within a collaborative setting and interact with experts through a cognitive apprenticeship model (Lave & Wenger, 1991; McLellan, 1996).

Authentic collaborative learning opportunities include situated and relevant experiences for novices similar to the practices of experts. Providing novices access to *authentic learning environments* allows them to interact with others to actively learn appropriate language of experts, learn concepts and skills experts know and are able to do, and learn the significance of these concepts/skills to the expert (Lave & Wenger, 1991). In other words, it is not learning definitions and technical skills that support novices' transition to expert; it is their active involvement in the community of practice. This active involvement can take the form of increased participation, practicing language through the telling of *stories*, and *reflecting* on the transformation process (Lave & Wenger, 1991; McLellan, 1996).

Effective learning is essential for novices, and situated learning suggests a *cognitive apprenticeship model*, where the expert is the coach, provides the novice structure for the transformational process (Lave & Wenger, 1991). In cognitive apprenticeship, novices first observe the expert model appropriate behavior and language. This allows them to absorb the "culture of practice," or see what they need to do in order to become masters (Lave & Wenger, 1991, p. 95). Second, novices have multiple opportunities to practice the language and skills while the expert coaches and provides feedback. Effective learning through coaching, according to Lave and Wenger (1991), is an interactive, student-centered process. Didactic approaches to coaching hinder the apprenticeship process and learning. Finally, the expert fades coaching as novices increase their participation within the community of practice and transition to becoming experts themselves.

Characteristics of situated learning theory mirror TA professional development components identified in the research literature (Table 7). The TA community of practice includes both TAs (novices) and the course instructor (expert). Within this community of practice, TAs experience authentic learning by engaging in opportunities such as inquiry-based instruction and completing laboratories as students; two pedagogical approaches suggested as effective in the TA training literature. Learning how to become an expert in facilitative interactions with students can be achieved through the instructor modeling appropriate interactions, providing feedback on these interactions, and having TAs discuss teaching with the context of the course. The modeling, feedback, and discussion components of TA professional development align with the steps of cognitive apprenticeship.

Table 7

Alignment of Situated Learning with Characteristics TA Professional Development

TA training component	Characteristics of Situated Learning				
	Community of practice	Authentic context	Cognitive apprenticeship	Stories /Language	Reflection
Practical details		x		x	
Mentoring	x		x		
Feedback/reflection	x			x	x
Pedagogy	x	x			
Modeling	x	x	x	x	
Teaching Culture	x				

As TAs become more experienced with teaching, their participation within the community of practice increases and they tend to become empowered (Lave & Wenger, 1991). However, the focus on research in university science departments likely impedes the development of an empowered group of TAs within this type of community of practice. Thus, situated learning theory predicts a teaching culture within the scientific community is essential to the success of a TA teaching-based community of practice.

Methodology

In this study, social constructivism (Driver et al., 1994; Ferguson, 2007; Tobin, 1993) and situated learning (Lave & Wenger, 1991; McLellan, 1996) framed the studies' convergent parallel mixed methods approach (Cresswell, 2014; Cresswell & Clark, 2007; Hesse-Biber, 2010; Schram, 2014). In this approach, the quantitative and qualitative data were collected in parallel, analyzed separately, and compared in the results. The qualitative data also helped explain the quantitative data. This section outlines the appropriateness of the mixed methods design and explains how social constructivism was used to frame data collection and analysis.

Mixed Methods Design

One purpose of a mixed methods study is to expand and triangulate results through collection and analysis of both qualitative and quantitative data (Cresswell & Clark, 2007; Schram, 2014). This aligns with a social constructivist perspective where a researcher characterizes an individual's reality through the use of varied data sources. For example, in this study, TA learning (about content, beliefs, and confidence), student learning (about content), TA-student interactions, and prior experience were assessed through triangulating observations, interviews, and survey responses. Laboratory observations and TA interviews provided a rich data set to expand on differences, or lack thereof, in students' content knowledge. Further, Schram (2014) suggests a true mixed methods study incorporates a research question integrating qualitative and quantitative data sources. In this study, the first and fourth research questions integrated qualitative and quantitative data. Thus a mixed methods approach was appropriate for examining the relationship between TAs and student learning in the laboratory.

Social Constructivism, Data Collection and Analysis

Social constructivism drove the data collection and analysis in this dissertation. The social interactions between individuals within the context of the laboratory curriculum were the predominant meaning-making processes that focused and drove the study. During the professional development, TAs participated within their community of practice by interacting with each other as well as with the instructor and head TA. One example of this interaction occurred when TAs acted as students to complete each laboratory project. During this time, TAs interacted with each other about planning and completing experiments. The head TA also modeled how to facilitate student discussions and encouraged increased participation within the community of practice. The interactions between the TA and head TA helped the TA transition from a novice to more experienced teacher. This study examined this transformation by assessing changes in TAs' content knowledge, beliefs, and confidence, which have been shown to influence TAs' practice (e.g., Addy & Blanchard, 2010; Obsborne et al., 2003). Further, TAs' practice was observed to compare to TAs' perceptions.

During the semester, the interactions between the students and the TA in lab had the potential to influence student learning of chemistry. For example, TAs may interact with students in a facilitative manner by asking pointed, thoughtful questions to provoke in-depth discussions about the concepts related to the lab. This type of interaction emphasizes the active participation of students in the construction of knowledge, which research and theory both suggest improves student learning (e.g., Abraham, 2011; White, 1996). Conversely, TAs may interact with students in a directive fashion, telling students answers to the lab and not allowing for insightful discussions to occur. Interactions of this type fall under passive learning and limit opportunities for students to learn (Prince & Felder, 2006). In order to understand differences in student learning, TA-student interactions are essential to observe. According to social constructivism, prior experiences also play a role in the construction of knowledge (Ferguson, 2007; Tobin, 1993). Student prior knowledge was assessed and controlled for in order to focus on learning gains associated with laboratory interactions. TAs' prior research and teaching experiences was also assessed in this study to determine how they may relate to the TAs' content knowledge, beliefs, confidence, and teaching practice.

Further, how data are interpreted are key components in ensuring individuals' meaning making accurately and meaningfully characterize TAs' experiences. This was addressed in two ways in this study. First, a pilot study conducted prior to the present investigation helped inform the present study. Second, familiarity with the participants and context helped ensure the analysis of their data represents their experience. However, this may have introduced bias. Therefore, outside researchers helped collect and analyze the data to reduce bias. Elaboration on potential biases is found in the "Researcher as instrument" section at the end of the chapter.

Context and Participants

This study was completed during the fall 2014 semester within the general chemistry laboratory course at a public university in the Mid-Atlantic region. The curriculum for the course was a project-based guided inquiry (PBGI) approach. In this approach, students solve a real-world problem over time through the systematic analysis of data and are given guiding questions to support the development of investigations to answer the problem (Bell et al., 2005; Blumenfeld et al., 1991; Eastwell, 2009). Graduate teaching assistants, who instruct the laboratory classes, received professional development. Prior to this dissertation study, I helped lead a pilot effort to transform the general chemistry laboratory curriculum from an expository approach to the PBGI approach. The course instructor, lab manager, head TA (myself), and volunteer TAs collaboratively developed and provided feedback on all modifications to the course and course materials to ensure their alignment with the PBGI approach and that they provided the necessary support for students and TAs.

As part of this effort, I also developed and implemented professional development for TAs that occurred during the fall 2013 semester, the first year of full-scale implementation of the new curriculum. Relevant details of the pilot study are included in the course curriculum and professional development sections below. For this dissertation there were two different groups of participants for this study: the graduate TAs and their respective general chemistry laboratory students. I received IRB approval to obtain data from consenting participants. All TAs and students voluntarily participated in the present study, and all those who agreed to participate signed consent for use of the data presented in this study.

Project-based guided inquiry curriculum

In the first semester of the general chemistry laboratory, students attended a 3.5 hour lab period once a week for twelve weeks and during this time students completed four total projects. For each project, students were provided an overarching scientific research question within a real world context. The students worked collaboratively in heterogeneously assigned groups of 3 to 4 to plan and implement their approach to the project. For each lab period, students received guiding questions to help support the planning and implementation of the project. Students submitted a group plan for each experimentation day as well as a summary recapping the groups' experiment. Each student also kept a lab notebook detailing the experimental procedures completed in lab.

Finally, students worked together outside of lab analyzing their data and making connections to the larger project objectives. They created a presentation to present to other students in their section for each project. Individual formal lab reports were also required for each project. Like a scientific journal article, students included sections for the abstract, introduction, experimental, results, discussion, conclusion, and references in their lab report. See Table 8 for the semester schedule.

Table 8
Laboratory Project Semester Schedule

Week	Lab Experiment
1	----
2	Plan Glassware accuracy Project
3	Glassware Accuracy Project, Plan Unknown Compound- Day 1
4	Unknown Compound- Day 1, Plan Unknown Compound-Day 2
5	Unknown Compound-Day 2, Plan Unknown Compound-Day 3
6	Unknown Compound-Day 3
7	Unknown Compound Presentations, Plan Calcium Supplement-Day 1
8	READING DAYS: NO LAB
9	Calcium Project-Day 1, Plan Calcium Project-Day 2
10	Calcium Project-Day 2
11	Calcium Presentations, Plan Volatile Liquid Project-Day 1
12	Volatile Liquid Project – Day 1, Plan Volatile Liquid Project– Day 2
13	Volatile Liquid Project – Day 2
14	THANKSGIVING WEEK: NO LAB, NO LAB LECTURE
15	Volatile Liquid Presentations

Each student was associated with an individual section and worked with a single TA who was responsible for the section. Students signed up for a section based on their academic schedule and were unaware of the identity of their TA until after registration. TAs were assigned lab sections based on their availability and did now know who their students were until after assignments were complete. In other words, students could not choose their TA and TAs could not choose their students.

The TAs' responsibilities, as emphasized in the professional development, included interacting with the students on a weekly basis and assessing student work (Appendix A). Expectations also included supporting the students in lab through each project and interacting with students in a facilitative manner to support students' active learning in the laboratory setting. Throughout the planning portion of lab, the TA were expected to ask students probing questions to 1) help them connect their prior experience to the current experience, and 2) encourage student-student interactions to obtain a deeper understanding of the underlying concepts associated with the project. During experimentation time, the TA provided students feedback on lab technique and ensured students' safety in the lab. The TA also encouraged students to act like scientists, by writing down all procedures in their lab notebook, and striving to make sense of their data during lab. During group presentations, the TA facilitated a whole-class discussion on experimental limitations, relevance, and areas of future research to help solidify associated chemical concepts, laboratory techniques and scientific practices.

TA Professional Development

The creation of the professional development began during the spring 2013 semester, where the TAs received limited professional development for implementing one PBGI project. This included completing the PBGI project, grading sample lab reports, and attending weekly TA meetings to discuss the PBGI project. Based on the spring 2013 semester, the piloted professional development was developed based on characteristics of effective K-12 professional development (e.g., Desimone, 2009; Guskey & Yoon, 2009; Loucks-Horsley & Matsumoto, 1999; Luft & Hewson, 2014), components of TA training (e.g., Addy & Blanchard, 2010; Cho et al., 2010; Luft et al., 2004), and situated learning theory (Lave & Wenger, 1991; McLellan, 1996). The components of the piloted professional development included: completing experiments as students, modeling appropriate interactions, opportunities to discuss teaching experiences, practice grading and going over logistics, explicitly discussing TA expectations, and reading a learning theory article. The pilot study contained two additional components not found in the literature: content-based discussions and discourse. These components were identified as areas of weakness observed in the TAs during the spring 2013 semester. All components of the TA piloted professional development occurred during the fall 2013 semester in a week-long workshop, and TAs attended weekly follow-up meetings for both the fall 2013 and spring 2014 semesters.

Survey and interview data from the year-long pilot study indicated TA's perceived the most helpful components of the professional development included TAs completing experiments, modeling, and logistics (Wheeler, Maeng & Whitworth, in review). TAs perceived the content-based discussions and reading about learning theory as the least helpful and least relevant components of the piloted professional development. In general, TAs did not explicitly discuss other components of the professional development as contributing to their ability to teach but some felt they would have benefitted from more opportunities to practice facilitation. When analyzing pilot study data through a situated learning theory lens, the most effective components closely paralleled characteristics of situated learning theory whereas the least effective components were less closely aligned. Informal observations of TA practice and survey data from the pilot study suggest TAs transition from didactic teaching to facilitative teaching was present but limited.

Results from the pilot study informed the refinement of the professional development and weekly follow-up meetings that provided the context for this dissertation study. First, small modifications were made to content-based discussions and the learning theory article to be more situated within the context of the professional development and teaching in the PBGI general chemistry laboratory setting. For example, TAs from the pilot study found the learning theory article abstract, so a different article was chosen for the fall 2014 that closely aligned with the PBGI context. The content-based discussions were modified to include opportunities for discussion of relevant lab scenarios TAs might encounter. Second, the limited changes observed in TAs beliefs and practice across the semester as well as TAs feedback on ways to improve the professional development led to the integration of debriefing, peer observation, and reflection as components of the professional development. Table 9 outlines the components of the professional development and follow-up sessions implemented during the fall 2014 semester, and how they align with components of effective professional development, TA training characteristics, and situated learning.

Table 9

Alignment of TA Professional Development with Effective Professional Development Characteristics, TA Training Components, and Situated Learning

PBGI PD components	K-12 PD characteristics	Inquiry-based PD characteristics	TA training components (characteristics)	Situated learning characteristics
Plan and experiment for each project* *TA-led content-based discussions*$^{+}$	Content	Research experience for teachers	Practical course details (weekly meetings about lab content)	Authentic context, community of practice, stories/language
TA expectations* Weekly lab practicalities^{+}	Coherency	Essential features of inquiry	Practical course details (roles/responsibilities/expectations)	Community of practice, stories/language
*Community of practice** *Debrief of modeling**$^{+}$ *Lab scenario discussions*$^{+}$ Discussion of interactions with students^{+}	Collective participation	Collaboration, group discussions	Pedagogy (use of cooperative groups, group discussions), Culture (required TA meeting, develop community of practice)	Community of practice, stories/language
TAs run projects as students* Modeling appropriate interactions*$^{+}$ Discourse circle* Reading/discussing learning theory article*	Best-practices	Modeling, inquiry-based experience, teachers acting as students, learning theory, practice teaching	Modeling, Pedagogy (reform-based practice, GTAs acting as students, learning theory, micro-teaching)	Authentic context, cognitive apprenticeship, community of practice, stories/language
*Reflection on teaching**$^{+}$ *Reflect on application of theory to practice** *Peer observation and reflection*$^{+}$	Sustained support	Meetings to discuss implementation of inquiry, feedback, reflection	Mentoring, Feedback (peer, mentor), Reflection, Practical course details (weekly meetings)	Reflection, stories/language
Grade sample lab reports/plans/summaries* Practice grading presentations^{+}	----	---	Grading	Authentic context, cognitive apprenticeship

Note. * = included in week-long professional development. $^{+}$ = included in weekly follow-up meetings, *italicized* = modifications from pilot study.

The professional development began with a week-long initial workshop (~25 contact hours) followed by 14 weekly follow-up meetings (~20 contact hours). The professional development started with TAs getting to know each other in order to develop a *community of practice*. TAs were given opportunities to further develop their community of practice by working collaboratively through each project and having small group and whole group discussions about the course and *TA expectations*. On the first day of professional development each TA was given a packet with writing prompts to *reflect on their teaching* (Appendix B). For example, TAs initially wrote down one thing they were excited about, one thing they were nervous about, and one goal they had for teaching that they came back to at the end of the semester to see how they had met their goal. TAs were encouraged to discuss their reflections during the professional development, but their reflective writing was considered private.

A large component of the professional development was TAs *completing each project* to prepare for the semester. TAs worked in collaborative groups to plan, experiment, and analyze data as students would for two of the four projects. During this time, I took on the role of the TA in order to *model* how TAs should interact with students as a facilitator. After this interaction I facilitated a short *debrief* session to talk about what occurred during the interaction. Having TAs take on the role of students to complete labs, modeling interactions, and debriefing are pedagogical approaches aligns with best practices of K-12 professional development, TA training components, and the cognitive apprenticeship model of situated learning theory.

TAs completed a session on *discourse* during the week-long professional development. TAs also *read an article on guided inquiry*, observed discourse, and practiced facilitating discourse. After discourse, I explicitly discussed the strategies used during the discourse session, and the TAs *reflected on the application of guided inquiry to lab.* I asked TAs to complete think, pair, share to come up with examples of how they might use discourse in their own teaching. Returning TAs were purposefully paired with new TAs to provide insight on what teaching in the PBGI curriculum would be like. Using this approach helped new TAs increase their peripheral participation in the community of practice, a component of situated learning theory. TAs also had an opportunity to watch several video clips of former TAs interacting with students during lab. After each video, TAs wrote down what the TA did well and what could be improved in the TAs' teaching. We then had a whole group discussion on the TAs strengths and weaknesses for each video, with the goal of modeling how TAs should approach peer observations (i.e., as a feedback mechanism rather than a judgment of teaching).

Grading was one of the main roles of the TA in the general chemistry lab, so there was time designated during the week-long professional development to practice *grading lab reports/ plans/ summaries.* The TAs were given sample lab reports, plans, and summaries, along with the rubric for each assignment to grade outside of the professional development. During the professional development, TAs discussed the grading of each assignment in groups of three to four with the goal of coming to a consensus of the score for each sample assignment. I circulated and provided feedback to each group on their use of the rubric with each lab report. A whole group discussion ensued after all TA grading was compiled to ensure all TAs graded consistently using the provided rubrics.

During each weekly follow up meeting, I discussed the *practicalities* of the following week's lab. This included safety, waste management, grading issues, and agenda for the lab (i.e., whether it was planning or presentation day). TAs completed the remaining two projects during the follow-up meetings, and these occurred the week before students began the related projects' planning. The TAs also continued discussing and practicing facilitative student-TA interactions during the weekly meetings. I lead bi-weekly whole group *discussions on interactions with students* to allow TAs to share how they are feeling about being a facilitator in lab. I asked questions such as "Can anyone share a really great interaction they had with a group of students?" and "How have you dealt with groups who just want you to give them an answer?" Sharing stories in lab not only helped TAs learn other strategies for working with students but also further developed their community of practice and an understanding of teaching.

TAs were also able to practice how they interacted with students during the *lab scenario discussions* and *content-based discussions*. TAs signed up to lead one of four discussions, and they were tasked with coming up with challenging content questions and difficult lab scenarios for the other TAs to work through during the weekly meeting. The TAs leading the discussion circulated around to each group and facilitated small group discussions before leading a whole group discussion. Leading these discussions provided TAs opportunities to practice facilitative language and increase participation in the community of practice. It also served to model how TAs should facilitate the discussion portion of the student presentations.

Finally, the TAs provided peer feedback through one *peer observation*. The TAs also *reflected on their teaching* following the observation. Each TA was purposefully paired with another TA based on their teaching experience. For example, a returning TA with experience in the PBGI approach was paired with a new TA who had little teaching experience. Mid-way through the semester, each pair set up a one hour block of time to observe the other TA during an experiment/planning day. The TAs then discussed what went well and what could be improved. The TAs then switched roles, with the other TA observing and the other teaching. After all peer observations were complete, each TA wrote a reflection on the observations and their own teaching practice.

Teaching Assistants

A total of 16 graduate TAs were assigned to teach the general chemistry laboratory during the fall 2014 semester. All TAs were asked to voluntarily participate in the study, and 14 of the 16 TAs (87.5%) consented. Table 10 outlines demographic information for TA participants. The participants were first-, second-, or third-year graduate students whose funding came from their TA assignment. The first-year graduate participants were pursuing a Ph.D. in chemistry and taught while concurrently enrolled in graduate science classes. Those TAs who were in their second- or third-year of graduate school did not take classes but worked in a research lab and prepared for their candidacy exams over winter break. Second and third-year TAs were required to TA because their advisor could not provide research funding. All graduate TAs had B.A. or

B.S. degrees in chemistry and had different teaching backgrounds. The 1st year graduate participant TAs were equally distributed along a teaching spectrum from no teaching experience to having taught high school chemistry. All second- and third-year graduate participants had previously taught the PBGI labs.

With the exception of three TAs, all TAs had two sections of lab, totaling 25 sections of lab. The section sizes ranged from 10-24 students per section, with an average of 20.6 students per section. Students worked in groups of four, so each TA interacted with approximately five groups per section.

Students

A total of 713 students were enrolled in the general chemistry laboratory course during the fall 2014 semester. All students were asked to voluntarily participate in this study. Those students enrolled in sections for TAs who were not graduate students or did not consent to participation were excluded from the data set, leaving 519 students. Of those, 433 (83.43%) had complete data sets and were not identified and removed as outliers (see data analysis section below for methods used to identify outliers). No significant differences existed between pre-survey content scores or post-survey content scores for participants and all students in the course (Table 11), suggesting student participants in the present study had content knowledge representative of all students in the course.

Table 10

TA Participant Demographics

	Gender		Age			Ethnicity		International TA	Prior teaching experience*			
	Male	Female	22-23	24-25	26+	White	Other/Unreported		None	Tutor	TA	Teacher
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
1st year (n=8)	6 (75.0)	2 (25.0)	5 (62.5)	3 (37.5)	0 (0)	7 (87.5)	1 (12.5)	0 (0)	3 (37.5)	1 (12.5)	2 (25.0)	2 (25.0)
2nd/3rd year (n=6)	2 (33.3)	4 (66.7)	3 (50.0)	2 (33.3)	1 (16.7)	4 (66.7)	2 (33.3)	2 (33.3)	0 (0)	0 (0)	6 (100)	0 (0)
Total (n=14)	8 (57.1)	6 (42.9)	8 (57.1)	5 (35.7)	1 (7.1)	11 (78.6)	3 (21.4)	2 (14.3)	3 (21.4)	1 (7.1)	8 (57.1)	2 (14.3)

Note. * indicates the highest level of prior teaching experience.

Table 11

Comparison of Pre and Post-survey Scores for Participants and All Enrolled Students

	Pre-survey	Post-survey
Participants (n=433)	52.48%	73.29%
All students (n=690)*	52.75%	72.08%

Note. * indicates the total number of students in the course who had both pre and post survey scores. No significant differences (p>.05) existed between groups on pre and post survey scores.

The majority of student enrolled in the general chemistry lab course were white, first-year females (Table 12). There were very few minorities or upperclassmen in the course. Student current and previous chemistry experience provide further insight into the types of students enrolled in the course (Table 13). Over one-third of student participants took honors chemistry in high school, and another one third of students took AP chemistry. Every student indicated having taken at least one chemistry course in high school. Nearly 90% of students were currently enrolled in the associated general chemistry lecture course. The ethnic, racial, year, chemistry background, and concurrent enrollment percentages were similar for student participants and all students enrolled in the course, providing further evidence that participants were representative of the course population.

Data Collection

Aligned with a convergent parallel mixed methods approach, both quantitative and qualitative data were collected (Cresswell, 2014; Cresswell & Clark, 2007; Hesse-Biber, 2010; Schram, 2014). Quantitative data included TA survey data and student assessment data. Qualitative data included open-ended responses on the TA survey, interviews and observations of purposefully selected TAs, and students' open-ended survey questions for a subset of TAs. The TA survey and interview protocols piloted during the fall 2013 semester (Wheeler et al., 2014) were modified based on the results of that study. Specifically, questions added to the TA survey and interview further address teaching beliefs and TA confidence as a subcomponent of self-efficacy.

Table 12

Student Participant Demographics

	Gender		Ethnicity						Year				
	Male	Female	Black	East Asian	Hispanic	Middle Eastern	White	Other/No response	1st	2nd	3rd	4th	No response
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Participants	124	309	34	81	15	16	270	15	325	71	5	7	25
(n=433)	(28.6)	(71.4)	(7.7)	(18.3)	(3.4)	(3.6)	(62.4)	(3.4)	(75.1)	(16.4)	(1.2)	(1.6)	(5.8)
All students	211	502	62	125	31	25	411	38	494	132	12	12	63
(n=713)	(29.6)	(70.4)	(8.7)	(17.5)	(4.4)	(3.5)	(57.5)	(5.4)	(69.3)	(18.5)	(1.7)	(1.7)	(8.8)

Note. Sum of ethnicities may be greater than total number of students as students were able to choose more than one ethnicity.

Table 13

Student Previous and Current Chemistry Experience

	High school chemistry course (highest level)				Concurrent enrollment in lecture	
	Regular	Honors	AP	No response	Not enrolled	Enrolled
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Participants	95	144	166	28	44	389
(n=433)	(21.4)	(33.2)	(38.3)	(6.4)	(10.2)	(89.8)
All students	178	230	242	63	86	627
(n=713)	(25.0)	(32.6)	(33.9)	(8.8)	(12.1)	(87.9)

Prior to administering these instruments in the fall 2014 semester, a panel of four science education experts, including one teaching beliefs expert and one self-efficacy expert, and a panel of four chemistry content experts, including two former TAs and two science education experts, reviewed instruments for face and content validity as detailed below. Modifications based upon feedback from this panel were incorporated into the final versions of the instruments used in the study.

TA survey

The purpose of the survey was to assess changes in TAs content knowledge, beliefs about teaching, and confidence in teaching following the professional development and at the end of the semester. Beliefs were defined as 'epistemological commitments to how a content domain should be taught' (Harwood, Hansen, & Lotter, 2006, p. 70). Confidence in teaching, also used synonymously with efficacy expectations (e.g., Marshall, Horton, Igo & Switzer, 2009) is one component of self-efficacy and can be defined "the conviction that one can successfully execute the behavior required to produce the outcomes" (Bandura, 1977, p.3). Outcome expectancy, or a "person's estimate that a given behavior will lead to certain outcomes," is the second component of self-efficacy (Bandura, 1977, p.3). This dissertation focused on measuring efficacy expectations/teaching confidence rather than outcome expectancy. The TA survey took approximately 60 minutes and was administered to all TAs before and after the week-long professional development (pre-survey and post-survey, respectively) and at the end of the semester (delayed post-survey). The survey included a total of 16 multiple choice, 3 open-ended questions, and 33 Likert scale questions (Appendix C). The delayed post-survey contained an additional 10 questions about the TA's demographics and prior experience. Demographic information included age, ethnicity, gender, prior degrees, and year in program. Prior experience questions encompassed previous research experience, previous teaching experience, and previous experience with inquiry-based teaching and learning. Content knowledge questions were reviewed by the chemistry content experts for clarity, accuracy, and alignment of the questions with the laboratory objectives. Beliefs and confidence questions were reviewed by the science education expert panel to evaluate questions for clarity and alignment with the belief and confidence constructs.

Content. The 16 multiple choice questions assessed TAs' understanding of chemistry content. Prior to developing the survey for the pilot study, content-based objectives were developed for each of the four PBGI projects. Eighteen multiple-choice questions modified from Kautz, Kennedy, Kreutz, Hermann, & Pienta (2010) aligned with the project objectives and comprised the pilot study survey. Panel member's feedback allowed for changes to these questions prior to pilot study administration. Questions were analyzed using item discrimination and those that met the following criteria were removed from the survey: 1) the majority of TAs correctly answered the question and 2) item discrimination value was .2 or less. Those questions with low item discrimination in which the majority of TAs did not correctly answer the question were retained as the questions had the potential to reveal TAs' content understanding on the post- and delayed-post- surveys. A total of seven multiple choice pilot survey questions met these criteria. The majority of the fall laboratory projects include familiar topics such as solubility, stoichiometry, and chemical reactions, which may be why many of the TAs correctly answered these content questions on the piloted pre-survey.

Eight multiple choice were added after the pilot study to further probe participants' understandings of the concepts related to each project (Chemical Education Digital Library, 2014; Mulford & Robinson, 2002). Similar to the pilot study, these questions aligned with the objectives of the PBGI projects, but were more conceptually challenging questions than those content questions removed from the piloted survey. The same panel of chemistry content experts provided feedback on the added questions. Changes were incorporated into the survey instrument based on the feedback prior to administration.

The 16 multiple choice content questions were coded as correct (1) and incorrect (0). One question contained errors in wording making multiple responses correct, thus it was removed from the data set. Item discrimination and index of difficulty analyses performed on each TAs pre-survey responses revealed one question with a moderate index of difficulty (.57) and a negative item discrimination (-.33). This suggested only half of the TAs got the question correct and TAs with low scores got the question correct more than TAs with high overall scores. Further examination of the question revealed no one clear answer, so the question was also removed. The 14 remaining questions were kept as none were identified as having both large/small item discrimination values and negative index of difficulty values.

Teaching beliefs. The four open-ended teacher belief survey questions were modified from the Teaching Belief Instrument card sort (Harwood et al., 2006) and piloted during the fall 2013 semester. These survey questions asked TAs about their beliefs about how students learn, what their ideal chemistry lab would look like, and what they believed their role would be in lab. Pilot study data revealed these questions appeared to accurately assess participants' beliefs about teaching (Wheeler et al., 2014). The pilot survey also contained 11 Likert scale questions assessing participants' beliefs about teacher-centered versus student-centered instruction. Low alpha reliability of these 11 items indicated these questions may not have been a measure of a single belief construct. Thus, these questions were removed for this dissertation study.

Further investigation of teacher beliefs literature identified two studies that included relevant Likert questions on teacher beliefs (Haney, Czerniak, and Lumpe, 1996; Horizons Research, 2002). Haney and colleagues (1996) developed a Likert scale beliefs questionnaire assessing K-12 science teachers' beliefs about inquiry, knowledge, conditions, and applications following the implementation of The Ohio Science Model. The four Likert scale questions pertaining to inquiry beliefs from this survey were modified to be applicable for participants in the proposed study. For example, instead of asking "My implementing the inquiry strand of the Ohio Science Model would increase students' interest and enjoyment in learning science," the modified question read "My implementing guided inquiry in the general chemistry labs will increase students' interest and enjoyment in learning science." A total of four Likert scale questions from Haney et al. (1996) were included in the survey for this study. The panel of science education experts agreed these questions were valid measures of TA teaching beliefs.

Participants' beliefs about the role of lab on student learning inductively arose out of the qualitative data from the pilot study, thus Likert scale questions to triangulate these data were also added to the survey. The National Survey of Science and Mathematics Education Mathematics Teacher Questionnaire (Horizons Research, 2002) administered to a national sample of secondary science teachers contained the desired types of questions. Sixteen questions from this survey were modified to be relevant for TA participants. For example, on the Horizon survey a question asked "Think about your plans for this science class for the entire course. How much emphasis will each of the following student objectives receive?" The modified question for this study read "Thinking about your role as a teaching assistant for the general chemistry labs. How much emphasis do you think each of the following student objectives should receive?" Expert panel review agreed these questions were valid measures of TA beliefs about the role of the laboratory in student learning.

Teaching confidence. Interview data from the pilot study revealed TAs' teaching confidence, one component of self-efficacy, played an important role in their interactions with students. DeChenne and colleagues (2012) developed a valid and reliable self-efficacy instrument for STEM graduate TAs that included 18 Likert scale questions measuring self-efficacy. In DeChenne's study, a panel of social science experts examined the instrument for face validity, and exploratory and confirmatory factor analysis of the instrument revealed two subscales within the teaching self-efficacy instrument: instructional self-efficacy (n=8, α=.85), and learning self-efficacy (n=11, α=.90). The learning self-efficacy subscale questions focused on the TAs' confidence in helping students become active participants in lab and in their learning. These questions aligned with the main goals of the PBGI curriculum, so the eleven learning self-efficacy questions were included as a measure of teaching confidence on this dissertation's TA survey. Pilot study data also revealed TAs' content knowledge played a role in their confidence. Thus, two additional Likert questions about the TAs' confidence with the chemistry concepts were included on the survey. These 13 questions were reviewed by a science education and self-efficacy belief expert panel. Feedback resulted in the development of an additional question on TAs' confidence in implementing inquiry. Another question assessing TAs' confidence in supporting and encouraging students who are having difficulty was separated into two questions based upon expert feedback. The final survey contained 15 Likert scale questions assessing TAs' teaching confidence.

TA Interviews

The approximately 30 minute interview was administered to a purposefully chosen subset of six TAs (42.9%) after the week-long professional development in September (Interview 1) and at the end of the semester in December (Interview 2) (Appendix D). The survey contained questions that followed up on TAs prior experiences, beliefs about teaching, confidence, and interactions with students in lab. A description of the development and validation of these questions is described in subsequent subsections.

Purposeful selection of TAs was based on results from the pilot study, which indicated TA beliefs, confidence, content knowledge, and prior teaching experience may be important factors differentiating TAs. The percent changes in TAs pre/post survey scores for beliefs, content knowledge, and confidence were calculated and used to select TAs (Table 14). To select TAs, prior teaching experience was first considered, with the goal of interviewing TAs with little/no teaching experience, extensive teaching experience, and TAs who had previously taught in the general chemistry lab context the previous year. From these three groups, TAs were chosen for having positive, negative, and no change in either content knowledge, beliefs, or confidence. For example, Jeremy was chosen as a TA with some prior teaching experience and with large positive changes in content knowledge and confidence.

Table 14
Overview of Characteristics Used to Purposefully Select TAs for Interviews

Prior teaching	TA Name[*]	% Change in content	% Change in beliefs	% Change in confidence
None	Stanley	0	8.33	22.6
	Jack	**-7.7**	**-6.67**	**1.5**
	Chris	-8.3	0	4.6
Some (tutor, undergrad TA)	**Jeremy**	**57.1**	**-6.7**	**26.8**
	Jason	0	0	-1.6
	Ellen	**25.0**	**0**	**-16.4**
Previous PBGI TA	**Stephanie**	**18.2**	**0**	**10.0**
	Yvonne	10.0	0	2.9
	Cameron	8.3	0	-1.8
	Kelly	0	-14.3	6.1
	Todd	-7.7	16.1	0
	Martha	**9.1**	**-16.7**	**-15.32**
Former high school chemistry teacher	**Lawrence**	**9.1**	**-15.4**	**-1.7**
	Susan	22.2	-6.67	0

Note. [*]Pseudonyms used for participants throughout. **Bolded** names indicate interviewed participants. Changes based upon post-pre survey scores.

Teaching beliefs. The teacher beliefs interview questions originated from the Teaching Belief Instrument (TBI) developed by Luft & Roehrig (2007) for K-12 teachers that was subsequently modified for TAs (Addy & Blanchard, 2010). Two of the beliefs questions related to curricular decisions from the TA version of the TBI were removed for this study as the participants were implementing the PBGI approach and did not make curricular decisions. This modified interview protocol was reviewed by a panel of education experts and a former TA and piloted during the fall 2013 semester. Results from the pilot study suggest these questions captured participants' beliefs about teaching.

Teaching confidence. The five teaching confidence interview questions were developed based on interview data from the pilot study. The pilot study revealed TAs' teaching confidence was related to their content knowledge and ability to use questioning to facilitate student discussions. Thus, these interview questions probed TAs' confidence with content knowledge and questioning strategies. The confidence questions were reviewed by a panel of science education and self-efficacy experts for face and content validity. Modifications based on panel feedback included small changes to wording for clarity as well as adding a question investigating TAs confidence in implementing inquiry.

Laboratory Observations

The purpose of the videotaped observations was to characterize TAs' practice in the PBGI laboratory context. Each of the interviewed TAs was asked for consent to be videotaped twice over the course of the semester. Two of the six interviewed TAs agreed to be videotaped, and an additional three TAs not interviewed agreed to be videotaped (n=5, 35.7% of all TAs). Students enrolled in each of the five TA sections were asked for videotaping consent, and any student who did not want to be included in the video were placed in lab so they were out of camera view. Each TA wore a lapel mic to enhance sound quality, and all students were aware that all audio involving the TA would be included in the taping.

Both videotaped observations occurred during the 3rd project, Designing a Calcium Supplement (Appendix E) to capture the experiment, summary, and presentation components of the curriculum. TAs were videotaped on their second sections day of lab unless they requested their first section. The first observation occurred during the second experimental day of the Calcium project, and the second observation occurred during the presentation day of the Calcium project. Due to illness during presentation week, one TA was videotaped during the following projects' presentation day. Table 15 overviews the data source collected for all TA participants.

Table 15

Overview of Data Sources Collected for TAs

TA Name	Surveys	Interviews	Observation 1 (Experiment, Summary)	Observation 2 (Presentations)
Jason	x			
Stanley	x			
Cameron	x			
Yvonne	x			
Kelly	x			
Jack	x	x		
Jeremy	x	x		
Ellen	x	x		
Chris	x		x	x
Todd	x		x	x
Susan	x		x	x*
Stephanie	x	x		
Lawrence	x	x	x	x
Martha	x	x	x	x

Note. * Makeup observation.

In the Designing a Calcium Supplement project, student groups were tasked with developing a soluble calcium supplement to give to the elderly over the course of three lab periods. Prior to the first experimental day, groups developed a plan for creating a calcium supplement from insoluble calcium carbonate that was a clear solution containing the recommended daily allowance (RDA) of calcium at a drinkable volume and pH. They created this supplement on the first experimental day. On the first experimental day they also planned the second day of the project that tasked students with performing quality control testing on their developed supplement to compare their calculated calcium concentration to an experimentally determined value (see Appendix F for a detailed explanation of the chemical concepts associated with the project). Groups completed their proposed experiment on the second day. On the third day of the project groups presented their findings to their section and had a TA-led group discussion about the project. The videotaped observations included the second and third days of lab.

Student assessment

The purpose of this survey was to assess changes in students' chemistry content knowledge (Appendix G), one of the overall goals of the laboratory course. The survey took approximately 15 minutes and was administered on the first and last day of lab (pre and post-survey, respectively). This survey contained 24 multiple choice questions and was developed for the course. The questions were adapted from Kautz et al. (2010) and Mulford & Robinson (2002) to align with the PBGI project objectives. The survey contained four demographic questions on their age, gender, ethnicity, and prior chemistry experience. An additional self-report of learning was included on the post-survey to triangulate students' post-survey scores and observations of student learning in the lab. The student survey was reviewed by the panel of chemistry content experts to ensure the content questions aligned with the course content and provided face and content validity for the survey. Questions were modified based on panel feedback prior to administering the survey in the fall 2014 semester.

Index of difficulty and item discrimination were calculated for each question on the post-survey (e.g. the ‘outcome’ from the professional development). Five questions had low difficulty (i.e., 90%+ students got correct) and low discrimination (i.e., did not discriminate between students who did well and those that did not do well). Four of the five questions were related to the last two projects of the semester, so it was possible the item analysis results were based on the recent nature of the content in these questions. As a result of this analysis, no questions were removed.

In summary, both qualitative and quantitative data from TAs and students were collected throughout the semester. These data included surveys, interviews, and observations. All TA instruments were piloted during the fall 2013 semester to identify strengths, weaknesses, and missing questions. Both TA and student instruments were reviewed by chemistry content and science education expert panels to ensure face and content validity. TA surveys were administered at three time points and assessed TAs’ prior experience, chemistry content knowledge, teaching beliefs, and confidence. A purposefully chosen subset of TAs were interviewed twice during the semester to further probe their prior experiences, beliefs, and confidence. A subset of TAs were also observed twice during the semester to understand how TAs interacted with students during lab. Finally, students were assessed on their content knowledge twice during the semester. Table 16 overviews the data sources and collection times for each set of participants.

Data Analysis

Results from surveys, interviews, and observations were analyzed both qualitatively and quantitatively. In a convergent parallel mixed methods approach the data analysis process is mixed and transformative (Cresswell, 2014; Cresswell & Clark, 2007; Schram, 2014). In other words, analyses of both qualitative and quantitative data occur simultaneously, and some qualitative data is transformed to quantitative data, as described below. Further integration of quantitative and qualitative data sources occurred in this dissertation study when answering the first and fourth research questions. Qualitative data from open-ended survey questions, observations, and interviews were analyzed using analytic induction (Erikson, 1986), and cross case analysis (Miles & Huberman, 1994). Quantitative data from surveys and observations were analyzed using descriptive statistics, non-parametric tests, *t-test*s, correlation, and hierarchical multiple regression (Cohen, Cohen, West, & Aiken, 2013) and cross-case analysis (Miles & Huberman, 1994).

Table 16

Overview of Data Collection

Participants	Pre-semester		Semester				Post Semester
	TA PD		Project 1	Project 2	Project 3	Project 4	
TAs (n=14)	Pre-survey	Post-survey	Interview 1		Laboratory Observations	Interview 2	Delayed survey
Students (n=443)		Pre-survey					Post-survey

TA characteristics

According to situated learning theory, understanding changes in TAs' content knowledge, beliefs, and confidence provides insight into their transformation from novice to more experienced teacher within their community of practice. TA content knowledge was analyzed quantitatively, whereas TA beliefs and confidence were analyzed both qualitatively and quantitatively. This section begins with a description of the quantitative analysis procedures used to understand changes in TAs content knowledge, beliefs, and confidence. This is followed by qualitative analysis measures used to analyze TA beliefs and confidence responses.

Quantitative analysis. All TAs received numerical scores for content knowledge, beliefs, and confidence at each of the three time points. Missing TA data was replaced with average, called mean imputation, which included one TA's post-survey beliefs and confidence scores and another TA's delayed-post survey beliefs and confidence scores. Mean imputation was performed to preserve the total number of TA participants in the sample; however, this simplistic method of dealing with missing data reduces the variance in the sample and may introduce bias (Peugh & Enders, 2004). Details about how the content scores were calculated and analyzed are discussed in detail below.

Content knowledge. TAs content knowledge was quantified into three scores: overall, PD, and semester content knowledge scores. Overall content scores were calculated based on the number of correct responses out of 14 total responses ranging from 0% (no correct responses) to 100% (all correct responses). This overall score was then separated into two categories: questions related to the two projects completed by TAs during the professional development (PD content knowledge) and questions related to the two projects completed by TAs during the weekly follow-up meetings (semester content knowledge). Eight of the 14 questions were grouped into the former category, and six of the 14 questions were grouped into the latter category. TA participants received two separate percentage scores at each time point. The goal of separating the questions was to understand whether completing experiments, teaching, or a combination of both related to increases in TA content knowledge. Statistical analyses of these questions are discussed at the end of the section.

Beliefs. The 20 Likert beliefs questions were organized into three categories: beliefs about inquiry-based teaching, general teaching beliefs, and beliefs about what students can learn in the laboratory context. Four questions were categorized as inquiry teaching beliefs (e.g., "Implementing inquiry will help students learn to think independently") and seven questions were identified as general laboratory teaching beliefs (e.g., "Laboratory courses should be used primarily to reinforce science idea that the students have already learned in lecture"). Ten questions focused on beliefs about the emphasis of different objective in a laboratory course (e.g., Understanding chemistry concepts, learning science process skills, evaluating evidence-based arguments), called lab beliefs.

Analysis of TA pre-survey responses helped identify the most reliable beliefs subscales as TAs inquiry teaching beliefs ($n=3$, $\alpha=.73$) and TA lab beliefs ($n=8$, $\alpha=.87$) (Cronbach, 1951). The inquiry teaching beliefs excluded the question "inquiry will cause frustration in students," and lab beliefs excluded the question "memorizing chemistry vocabulary" as they both decreased the reliability of the subscale respectively. TAs general teaching beliefs subscale was the least reliable (α=.39) and was not used in any subsequent statistical analyses. TA Likert responses to the three questions related to inquiry teaching beliefs were averaged for each survey and were used as a single quantitative measure of TA beliefs ranging from 1 (traditional beliefs) to 5 (reform-based beliefs). Traditional beliefs were beliefs that did not align with inquiry whereas reform-based beliefs aligned with the goals of inquiry. TAs responses to the eight Likert questions related to laboratory beliefs were averaged for each survey and used as a second quantitative measure of TA beliefs ranging from 1 (traditional beliefs) to 4 (reform-based beliefs). A reform-based lab beliefs score indicated participants believed more objectives (e.g., understanding chemistry concepts, learning how to effectively communicate), should be heavily emphasized in the laboratory setting, whereas a traditional lab beliefs score indicated participants viewed lab as a venue for learning a few objectives such as just chemistry concepts or laboratory skills.

Teaching confidence. A high alpha reliability on TA pre-survey responses to teaching confidence questions (n=14, α=.88) indicated these were a reliable measure of the confidence in teaching component of self-efficacy. TA responses to these confidence Likert questions were averaged for each survey to create a single quantitative measure of teaching confidence ranging from 1 (not at all confident) to 5 (very confident).

Demographics. Open-ended questions regarding TA prior teaching and research experiences were transformed into quantified data using the coding scheme from the pilot study (Wheeler et al., 2014). Prior teaching experience was coded as no experience (0), tutoring or TA as an undergraduate (1), previous PBGI TA (2), and former high school chemistry teacher (3). Prior research experience was coded as no experience (0), undergraduate research experience (1), graduate research experience (2), full time research experience (3).

Statistical analysis. Due to the small sample size of TAs (n=14), normality assumptions were tested using Shapiro-Wilks, skewedness, and kurtosis prior to running paired sample *t-test*s and correlations. Each of the six quantitative measures (overall content, PD content, semester content, teaching/learning beliefs, lab learning beliefs, and teaching confidence) were compared at each time point, resulting in three *t-test*s run for each measure (pre/post, post/delayed, and pre/delayed). A conservative p-value was used (p=.05/3=.02) for the *t-test*s to account for multiple tests run on the same set of data. These measures were also correlated to each other, the quantized demographics (i.e., gender, ethnicity) and prior experience (i.e., teaching, research) to understand any relationships between variables.

Non-parametric statistics were also used to analyze the quantitative data. Any non-normal data (e.g. semester content knowledge, laboratory beliefs) were analyzed using a Wilcoxon sign-ranked test to identify differences across time points. Any non-normal data were not included in any additional statistical tests. The data were also split by whether participants were previous PBGI TAs (n=6) or new PBGI TAs (n=8) to identify whether participant experiences in the pilot study were significant factors differentiating TAs coming into the professional development. A Mann-Whitney U test was used to identify any significant differences between new and returning participants for the quantitative measures at the three different time points. No significant differences existed for any data (all ps>.1), suggesting new and returning PBGI TAs could be combined into one TA group. The data were also disaggregated by male (n=8) and female (n=6) and analyzed using a Mann-Whitney U test for between group differences in gender.

Descriptive statistics were used to further understand differences by subgroups and individual questions. Each measure at each time point was disaggregated based on TA teaching and research experience to observe similarities and differences between subgroups. Understanding what, if any, differences existed between TAs with differing prior experiences aligned with the social constructivist framework. No inferential statistics were performed on these subgroups due to the small sample size. Finally, the variables were deconstructed into each survey question and used in combination with the qualitative data to help explain the inferential statistics. The combining of qualitative and quantitative data in the results supports the mixed methods design of the study.

Qualitative analysis. The open-ended survey responses and interview data related to TA beliefs and confidence were analyzed using analytic induction (Erikson, 1986). For this process, the data was first coded inductively to identify themes that emerged from the data. Themes related specifically to beliefs were combined with an a priori beliefs coding scheme (Luft & Roehrig, 2007) and used by a set of coders to re-analyze the qualitative data. The inductive codes were utilized as supporting themes related to beliefs. Details on the coding process are discussed below.

Inductive coding. The inductive coding began with a holistic reading of the first set of interview data. As the data was read, recurring themes were identified and used as coding categories. For example, participants who discussed their role as 'being a guide' or 'to ask students questions without giving the answer' were coded as "facilitator," whereas participants who believe their role was to 'give students answers' or 'lecture to students' were coded as "disseminator." The data set was then reread in order to identify overlapping codes or codes needing further expansion. For example, the code for "facilitation" comprised multiple different facilitation ideas and was expanded into "facilitation beliefs" and "confidence in facilitation." During the collapsing and expanding process, memos were created to connect codes. One such memo indicated TA interactions with students appear to relate to TA beliefs about teaching through facilitation.

After the coding scheme was developed from the first set of interviews, the second set of interviews and surveys were coded. Again, categories were expanded and collapsed as more data were added. For example, the code for "facilitation beliefs" was combined with "disseminator beliefs" and was termed "beliefs about teaching." Teaching beliefs were then reorganized based upon beliefs that teaching was a "passive," "directive," or "active" process. Passive facilitation beliefs included responses such as 'TAs are caretakers, but not really', directive beliefs included responses such as 'sometimes you just need to tell students the answer', and responses coded as active beliefs included 'the TA should encourage students to bounce ideas off of each other'. The data was reread and confirming and disconfirming evidence was added to the revised coding scheme. To illustrate this point, interview data coded as "confidence about content knowledge" could be identified as either something the TA perceived they were confident, somewhat confident, or not confident about. The iterative process of coding, reorganizing codes, re-reading data sources, memoing, and recoding as needed continued until the researcher was satisfied that the inductively developed coding scheme accurately represented the data sources.

Deductive coding. After developing the inductive coding scheme, the codes related to participant beliefs were compared with the previously developed rubric used to categorize teacher beliefs (Luft & Roehrig, 2007). In this rubric, participant responses were coded as traditional, instructive, transitional, responsive, or reform-based. When compared, there was a large amount of overlap between the inductive and deductive beliefs coding schemes. For example, an inductive category related to participants "beliefs about teaching" aligned with the a priori rubric category of "beliefs about the teachers' role." An additional category related to participants' beliefs about inquiry arose from the inductive coding, a category not included in the beliefs rubric. This evidence suggested a combination of the inductive and deductive coding schemes would most accurately capture participants' teaching beliefs.

To create the modified rubric, additional examples relevant to TA instruction and based on the inductive coding categories were added to Luft and Roehrig's (2007) beliefs rubric for clarity. For example, participants' beliefs that students learn best when applying lecture concepts to lab was not captured in the rubric. This belief was added to "How students learn" section of the rubric as a transitional belief about learning. The inductive coding also suggested some participants had negative/passive beliefs about teaching and learning, so an additional level of beliefs, termed ‘Deficit’, was added to the five beliefs in the original rubric. Finally, beliefs about inquiry were added to the rubric, and characteristics/examples from the inductive coding scheme were included in the rubric for the six levels of beliefs. Table 17 shows an overview of the final beliefs rubric (detailed rubric in Appendix H). This rubric was used to code the entire data set, and participants could receive multiple codes for each category. For example, in the interview participants’ multiple discussions of their role may reveal both traditional and responsive beliefs.

Inductive categories about participants’ confidence in implementing inquiry arose from the qualitative data and were developed into a coding rubric (Table 18). The three categories related to confidence included confidence about content, confidence in facilitation, and confidence in interacting with students. Inductive coding revealed three levels of confidence for each of these three categories: “confident,” “reservations,” and “not-confident.” For example, participants received a “reservations” code for content confidence if they revealed an area of content they were unsure about that appeared to influence their interactions with students. All data were coded for confidence using the rubric.

Table 17

Abbreviated Beliefs Coding Rubric

	What can students learn in guided inquiry labs?	How would you describe your role?	How do you maximize student learning?	How do you know when students understand?	What evidence do you have of student learning?	How do your students learn science best?
Deficit	"Student frustration limits learning"	"Babysitter." "Caretaker." "Dealing with logistics."	Making learning easy, telling them the answers	NA	NA	Struggling/ frustration hinder student learning.
Traditional	"Facts"	"Telling students what to do"	"By using ppt presentations"	"They covered it in lecture"	"It is still and quiet at the end of the less"	"Being told what to do"
Instructive	"Laboratory skills, math skills or connecting concepts"	"Helping students with lab techniques"	"I watch my students closely as they complete a lab"	"When they repeat a correct answer"	"I look at their lab write-ups"	"They watch me practice, then they practice it"
Transitional	"Critical thinking or problem solving skills"	"Guide Ss to develop understanding and critical thinking"	"Encouraging them to do their own thinking"	"Their faces light up"	"I can tell by the look in their eyes"	"By doing hands-on activities that apply lecture concepts"
Responsive	NOS, applications of chemistry, excitement for learning skills and concepts	"Working with rather than over students"	"By giving students the opportunities to defend their ideas in front of their peers"	"Ss defend their ideas using evidence and examples"	"When students are helping each other"	"Building upon prior knowledge to create new knowledge." "Interpreting"
Reform-based	Focus on NOS, chem applications, or inquiry as learning outcome	"A tour guide who helps Ss make sense of surroundings consistent with what is known"	"Allowing students to approach problems in different ways, and use as a learning opportunity"	"Ss apply knowledge to novel setting"	"When students are challenging one another"	"Students struggle with material in different ways to make sense of it" "Constructing"

Table 18

Confidence Coding Rubric

Code	Confident	Reservations	Not confident
Content	Felt comfortable or sure of their content knowledge. Made efforts to address areas of weakness	Acknowledgement of areas where their content knowledge was not at 'expert'/in-depth level but still felt okay about the content associated with the labs	Did not know content at all and limited ability to work with students
Facilitation	Felt comfortable guiding students (i.e., using questions, moving them in a productive direction, not giving direct answers)	Difficult to not give answer but trying; worried about frustrating students (Some struggle present but positive about being able to facilitate)	Not comfortable with difficult situations (i.e., students completely lost, getting students back on track when going off in wrong direction, leading students too much) or explaining at students level. Not comfortable with guided inquiry
Student interactions	Felt comfortable making students feel comfortable and confident in lab. Interacting with students was enjoyable and fun.	Some struggle with interacting	Not comfortable with difficult situations (i.e., students not listening to TA, students pushing back to guided inquiry approach, students freaking out)

After both rubrics were developed and modified, the survey and interview data were coded for beliefs and confidence. A second coder read and coded a 33% subset of the interviews and surveys to ensure the data was accurately coded using the coding rubrics. Reliability between the two coders was 75%, and all discrepancies were resolved upon discussion.

Coding analysis. Finally, the beliefs and confidence codes were analyzed in multiple ways. The five belief categories were given numerical values from 1 (traditional) to 5 (reform-based), and participants received an average score for all codes within one category. For example, if a participant received both a traditional code (1) and a transitional code (3) for their role, they would receive a ‘role’ score of 2. These numerical scores were grouped in two ways to help understand trends related to the inductive coding scheme and the quantitative beliefs questions. First, the numerical scores were collapsed into three categories: traditional (deficit, traditional, instructive), transitional (transitional), and reform-based (responsive, reform-based). The collapsed scores from the coding rubric confirmed the original inductive coding, increasing the reliability of the results. Second, the beliefs questions were collapsed into three beliefs subgroups: beliefs about teaching, beliefs about how students learn, and beliefs about what students learn. These categories and subgroups helped explain the quantitative data.

The qualitative confidence data contained only three categories and was not collapsed; however, the codes were also compared to the quantitative teaching confidence data to help triangulate and explain the confidence component of these data. For example, two Likert questions related to participants confidence in their content knowledge and implementing inquiry. Comparing participants' responses on these two questions with the coded interview data helped explain participants' high confidence in content knowledge and low confidence in implementing inquiry across the semester.

Finally participants beliefs (i.e., traditional, transitional, reform-based) and confidence (i.e., confident, reservations, not confident) were analyzed in nVivo by TA and time point to understand differences in beliefs and confidence. As an example, participant confidence in content knowledge and facilitation were grouped based upon the interview (i.e., interview 1 or interview 2) to understand how TAs confidence changed, if at all, across the semester.

Social constructivism and qualitative data. Categories related to the influence of prior experiences and current interactions on participants' beliefs and confidence inductively arose from the data. For example, when asked about their inquiry beliefs, participants discussed their previous experience as a student in the general chemistry lab. Participants also discussed their prior teaching and learning experiences when explaining their confidence in implementing inquiry. These data were developed into codes to help relate and explain participant changes, or lack thereof, in beliefs and confidence.

TA Characteristics and Student Outcomes

Each student was given a pre-survey and post-survey score based on the percent of correct answers on the 24 content-based multiple choice questions, ranging from 0% (no questions correct) to 100% (all questions correct). Student post-survey scores were examined for outliers and were identified through computing residual values, leverage values, and Cook's values for each student participant (Table 19). A total of 15 of the

448 students (3.3%) were identified using one of the three methods. Examination of these outliers indicated all 15 should be removed from the data set due to extreme post-survey scores (i.e., 0%) or extreme change from pre to post survey scores (i.e., 20% to 90% or 85% to 30%), leaving 433 student participants in the data set.

Table 19

Outlier Tests Performed to Justify Removal of Student Scores from Data Set

Outlier test	Formula used to numerically identify outliers (value)	Number of outliers identified & removed
Residuals	+/-3 $SD_{residual}$ (41.07)	7
Leverage	(2k+2)/n (0.0226)	4
Cook's	4/n (0.0089)	4

Note. $SD_{residual}$ = 13.69; k=number of predictors used in the final regression model=4; n=448.

To interpret the relationship between predictors and student post-survey scores, students' pre-survey scores were grand mean centered where positive values indicated a higher-than-average pre-survey. Each normally distributed quantitative TA delayed survey measure (i.e., content, teaching beliefs, and confidence) was used as a predictor variable for student post-survey scores, while controlling for student pre-survey scores, student demographics, and TA pre-survey scores. Means and standard deviations were calculated for all measures.

Student demographic data were coded and utilized as controlling variables. Student ethnicity was coded based upon different ethnicities (e.g., Caucasian, African-America, Middle Eastern). For example, students who identified as Caucasian were given a (1), and non-Caucasian (0). Student gender was coded as female (1) and male (0). Students' most advanced high school chemistry course was coded and used as a control variable. The three types of chemistry courses included regular chemistry (1), honors chemistry (2) and Advanced Placement (AP) chemistry (3)[1]. Concurrent enrollment in the general chemistry lecture course was another coded variable used to control for differences in student laboratory learning coded as concurrent enrollment (1) or AP credit/previous course enrollment (0). Student self-reported year in college was coded from 1 to 4. Missing data from student self-report of previous chemistry experience and year in college was replaced with mean values (n=29).

Due to the nested nature of students within TAs, a hierarchical linear modeling (HLM) approach was initially used to predict student outcomes. In this model, student pre-survey scores and demographics were placed in the first model, and TA scores were level 2 variables. However, small intraclass coefficient (ICC) values (.017) and design effect values (1.50), along with the small number of level 2 participants (i.e., TAs) suggested HLM was not warranted to predict student outcomes (Peugh, 2010).

Subsequently, correlation and a hierarchical multiple regression model were utilized to explore the TA factors that predicted student post-survey scores when controlling for students pre-survey scores, demographics, and TA pre-survey scores (Cohen et al., 2013). Collinearity, multicollinearity and homoscedasticity tests were performed with these data to verify the assumptions of multiple regression modeling were met (Lewis-Beck, 1980). Collinearity (all VIFs<5), multicollinearity (all $R^2<.8$), and

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[1] Advanced level of courses ranked from AP chemistry, honors chemistry, then regular chemistry.

homogeneity of variance (Levine's statistics=1.37, p=.169) assumptions were met for all predictor and outcome variables.

With all assumptions met, a correlation matrix was run to understand relationships between the following variables: student pre-survey, student post-survey, student gender, student year in school, student ethnicities, TA content, TA teaching beliefs, and TA teaching confidence[2]. A conservative p-value (p=.01) was used to account for multiple variables being included in the correlation matrix. For hierarchical multiple regression, three models were created to identify the best predictor variables for student post-survey scores (Table 20). To control for differences in students, the first model included student pre-survey scores, student demographics, and student prior chemistry experience. To account for changes in TA content knowledge, beliefs, and confidence across the professional development/semester, TA pre-survey scores were added in the second model. The third model included the four TA variables (i.e., delayed content, delayed teaching beliefs, delayed teaching confidence), TA demographics (i.e., gender, ethnicity), and TA experience (i.e., prior teaching experience, prior research experience). These 7 predictor variables were included in the third model to determine the variables that were significant predictors of student post-survey scores accounted for the variance in these scores. Accumulating error was mitigated by using a conservative p-value (p=.05/3=.017) to account for three regression models.

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[2] TA lab beliefs excluded due to non-normality of the data.

Table 20

Hierarchical Linear Regression Model Overview

Model	Predictor variables added
1 – Student variables	Pre-survey, gender, ethnicity, year, high school chemistry, concurrent enrollment in lecture
2 – TA pre-survey variables	Content pre-survey, teaching confidence pre-survey, teaching beliefs pre-survey, & lab beliefs pre-survey
3 – Additional TA variables	Content delayed-survey, teaching confidence delayed-survey, teaching beliefs delayed-survey, gender, ethnicity, teaching experience, research experience

TA practice

A total of 20 hours of videotaped observations were analyzed to provide rich, thick description of TA practice and to provide insight into student learning in the laboratory. Aligned with social constructivism, the researcher focused on the TA-student interactions during lab and how the students participated in those interactions. These videotaped observations were analyzed using analytic induction in which the literature focused the analysis, but the coding scheme arose inductively out of the data (Erickson, 1986).

First, the researcher watched the videos and took field notes, and the observed trends across TA practice were developed into initial codes. For example, all TAs asked students questions during their interactions, which was developed into a code for 'questioning'. The field notes were then read holistically and coded using the initial coding scheme to identify evidence supporting each code. As the data were read, the initial coding scheme was refined and additional codes were added. For example, the questioning code was expanded to the different types of questions TAs posed to students such as open-ended questions and close-ended questions. The data were then re-read to determine non-examples that fit into the coding scheme. For example, instances of when the TA did not ask questions during their interaction but observed students to allow for more student-student interaction were included within the category of codes about questioning. The researcher then created memos to help identify larger themes and modified the codes after reflecting on the data. One memo suggested different types of questions TAs ask students may prompt a different response in students.

Assertions were created by combining the memos and codes. Analysis ended when the larger themes fully represented the data and the assertions were unchanged as additional confirming/disconfirming evidence was added. The assertions and supporting evidence were then reviewed by a panel of experts, and their feedback was used to refine the assertions. For example, the assertion "The methods TAs used to interact with students during experimentation promoted or limited students' ability to explain concepts or justify procedures" combined the codes and memos relating to how TAs used questions and how students responded. This assertion, along with two others, organized the data by event (i.e., experiment, presentation, and presentation discussion) and reviewers suggested collapsing these three assertions into one and reorganizing based upon scientific practices (i.e., analyzing data, evaluating information). The final assertion then became "Students level of engagement in scientific practices varied based upon the types of TA interactions."

TA characteristics and TA practice

In order to analyze the relationship between TA characteristics and TA practice, a cross case comparative method was utilized (Miles & Huberman, 1994). Two TAs with the most divergent content knowledge, beliefs, confidence, and practice were selected, and their entire data set was used as a “case” in the analysis. Data sources include TAs pre/post/delayed post surveys (qualitative and quantitative), prior experience, demographics, post/delayed post interviews, student pre/post content scores, student self-report of learning, and the two observations.

A case-oriented approach to analysis was taken to look for additional themes across the two TAs with the focus on relationships between TA characteristics and TA practice as well as TA practice and student learning. The data sets were re-read for each TA to identify latent themes unobservable aggregated with other TA’s data or when analyzing each data set separately. For example, relationships were observed between students’ self-reported learning and TA practice that would not have been identified using just TA practice and student’s quantitative post-survey scores. The analysis was complete when all data were analyzed together and no additional themes emerged.

Methodological Considerations

Researcher as Instrument

My previous experience as a high school chemistry teacher and TA in the general chemistry labs provided valuable insight into the meaning making of TAs and the interactions TAs engaged in with their students. My role in this study was as the head TA and researcher, so an understanding of how I addressed these potentially conflicting positions is warranted. As the head TA, I have been responsible for curriculum development and TA training and have a close working relationship with the course and participants. This relationship was beneficial to the study for two reasons: 1) I was able to provide participants with a reform-based curriculum developed from the literature and had the experience and knowledge to effectively support them in implementing the curriculum and 2) I had valuable insight into participants' experience during the training that ensured the meaning-making reported in this study reflected participants relative views. Due to my development of the curriculum, I understood references made in videotaped observations that an outside researcher would not understand. For example, I knew students had developed the discussion questions that the TAs used to facilitate the group discussions following presentations.

This role also had the potential to introduce bias into the study for two reasons: 1) the participants may have behaved in ways they thought the researcher wanted and 2) the researcher may have interpreted data in ways that aligned with her expectations. These potential biases were addressed in multiple ways throughout the study. To address potential bias in data collection, participants were interviewed by impartial researchers to ensure the responses were representative of the TAs' actual experience. Participants and students were encouraged to act as they normally would during videotaped observations, and I maintained the same role during the videotaped observations as I typically would (e.g., checking in on TAs).

Potential bias in my interpretation of the data was addressed by having a second researcher code a subset of the interview and survey data for beliefs and confidence to improve the reliability of the conclusions drawn from the data. A group of researchers provided feedback on the assertions and supporting evidence from the videotaped data to ensure the assertions reflected the data. A former TA also provided a member-check of my interpretations of the data. This former TA read over the TA characteristics results and discussed the accuracy of my understanding of participants' experiences. Finally, I also personally reflected on and discussed with the other researchers my role as implementer and researcher, which facilitated awareness of my own bias.

Rigor of Study

There exists a plethora of research understanding student learning in the undergraduate laboratory; however, almost half of these studies contain critical flaws that limit the reliability and validity of the results (e.g., Basey & Francis, 2011; Poock et al., 2007; Spiro & Knisely, 2008). While there exists limitations to any study, I made every effort to address each of these potential flaws identified in the literature in this dissertation.

Some studies examining student learning in the undergraduate laboratory failed to use validated instruments (e.g., Basey & Francis, 2011; Bryant, 2006), and this dissertation addressed validity by using previously validated instruments used with similar populations and had a panel of experts review all instruments. Researchers in previous studies compared across student groups without controlling for differences or providing evidence the groups were similar (e.g., Berg et al., 2003; Rissing & Cogan, 2009). Only TAs and students in the fall 2014 semester of the general chemistry laboratory course were used in this study, and students' pre-assessment scores, demographics, and prior experiences were incorporated to account for differences in students entering the course. Differences in new and returning PBGI TAs' data were acknowledged and assessed to ensure these TAs could be combined. Missing qualitative data analysis was another flaw in some of the studies examining student learning in the undergraduate laboratory (e.g., Domin, 2007; Ketpichainarong et al., 2010). Every effort was made to be transparent in this study, as evidenced in the detailed qualitative data analysis section of the methods.

Inherent bias in other studies (e.g., Luckie et al., 2004; Spiro & Knisely, 2008) was addressed in this dissertation in multiple ways. External researchers interviewed TAs and helped with data analysis, a former TA checked the interpretations of the results, and I continuously reflected on possible biases I may have toward the data. Finally, clear misconceptions on educational theory by other researchers (e.g., Bryant, 2006; Rissing & Cogan, 2009) were reduced in this dissertation by extensive review and discussion of situated learning theory and social constructivism. The differences between previous studies and this dissertation related to rigor illustrate the reliability and validity of the results presented.

CHAPTER 4: RESULTS

The results from surveys, interviews, and observations are organized by research questions below[3]. Qualitative and quantitative changes in TAs' content knowledge, beliefs, and confidence are discussed first. These data were then analyzed using a social constructivist lens to better understand the process of learning for TAs. Relationships between TA and student data are presented next. For both TA characteristics and student outcomes, the quantitative and qualitative data sources are presented sequentially, with the qualitative explaining the quantitative data. Then the data were mixed to provide a more detailed understanding of the relationship between these characteristics. Detailed descriptions of TAs practices and the interactions evidenced during these observations follow, and the results concludes with a cross case comparison of two TAs.

TA Characteristics

Due to the small sample size, all TA participant data were tested for normality to ensure inferential statistics could be used. Shapiro Wilks test of normality for all TA outcome scores (i.e., delayed-survey scores for content knowledge, PD content knowledge, teaching beliefs, lab beliefs, and teaching confidence) were not significant (all ps>.05), indicating data were normal (Table 21). Semester content knowledge was

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[3] An important caveat to note is that the qualitative data represents what the TAs shared in open-ended survey questions and interviews, and the lack of qualitative data is not necessarily indicative of a negative or absent idea. It merely indicates it was not something the TA communicated in their responses.

the only non-normal TA outcome variable, according to Shapiro Wilks. All delayed-survey data were plotted to visually examine for normal distribution. Almost all data appeared normal, with reasonable skewedness and kurtosis values (i.e., less than 1.0), with the exception of participants' laboratory beliefs, which had large skewedness and kurtosis values. The non-normal data (i.e., semester content knowledge and laboratory beliefs) were analyzed using non-parametric tests. All other values were analyzed using *t-tests* and correlations.

Table 21
Normality Assumption Values for TA Delayed-survey Data

	Shapiro Wilks (t-values)	Skewedness	Kurtosis
Content knowledge	.930	-.150	-.748
PD content knowledge	.893	.240	-.491
Semester content knowledge	.731**	-.978	.176
Teaching beliefs	.897	-.717	-.348
Beliefs about lab	.831	-1.46$^+$	2.06$^+$
Teaching confidence	.957	.262	-.930

Note. ** indicates Shapiro Wilks test was significant ($p<.01$), suggesting non-normality. $^+$ indicates large values, suggesting non-normality

TA content knowledge

Participants' content knowledge significantly improved from pre-professional development to the end of the semester; however, there was no significant change directly following professional development or after professional development to the end of the semester (Table 22). In other words, the significant increase in TA content knowledge occurred after TAs experienced professional development, weekly follow-up meetings, and taught for an entire semester but not after just one of these components. No significant differences existed between male and female participants.

Table 22

Participants' Average Content Scores

Groups		Pre % (SD)	Post % (SD)	Delayed % (SD)
All TAs (n=14)		76.02 (12.41)	81.63 (6.70)	85.20 (8.62)**
Gender$^+$	Male (n=8)	80.36 (13.63)	83.04 (5.31)	86.61 (8.61)
	Female (n=6)	70.24 (8.35)	79.76 (8.35)	83.33 (8.65)

Note: $^+$ = non-parametric testing performed. ** = significant difference from pre-survey response ($p<.01$). No inferential statistics performed on gender sub-group due to small sample size. No missing data present.

TA content knowledge related to the projects completed over the course of the professional development did not indicate significant changes following professional development or over the course of the semester (Table 23). Significant differences existed in TAs' content knowledge related to the semester projects over the course of the professional development and semester. No significant differences occurred in between (i.e., pre to post-survey or post to delayed-survey).

Table 23

Overview of Participants' Content Knowledge by Completion of Experiment

	Pre-survey % (SD)	Post-survey % (SD)	Delayed-survey % (SD)
PD content knowledge	76.98 (14.76)	82.54 (9.46)	82.54 (10.42)
Semester content knowledge$^+$	74.29 (16.51)	80.00 (13.59)	90.00 (13.01)**

Note.$^+$ non-parametric testing performed. ** significant $p=.01$.

Disaggregation of TA's Likert data based upon prior teaching experience and prior research experience revealed similar trends in content scores following professional development and over the course of the semester (Table 24). Participants of differing research experience showed continual improvement in content knowledge in similar ranges. When grouped by prior teaching experience, different trends were observed. Participants with little prior teaching experience had the lowest pre-survey scores and showed continual improvement across the semester. Participants with no prior teaching experience started with the highest content knowledge prior to professional development, and this content knowledge decreased following professional development. These TAs' content knowledge by the end of the semester appeared to be similar to all other groups of participants. Former teachers had lower content knowledge coming into the professional development, improved content knowledge following the professional development, but then regressed in their content knowledge by the end of the semester.

Table 24
Participants' Content Knowledge by Previous Experience

Groups		Pre % (SD)	Post % (SD)	Delayed % (SD)
Teaching Experience	None (n=3)	85.71 (7.14)	80.95 (4.12)	88.10 (10.91)
	Tutor/undergrad TA (n=3)	61.90 (14.87)	76.19 (4.12)	85.71 (7.14)
	PBGI TA (n=6)	79.76 (8.35)	84.52(8.35)	88.10 (5.83)
	Chemistry teacher (n=2)	71.43 (10.10)	82.14 (5.05)	71.43 (0.0)
Research Experience	Undergraduate (n=6)	75.00 (15.49)	80.95 (3.69)	82.14 (10.83)
	Graduate (n=6)	79.76 (8.35)	84.52 (8.35)	88.10 (5.83)
	Full time lab tech (n=2)	67.86 (15.15)	75.00 (5.05)	85.71 (10.10)

Note. Higher scores indicative of more content knowledge. No inferential statistics performed due to small size of sub-groups.

TA beliefs

TA beliefs were organized by participants' beliefs about teaching and learning in an inquiry-based context (i.e., teaching & learning beliefs) and by participants' beliefs about what students should learn in the guided inquiry laboratory context (i.e., lab beliefs). Each beliefs section begins with participants' quantitative beliefs. These are followed by qualitative data to compare and contrast with trends in the quantitative data.

Next, analysis of the data from a social constructivist perspective follows, and the section concludes with a summary of the results related to TA beliefs.

Teaching & learning beliefs. Average initial quantitative survey responses revealed TA beliefs aligned with inquiry-based teaching, suggesting participants in general held more reform-based teaching beliefs than traditional teaching beliefs. For example, participants agreed with statements that inquiry could foster students' independent thinking and positive attitudes about science. These beliefs were resistant to change following professional development and following a semester of teaching (Table 25). No significant differences existed between male and female participants, but significant, strong, positive correlations existed between participants' teaching beliefs across the professional development (r=.739, p=.003) and the semester (r=.688, p=.007). These correlations indicated participants who had more reform-based beliefs at the beginning of the professional development tended to have continued reform-based beliefs. This may help explain that lack of significant differences observed across the three time points.

Table 25
Participants' Teaching Beliefs

Groups		Pre (SD)	Post (SD)	Delayed (SD)
All TAs (n=14)		4.40 (.52)	4.26 (.51)	4.31 (.62)
Gender$^+$	Male (n=8)	4.29 (.49)	4.24 (.34)	4.21 (.62)
	Female (n=6)	4.55 (.58)	4.28 (.71)	4.44 (.66)

Note. $^+$ = non-parametric testing performed. Likert scale averages reported where 1=traditional beliefs and 5=reform-based beliefs. No significant differences for all groups (all ps>.05). One participants' post-survey score and one participants' delayed-survey score were missing, and mean imputation was used to deal with missing data.

In aggregate, the quantitative data suggested participants' teaching beliefs did not change following professional development or across the semester; however, qualitative data provided a more nuanced view of teaching as well as beliefs about learning that suggested different changes may have, in aggregate, indicated no change. From the coding rubric, beliefs were organized based upon the six categories for both surveys and interviews across their respective time points. These six categories were organized in two types of beliefs: beliefs about teaching and beliefs about student learning.

Survey data revealed some participants maintained consistent beliefs for both teaching and learning across all three time points (i.e., Stephanie), whereas others showed more consistent trends toward reform-based beliefs (i.e., Stanley) (Figure 8). Yet other participants had conflicting teaching and learning beliefs (i.e., Chris) or a shift toward more reform-based beliefs following professional development that reverted to more traditional beliefs and the end of the semester (i.e., Yvonne). Overall trends cannot be identified from the open-ended survey data, suggesting similar differences occurred in the Likert data on teaching beliefs that led to no significant differences.

Interview data detailed below revealed similar trends as the survey data (Table 26). Three of the six participants (50%) had varying teaching and learning beliefs that were resistant to change (Ellen, Stephanie, Jack), whereas three participants (50%) had varying beliefs that shifted to either more traditional or more reform-based (Martha, Jeremy, Lawrence). These positive, negative and no change trends across the two interviews provided additional evidence to support the lack of change in the quantitative data.

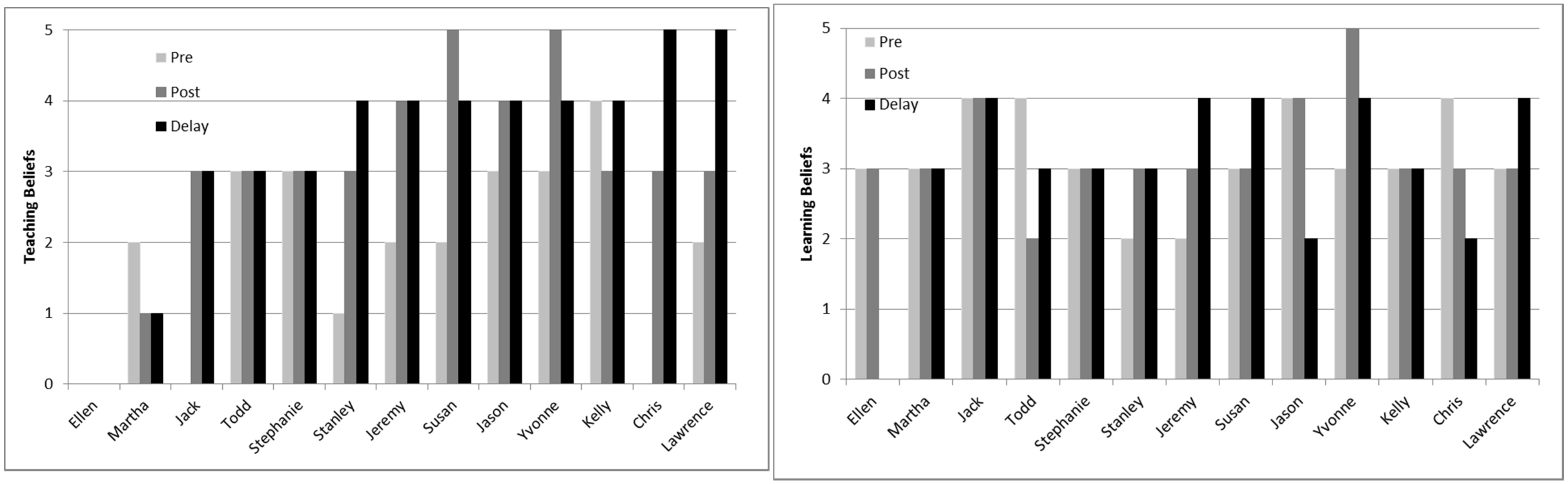


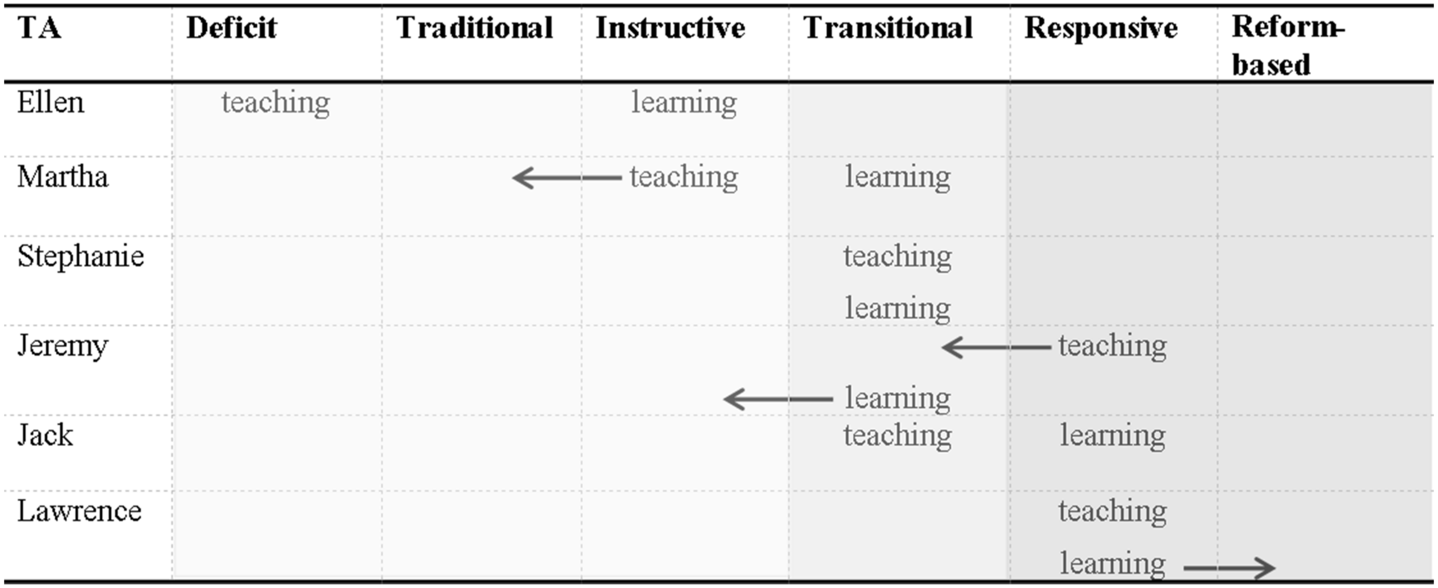
Figure 8. Participant's Surveyed Teaching & Learning Beliefs. Note: 0=Deficit beliefs, 5=Reform-beliefs. Cameron not included due to no delayed-post survey response**.**

By organizing the qualitative data by the six beliefs categories, participants continued to be included in the same general area for the majority of their qualitative data. Ellen and Martha consistently held the most traditional beliefs and Stephanie and Jeremy's beliefs appeared in the middle of the spectrum. Jack held more reform-based beliefs than Stephanie and Jeremy, and Lawrence continued to have the most reform-based beliefs. Using these more general beliefs classifications - traditional (i.e., deficit, traditional, instructive), transitional, and reform-based (i.e., responsive, reform-based) - provided a foundation for discussing differences in 'traditional' and 'reform-based' beliefs.

Traditional teaching and learning beliefs. Three of the six interviewed participants (50%) believed students learned in lab by applying what they had previously learned in lecture, rather learning new concepts within lab through the analysis of data. Martha explicitly stated, "I would think a combination of lecturing and having them try things on their own" (Martha, TA, 9/30/14, Interview 1) was the best way students learned in lab. Jeremy agreed with Martha, believing in learning, then applying. On his initial survey he indicated, "The best way to learn, in my opinion, is to have a guide teach the student, and then the student will use what the guide taught him or her to perform a similar task" (Jeremy, TA, Pre-survey).

Table 26

Participants' Teaching & Learning Beliefs Elucidated from Interviews



TA	Deficit	Traditional	Instructive	Transitional	Responsive	Reform-based
Ellen	teaching		learning			
Martha			← teaching	learning		
Stephanie				teaching learning		
Jeremy				← learning	← teaching	
Jack				teaching	learning	
Lawrence					teaching learning →	

Note. → indicates shift in beliefs in direction of interview 1 to interview 2. No arrow indicates consistent beliefs across both interviews. Six beliefs categories collapsed into traditional beliefs (i.e., deficit, traditional, instructive), transitional, and reform-based (i.e., responsive, reform-based) for ease of comparing participant data.

Beliefs about lab-as-application of lecture were present at the end of the semester for two of the three participants (67%) who initially held these beliefs. When Martha was asked at the end of the semester about how she thought students learn best, she indicated, “I would say a mixture of feeding them information and having them come up with their own ideas” (Martha, TA, 12/2/14, Interview 2). Martha believed a more direct instruction teaching approach was a pre-requisite for constructing knowledge on their own. This belief conflicted with the goals of guided inquiry for TAs to be facilitators of learning rather than disseminators of information.

When asked about their role in lab, some interviewed participants continued to describe themselves in passive teaching terms, supporting the more traditional teaching beliefs elucidated in the Likert data. Five of the six interviewees (83%) initially described their role in lab in terms such as “A caretaker but not really” (Jeremy, TA, 9/10/14, Interview 1), and as “Answering questions about the structure of the class, or dealing with, like, a problem” (Jack, TA, 9/25/14, Interview 1). They did not perceive their role as being an active participant in helping students learn. Of the five participants who believed in a more passive TA role, four (80%) maintained these beliefs at the end of the semester. Jeremy indicated he was “Pretty much there to make sure they don't hurt themselves” (Jeremy, TA, 12/10/14, Interview 2), and Ellen indicated her role was a “Babysitter” (Elizabeth, TA, 12/2/14, Interview 2).

Reform-based teaching and learning beliefs. Four of the six participants (67%) initially believed students learned best by struggling through the learning process, which aligned with the quantitative inquiry teaching beliefs data. Similar to the quantitative beliefs, the qualitative beliefs were maintained by all four (100%) participants at the end of the semester. On the delayed-post survey Jack described how struggling with information could benefit students:

> I think the best way to learn is in a way where one must struggle to understand a concept and why it is true rather than being told facts to memorize. This both makes it more likely that a student will remember the concept and more sets a framework to where students gain an understanding of the topic and can infer new results rather than simply needing to hear more facts. (Jack, TA, Delayed-post survey).

He believed retention of conceptual understanding occurred when students grappled with information and this benefited their learning process in the long run. This view aligned with the goals of guided inquiry. Lawrence also perceived benefits in knowledge-as-a-struggle approach to student learning. At the end of the semester he explained his beliefs:

> [Students] learn through seeing the end result. Getting their data back after lab and looking at it and then analyzing it and figuring out that, in a real sense, there's not necessarily a right answer. There're the answers you get and then you have to assess it and make determinations from, and they've learned that a lot. They learn that by taking what they did in lab, taking their data for better or worse and using it. (Lawrence, TA, 12/7/14, Interview 2)

Not only did Lawrence believe students should grapple with information, he believed students could learn new concepts through lab rather than lab being a place to apply knowledge. This viewpoint was in contrast to Martha and Ellen’s traditional teaching beliefs of lab-as-application of knowledge.

Four of the six participants (67%) believed in a reformed-based teaching philosophy that was student-centered and hands-on for the TA. Participants described this type of teaching as “Coming alongside students” (Lawrence, TA, 9/24/14, Interview 1), and “To be there to bounce off ideas and ask them questions to see what they actually really know” (Jeremy, TA, 9/10/14, Interview 1). These beliefs were maintained by two of the four (50%) participants who initially held these beliefs. In addition to being the facilitator of discussions, Jack also believed he could promote student learning by “facilitating discussions between them, so like if somebody doesn't know an answer once they're working as a group, being able to get them as a group to discuss what they know” (Jack, TA, 12/3/14, Interview 2). He held the belief that students themselves could share information and that he did not have to disseminate information to students. In a more facilitative approach to teaching, participants believed their TA role was to support student learning, which was a distinctly different belief than the passive teaching beliefs observed in Ellen and Martha’s responses.

Laboratory beliefs. The quantitative data suggested participants had more reform-based beliefs than traditional beliefs about what students should learn within an inquiry-based laboratory context. This was evidenced by higher Likert scores indicating participants believed labs should emphasize a variety of objectives. Similar to participants’ beliefs about teaching and learning, participants’ beliefs about what objectives should be emphasized in lab were resistant to change (Table 27). Non-parametric tests revealed no significant differences between any time point for all participants or disaggregated by gender. No correlation analysis was performed on the data due to non-normality.

Table 27
Participants' Beliefs about Laboratory

Groups		Pre (SD)	Post (SD)	Delayed (SD)
All TAs (n=14)		3.57 (.45)	3.55 (.40)	3.36 (.44)
Gender	Male (n=8)	3.59 (.52)	3.53 (.38)	3.67 (.28)
	Female (n=6)	3.54 (.39)	3.57 (.47)	3.54 (.62)

Note. Non-parametric testing was performed on all groups due to non-normality of the data. Likert scale averages reported where 1=little emphasis on a few objectives and 4=heavy emphasis on a variety of objectives. Higher Likert scores indicated more reform-based beliefs. Lower Likert scores indicated more traditional beliefs. No significant differences for All TAs (all ps>.1).

Laboratory beliefs by objective. To provide further insight into the types of objectives participants believed should be most emphasized in an inquiry-based lab, the lab beliefs construct was broken down into its individual questions (Table 28). Due to the non-normality of the per-question data, no inferential statistics were performed; however, some trends can be understood from this representation of the data. Participants believed all of the objectives should be emphasized to some extent in the laboratory context. Memorization of facts was least emphasized across all time points, and this emphasis decreased across the semester (M=2.57 to 2.23). Coming in to the professional development participants believed understanding chemistry concepts should be the most emphasized (M=3.93), and this belief persisted across the semester (M=3.92). Initially participants believed learning science process skills (M=3.86) should be emphasized as much as chemistry concepts. By the end of the semester participants believed evaluation should be emphasized as much as understanding chemistry concepts (M=3.92) and science process skills were de-emphasized in comparison (M=3.69). Participants believed communication should be fairly heavily emphasized (M=3.79), and these beliefs decreased by the end of the semester (M=3.62).

Table 28

Participants' Laboratory Beliefs Likert Question Responses

Lab beliefs questions	Pre (SD)	Post (SD)	Delay (SD)
Memorizing chemistry vocabulary and/or facts	2.57 (.65)	2.46 (.50)	2.23 (.42)
Understanding chemistry concepts	3.93 (.27)	3.85 (.36)	3.92 (.27)
Learning science process skills (ex: observing, measuring)	3.86 (.36)	3.92 (.27)	3.69 (.46)
Learning how to communicate chemistry ideas effectively	3.79 (.43)	3.69 (.46)	3.62 (.49)
Learn how to evaluate arguments based on scientific evidence	3.79 (.58)	3.85 (.36)	3.92 (.27)
Learning about the nature of science (ex: scientific knowledge may change as new evidence is gathered)	3.29 (.61)	3.46 (.63)	3.54 (.63)
Learning about real-life applications of chemistry	3.14 (.77)	3.23 (.70)	3.38 (.62)
Increasing students' interest in chemistry	3.36 (.93)	3.31 (.72)	3.23 (1.12)
Preparing students for further study in chemistry	3.42 (.76)	3.38 (.74)	3.62 (.49)

Note. Likert scale averages reported where 1=little emphasis and 4=heavy emphasis. Memorizing vocabulary and facts was not included in the 'lab beliefs' construct represented in Table 27 due to the decrease in reliability of the construct when this question was included. *Italicized* question had the lowest delayed survey scores. **Bolded** questions had the highest delayed survey scores.

From pre-survey to delayed post survey there also appeared to be an positive trend in the emphasis participants believed should be on larger laboratory goals such as nature of science (M=3.29 to 3.54), real-life chemistry applications (M=3.14 to 3.38), and preparation for further study of chemistry (M=3.42 to 3.62). Participants' beliefs on average exhibited a negative trend about using the general chemistry laboratory as a venue for increasing students interest in chemistry (M=3.36 to 3.23). The large standard deviation for the delayed post-survey average for this question (SD=1.12) suggested participants had varying beliefs about how much interest should be emphasized in the laboratory. These varying views may help explain the lack of significant changes in overall laboratory beliefs across the semester.

Qualitative data may provide additional explanations for the lack of changes observed in the quantitative lab beliefs data. Inductive categories that emerged from the interview data related to the individual Likert questions on what participants believed students could learn through inquiry. These beliefs were evidenced in participants' understanding of the different learning outcomes[4]. Participants who identified a limited number of objectives, such as content and laboratory techniques, as what students could learn in the laboratory were considered to have more traditional beliefs. A more complex understanding of outcomes, such as identifying nature of science or evaluation as laboratory outcomes, corresponded to a more reform-based belief about lab. Five of the nine Likert questions aligned with the inductive qualitative categories, suggesting participants believed these objectives could be achieved by students in the inquiry-based laboratory. Critical thinking was an additional learning outcome not explicitly discussed in a Likert question. Overall, participants shifted their understanding of what students could learn in the laboratory over the course of the semester from more simplistic to more complex (Table 29). This suggested their beliefs about what students can learn in lab may have shifted from traditional to more reform-based.

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[4] It is important to note that the qualitative data related more to participants' understanding about the types of learning outcomes, whereas the quantitative data related more to participants' beliefs about what types of learning outcomes should be emphasized in lab. While understandings and beliefs are not synonymous, the qualitative data provides insight into participant's ideas about the different learning objectives discussed on the survey.

Table 29

Overview of Participant Ideas about What Students Can Learn in a Guided Inquiry Laboratory

	Beginning of semester	End-of-semester
Memorization of facts	**---**	**Memorization hinders students learning.**
Understanding concepts	Students not learning as much content as in traditional lab.	Students not learning as much content as in traditional lab **Students can learn concepts in different ways rather than one prescribed way.**
Science process skills	Students learn math skills and may miss lab skills needed in future.	Students struggle with data analysis. **Students learn problem solving, experimental design, and scientific writing.** **Guided inquiry increases students' comfort and confidence with learning skills.**
Chemistry applications	Applications of chemistry engage students in learning.	Applications of chemistry engage students in learning. **Applications of chemistry is a learning outcome.**
Critical thinking	Students learn critical thinking skills.	Students learn critical thinking skills.
Nature of Science	---	**Students acting like scientists promotes learning and prepares students for future chemistry work.**

Note. **Bolded** ideas indicative of more complex understanding of learning objectives.

Traditional laboratory beliefs. All participants initially described the laboratory learning objectives in more simplistic terms and lacked a more complex understanding of what students could learn in an inquiry-based laboratory. For example, two participants (33%) initially described mathematical and laboratory skills as important learning outcomes in the laboratory course. When asked about the benefits of learning through guided inquiry, Ellen indicated, "it's helping with their dimensional analysis skills" (Ellen, TA, 12/2/14, Interview 1). She perceived this mathematical skill as a learning objective that was achieved in the laboratory. No participants discussed skills such as developing an experiment, analyzing data, communicating results and evaluating evidence-based arguments.

Participants' initial understanding of learning about the application of chemistry was either absent or focused on application as a means of learning. In her first interview, Martha discussed how applying chemistry was an important component to the laboratory, "I think just being excited about chemistry helps, trying to make real world connections for them whenever possible. They tend to like that if they don't like science" (Martha, TA, 9/30/14, Interview 1). She did not perceive learning about real-world applications as an outcome itself but as a method to engage students in learning. None of the participants initially discussed the nature of science as a laboratory learning objective.

Initial interview responses also revealed participants focused on the limitations what students could learn in an inquiry-based context, suggesting they held more traditional laboratory beliefs at the beginning of the semester. In particular, participants focused on the limitation of guided inquiry in promoting student learning of concepts and laboratory skills. At the beginning of the semester Stephanie indicated she perceived other TAs believed guided inquiry limited students' learning of concepts, "A lot of the other TAs I talked to, they think that it's great and that the students are getting their problem solving skills and being able to be more confident about that, but they're not learning the content" (Stephanie, TA, 10/1/14, Interview 1). Stephanie expressed that other TAs identified benefits and limitations of inquiry. For example, TAs perceived the lack of content knowledge students were learning in lab appeared to be a limitation of inquiry. Jeremy perceived inquiry as limiting students' ability to learn a variety of laboratory skills. He stated, "In this lab, there's multiple ways-- sometimes there's multiple ways to approach a problem, and what if you miss out on one of those that you need in the long run?" (Jeremy, TA, 9/25/14, Interview 1). He understood that students should be able to use different methods to arrive at a conclusion; however, he thought this would be harmful to students in the long run if they approached a problem differently and as a result did not develop all of the skills they needed.

Ellen was the only participant that did not illustrate an expanded understanding of laboratory learning in her second interview, suggesting her more traditional laboratory beliefs were maintained across the semester. Ellen expressed a similar view about inquiry and content knowledge that was perceived by Stephanie at the beginning of the semester, "I don't think as far as basic chemistry they really got the volume of knowledge they would have with the traditional lab" (Ellen, TA, 12/2/14, Interview 2). Her traditional view of laboratory instruction and belief that learning content knowledge was a primary goal of the laboratory curriculum continued to play a role in how Ellen perceived the guided inquiry laboratory.

Ellen also discussed data analysis as something the students learned in the laboratory; however, she indicated, “They could get the data. Interpreting it was always iffy” (Ellen, TA, 12/2/14, Interview 2). While she understood data analysis as an outcome of the guided inquiry process, she believed students struggled with this. She also indicated, “I guess just in general a lot of them seem a lot more confident with being able to plan and design labs...and it builds their confidence with the concepts” (Ellen, TA, 12/2/14, Interview 2). She perceived that students were more confident in what they were doing in lab but students had difficulty with the learning itself. Thus, it did not appear that Ellen believed increased confidence helped student learning.

Two of the six interviewed participants (33%) indicated they believed the inquiry-based laboratory instruction was an effective method for students to learn critical thinking and problems solving skills. The same two participants (100%) held these beliefs at the end of the semester. For example, Ellen initially stated, “It's a really great way to teach critical thinking skills” (Ellen, TA, 9/15/14, Interview 1) and reiterated this point at the end of the semester, saying, “Guided inquiry, I see its usefulness in problem solving skills” (Ellen, TA, 12/2/14, Interview 2). The only change in this perception about learning outcomes in the laboratory was the replacement of ‘critical thinking’ with ‘problem solving’. There did not appear to be an increase in complexity in these two participants’ understanding of students’ ability to think critically or to solve problems.

Reform-based laboratory beliefs. While participants' initial beliefs about laboratory learning were more traditional, interview data suggest five of the six participants (83.3%) shifted to more reform-based laboratory beliefs by the end of the semester. These shifts were evidenced by participants' increased understanding of the learning objectives as well as an increase in an understanding of the variety of learning objectives that could be met in a guided inquiry laboratory context.

At the end of the semester, one interview participant (16.7%) explicitly discussed how students tended to memorize facts but not understand concepts. No other participants discussed memorization, which in combination with the low Likert scores on the memorization question, suggests memorization was not something participants believed should be emphasized in lab. Jack explicitly discussed his belief of having students memorize facts:

> They don't just memorize that things that form hydrogen bonds have stronger intermolecular forces than things that don't form hydrogen bonds. You can state stuff like that as a fact, but if they just memorize it they haven't gained any real understanding of what's going on. (Jack, TA, 12/10/14, Interview 2)

Jack believed students tended to memorize instead of understand, which was a belief evident in both his interview and survey responses.

By the end of the semester four of the six participants (67%) perceived the laboratory as a venue for learning a variety of different skills, whereas the remaining two did not discuss increasingly varied skills. The skills participants mentioned as being important included developing an experiment, analysis of data, and writing lab reports. When asked about what changes he observed in his students across the semester, Jack indicated, "Once they got some experience of how to design an experiment, how to think through different things you need to test and control for, it became easier for them to do that" (Jack, TA, 12/10/14, Interview 2). He was able to observe students' ability to develop a method for solving a chemistry problem at the end of the semester, which was something he did not mention observing at the beginning of the semester. Thus, Jack understood how students could learn more than just concepts in the guided inquiry laboratory setting.

There appeared to be a more complex understanding in one participants' view of lab-as-application. At the end of the semester Lawrence emphasized the application of chemistry as part of students' learning in the laboratory:

> There have been a few times in the class where I've had students realize that whatever they're working on has very specific relationship to some more common or more important industrial application. Even a simple chemical reaction that they've witnessed at home, but they didn't know it was a chemical reaction. (Lawrence, TA, 12/7/14, Interview 2)

Lawrence's believed learning about applications of chemistry was an outcome of lab rather than a method for learning concepts or skills. Lawrence also appeared to understand learning concepts in lab increased students' understanding of how chemistry plays a role in everyday activities. Martha's view of applying chemistry at the beginning of the semester was much simpler than Lawrence's reciprocal view between learning chemical applications and chemical concepts at the end of the semester.

None of the interview participants initially discussed how guided inquiry helped students learn about the nature of science, but by the end of the semester four of the six participants (67%) expressed beliefs related to this construct. When asked about student learning in the laboratory, Jack indicated their experience was more memorable because, "I guess in a lab setting it's helpful because they're doing the experiment and then gathering these measurements...they have to approach it in a way that an actual scientist does" (Jack, TA, 12/10/14, Interview 2). He believed the laboratory yielded itself to doing things as a scientist would, and this would increase student learning. The emphasis on the nature of science for participants who discussed this construct (e.g., Jack, Lawrence, and Martha) was a means to learning, not a learning objective itself. While the Likert data suggested participants believed evaluation of ideas and communication of ideas were important learning objectives to emphasize, the qualitative interview data did not illustrate participants' belief that these were important.

Beliefs and social constructivism. From a social constructivist perspective, participants' prior teaching and research experience as well as their interactions with students and other TAs appeared to play a role in the construction of their beliefs. Disaggregation of Likert data based upon prior teaching experience and prior research experience revealed potential differences between participants' beliefs (Table 30). The two participants with extensive research experience held more traditional teaching and laboratory beliefs than all other subgroups across all time points, whereas the six participants with only undergraduate research experience had the most reform-based beliefs across all time points.

Table 30

Participants' Teaching/Learning and Laboratory Beliefs Based on Prior Experiences

Groups		Pre (SD)		Post (SD)		Delayed (SD)	
		Teaching	Lab	Teaching	Lab	Teaching	Lab
Teaching Experience	None (n=3)	4.58 (.50)	3.84 (.16)	4.50 (.19)	3.75 (.21)	4.58 (.17)	3.69 (.39)
	Tutor/undergrad TA (n=3)	4.22 (.69)	3.54 (.51)	4.11 (.51)	3.33 (.58)	3.89 (.38)	3.08 (.56)
	PBGI TA (n=6)	4.39 (.57)	3.40 (.58)	4.26 (.65)	3.50 (.42)	4.17 (.78)	3.64 (.33)
	Chemistry teacher (n=2)	4.67 (.47)	3.81 (.09)	4.17 (.71)	3.79 (.30)	4.83 (.24)	3.94 (.09)
Research Experience	Undergraduate (n=6)	4.61 (.44)	3.83 (.13)	4.39 (.39)	3.76 (.22)	4.67 (.21)	3.77 (.33)
	Graduate (n=6)	4.39 (.57)	3.40 (.58)	4.26 (.65)	3.50 (.42)	4.17 (.49)	3.64 (.33)
	Full time lab tech (n=2)	3.83 (.24)	3.31 (.44)	3.83 (.24)	3.07 (.51)	3.67 (.00)	3.06 (.80)

Note. Higher Likert scores for teaching/learning and laboratory beliefs indicate more reform-based beliefs. No inferential statistics were performed due to small size of sub-groups.

Prior teaching experience appeared to have the opposite impact on participants' beliefs. Those with more teaching experience had more reform-based teaching and laboratory beliefs compared to participants with little teaching experience. The two former high school chemistry teachers had the most reform-based teaching beliefs and nearly the most reform-based laboratory beliefs upon entering the professional development. These beliefs shifted toward more traditional following the professional development but returned to the most reform-based of all participant sub-groups by the end of the semester. Participants with only tutoring/undergraduate TA experience appeared to shift toward more traditional laboratory beliefs across the semester, whereas former PBGI TA participants shifted toward more reform-based laboratory beliefs across the semester. Participants with no previous teaching experience had initial beliefs similar to participants with the most teaching experience; however, both teaching and laboratory beliefs appeared resistant to change for participants with no teaching experience.

The qualitative data provided a more in-depth understanding of how participants' prior experience and current interactions shaped their beliefs (Table 31). Interview data suggested participants' experience with inquiry in chemistry courses as a student or teacher, not just teaching prior experiences, shaped participants' beliefs. Participants with positive past experiences with traditional instruction held more traditional beliefs whereas participants with positive past inquiry-based experiences held more reform-based beliefs. Participants' interactions with students in the inquiry laboratory setting were used by participants to support their beliefs about teaching and learning. Participants with traditional beliefs tended to interpret student interactions negatively whereas participants with reform-based beliefs tended to interpret similar student interactions more positively.

Table 31
Comparison of Participants' Qualitative Beliefs and Experiences

TA	Teaching/learning beliefs from interviews	Student-TA interaction	Prior teaching experience	Prior Gen Chem Experience
Ellen	Traditional	Negative	Undergrad TA	Traditional-positive
Martha	Traditional	Negative	PBGI TA	Traditional
Jeremy	Transitional	Negative	Undergrad TA	Traditional
Stephanie	Transitional	Negative/Positive	PBGI TA	Inquiry-based - positive
Jack	Reform-based	Positive	None	Inquiry-based – positive
Lawrence	Reform-based	Negative/Positive	Chem teacher	Traditional

Note. Identification of TA beliefs categories based upon Table 26.

Traditional beliefs and social constructivism. Qualitative data suggested Ellen and Martha were the most traditional in their teaching beliefs and continued to describe inquiry-based teaching experiences negatively. For example, when asked about inquiry-based teaching Ellen responded, “It's a great lab and theoretically, they should be able to do it without too much prior chemistry knowledge but a lot of them are struggling” (Ellen, TA, 9/15/14, Interview 1). Student difficulty for Ellen was not a positive experience, and this appeared to be related to her belief that TAs should take a passive role in student learning. Martha also had a negative perception of student struggle. When asked about improving the laboratory, she discussed her experience using technology in the lab:

> They're so buggy, and maybe it's just me, because I have never really used them before, but I feel like a lot of times they're failing, and I don't know why, and the students have to completely redo their experiment. Which is good, because they get a taste of what science is actually like, but it's also frustrating for them, and it's frustrating for me when it's not a chemistry problem that they're having, it's an equipment problem. (Martha, TA, 12/2/14, Interview 2)

For Martha this was a frustrating experience rather than an opportunity to engage students in discussions about the nature of science or use it as a learning experience.

Student struggle for Ellen and Martha may have been viewed negatively because of their different prior experiences. Ellen believed teaching should be ‘easy’, as illustrated in her response about helping students understand concepts in lab:

> If they had understood [equilibrium] and then tried the labs it would have been much easier to connect concepts. Rather than having them try the lab, explain equilibrium to them, and have them apply it backwards to the lab. (Ellen, TA, 12/2/14, Interview 2)

Ellen’s beliefs aligned with using the laboratory context as a place for students to apply lecture concepts, and she felt that this approach was much easier than the inquiry-based approach utilized in the course. She also believed that her role was to “explain equilibrium to them,” a more traditional role than a TA who facilitates student learning. These traditional beliefs appear to be ingrained in Ellen’s understanding of teaching, and her experience with students continued to support and confirm her beliefs that traditional teaching was ‘easiest’. This perception of passive, easy teaching was evidenced in Ellen’s description of an ideal chemistry lab:

> Ideally, the kids would be on their own and this particular TA would be somewhere else. A more realistic ideal lab would still involve the TA doing nothing. The children would collect their own data, troubleshoot, and interpret data all on their lonesome (Ellen, TA, Delayed-post survey).

Ellen clearly believed the TAs role was to be doing as little as possible. During the second interview she discussed experience taking a traditional general chemistry lab, “Comparing [inquiry] to what I had as an undergrad, like the traditional gen chem lab, I think I probably learned more as far as in terms of chemistry” (Ellen, TA, 12/2/14, Interview 2). At the end of the semester Ellen still believed the traditional laboratory experience was more beneficial for learning chemistry content than an inquiry-based approach.

Martha also held traditional beliefs and had negative experiences in lab that confirmed her beliefs; however, she appeared to want to facilitate student learning rather than be a passive teacher. For example, Martha described how students struggled during the planning process:

> I try to tell them key words of things that they look up on the internet that are usually good. Usually they end up looking cookbook labs anyway so it's not even, I feel like they're getting the guidance that they wouldn't be getting from guided inquiry but they're just not getting it from us and a lot of times they don't know how to vet those resources so they go off in directions that are not productive. That's probably been the tough thing. (Martha, 9/30/14, Interview 1)

Martha went on to describe how students should learn the concepts prior to coming to lab and apply these concepts within the lab setting. Similar to Ellen, student struggle in the course was not a positive experience for Martha, and while she desired to work with the students, she did not know how to do so within an inquiry-based context. Martha perceived a more direct instruction approach would have solved her problem of student struggle, and she continued to find experiences that confirmed this traditional belief.

Reform-based beliefs and social constructivism. Conversely, participants with more reform-based beliefs and more experience with inquiry described more positive interactions with students and realized the end learning goal for students was more important than student frustration. Stephanie's interview data suggested she held reform-based beliefs about student learning, and at the beginning of the semester she indicated, "I'm not there to give them the answers and although it frustrates them, I think when I make that clear right away, they accept it and we can move on from there and work on their chemistry content" (Stephanie, TA, 10/1/14, Interview 1). She did not allow students' frustrations to change these reform-based beliefs, and by the end of the semester she stated, "Yeah, they're less reluctant to the guided inquiry as the semester goes on. I think they really learn to appreciate it" (Stephanie, TA, 12/12/14, Interview 2). Stephanie understood the benefits of guided inquiry and saw the positive changes in students across the semester, which helped support her beliefs about student struggle as a requisite for student learning.

Lawrence had similar positive interactions with students and also realized the benefits to student learning through inquiry-based laboratory instruction outweighed students initial frustration with the process:

> I think it's fun to implement because students see what you're doing, and despite getting frustrated they know that it's making them do it for themselves, and process things individually, rather than taking an idea or procedure that was just given to them. (Lawrence, TA, 9/24/14, Interview 1)

Lawrence enjoyed implementing inquiry, and this appeared to translate to his students who were frustrated but understood why they were being tasked with struggling through the experience. He also believed in a more facilitative teaching approach to lab, but despite his extensive teaching experience still struggled teaching in an inquiry-based context. He described how his experience with facilitation could have a negative impact on student learning:

> The main difficulty that I find with it is the balancing between when you need to stop guiding them and need to really instruct them because there are times that I think students need direct instruction, and not that they're incapable of it, but they have no way or have not developed a way in their mind yet to really reach the goal if they're just guided. (Lawrence, TA, 9/24/14, Interview 1)

From this quote, it appeared Lawrence conflated direct instruction and focused feedback. Lawrence believed that reform-based instruction was defined by not providing any answers, and not providing any answers was a negative experience for him. He found some students needed constructive feedback in order for facilitation to be effective, but he thought this conflicted with inquiry instruction. His teaching beliefs were aligned with guided inquiry instruction; however, he did not believe that they were, and this struggle between his beliefs and what worked in practice were evident in his interview responses.

Participants who had positive experiences with student struggle and reform-based beliefs appeared to also have positive previous experiences with inquiry instruction. Jack had never taught before, but he was only one of two participants who had experienced inquiry as a student. He described his experience:

> We used a little bit while I was an undergrad. In general, I think it's a pretty good approach. Because I know at least from my experience as a student with guided inquiry, I thought that the things that I kind of had to reason through as opposed to just being told as fact were a lot more memorable. You remembered them a lot better because you had to struggle through the process of learning them. I think as a general teaching method, pretty effective. (Jack, TA, 12/10/14, Interview 2)

Jack's experience with inquiry-based instruction was positive, and this experience helped shape his view on teaching and learning in an inquiry-based laboratory context. Stephanie had similar views on her inquiry experience as a student. As a previous PBGI TA, Stephanie also explained her experience TAing the previous year:

> I try to maximize student learning by not giving them the answer. I do find that super challenging to not hold their hand, so I won't give them the answer but a lot of times I see that I lead them directly to it. Since I'm a second year TA, this year I tried a little bit more to not give them the answers like that and really make them think and do it on their own. (Stephanie, TA, 12/12/14, Interview 2)

She acknowledged the challenges of facilitating, and as she reflected on her previous teaching experience she realized she should be less instructive. Her approach ended up being much more passive than facilitative in response, as indicated in Table 31.

Participants with traditional teaching beliefs appeared to discuss their beliefs with other TAs. Stephanie hinted at these interactions when indicating she agreed with the goals and instructional approach of guided inquiry, "I really think that I fully stand behind implementing guided inquiry and again, some of them [TAs] don't agree with putting it so early in your chemistry stages, but I think that's the most important place to put it" (Stephanie, TA, 10/1/14, Interview 1). Stephanie's comments confirmed the traditional beliefs observed in other TAs' interview and survey data but also suggested participants with traditional beliefs vocalized these beliefs with other TAs. When discussing the use of facilitation as a tool to support student learning, Lawrence suggested why some TAs struggled with this approach:

> It's not always the easiest thing to remember to do and to try and implement because I think the tendency of most people is to want to tell students how to do a thing correctly, for multiple reasons. One, to get out of lab quicker and to help

> them more or two, to get the correct set of results. (Lawrence, TA, 12/7/14, Interview 2)

Lawrence's perspective on other TAs' beliefs about being a facilitator aligned with the views of interview participants with traditional teaching beliefs and helped triangulate their beliefs. Ellen believed teaching should require little effort, which aligned with Lawrence's statement about TAs wanting to 'get out of lab quicker', whereas Martha believed teaching should be more direct instruction, which aligned with Lawrence's statement about TAs wanting students to 'get the correct set of results'.

Both Lawrence and Stephanie held more reform-based beliefs about teaching; however, they clearly felt the presence of TAs with more traditional beliefs about teaching. It was possible the combination of their struggles (e.g., Stephanie with being more hands-off as a response to her desire to want to be less directive and Lawrence with wanting to provide more directive feedback that he felt conflicted with a facilitative inquiry-based approach) along with negative or more traditional beliefs of the TAs they interacted with may have been a reason for their quantitative beliefs data appearing more traditional in nature. Interview and survey data suggested there existed participants with more reform-based teaching beliefs, but these beliefs may have been muted by external factors related to their interactions with students and other TAs.

Beliefs summary. Participants' beliefs were organized by teaching/learning beliefs, and laboratory beliefs. Quantitative data suggested participants had reform-based teaching and laboratory beliefs that were resistant to change. Neither type of belief was significantly different for males or females. There were significant, strong, positive correlations between participants' teaching beliefs at the beginning of the professional development with the two other time points, and no correlations were performed for the laboratory beliefs due to the non-normality of the data.

Qualitative data from surveys and interviews provided possible explanations for why these beliefs appeared unchanging overall. Organizing these data by beliefs categories (deficit, traditional, instructive, transitional, responsive, and reform-based) and data collection time points revealed no overall trends in participants' teaching and learning beliefs. A lack of relationship in the qualitative data helped explain the lack of change in the quantitative beliefs data. Further examination of the qualitative data identified some interview participants as holding more traditional teaching/learning beliefs or more reform-based teaching/learning beliefs that were resistant to change, whereas transitional participants were more likely to change their teaching/learning beliefs. The qualitative data also revealed participants' understandings of different learning objectives became more sophisticated across the semester, which represented a shift in their beliefs about inquiry-based laboratory instruction. There appeared to be participants who perceived the guided inquiry laboratory curriculum promoted or inhibited students' learning certain objectives, and this differed for participants and time points. These differences may have, in aggregate, canceled each other out and explained why the quantitative data showed no changes across the semester.

Using a social constructivist lens revealed some differences in quantitative data for participants with different prior research and teaching experience. Participants' extensive research experience and their previous teaching in the PBGI laboratory appeared to produce more traditional and more reform-based quantitative results, respectively. These data suggest prior experiences are important factors in participants' teaching/learning and laboratory beliefs.

Quantitative data also revealed participants with no teaching experience entered into the professional development with beliefs similar to participants with extensive teaching experience. Qualitative data revealed participants' experience with inquiry, not just teaching experience, may help explain these similarities. Interview responses also shed light on the importance of social interactions on beliefs and suggested participants' present experiences were interpreted by the participant in ways that confirmed their beliefs. In other words, a similar experience for two TAs with two different beliefs sets was perceived differently. A negative experience for a TA with traditional beliefs confirmed that direct instruction was more effective than inquiry-based instruction, whereas a negative experience for a TA with more reform-based beliefs supported their belief that inquiry-based instruction was more effective than direct instruction. The retention of beliefs for some participants may provide another explanation for the lack of change in the quantitative data.

TA Teaching Confidence

Participants entered the professional development feeling confident about encouraging, motivating, and supporting students in their learning through a guided inquiry approach to the general chemistry laboratory (Table 32). This confidence was maintained following professional development and at the end of the semester. There were no significant differences observed between male and female participants in their confidence. Correlations between confidence across the semester reveal significant, strong, positive correlations between participants pre and post-confidence (r=.584, p=.03) and post and delayed-post confidence (r=.546, p=.04). This suggested that participants with high confidence in teaching prior to professional development tended to have high confidence in teaching following professional development, and this relationship was maintained for participants' end-of-semester confidence scores.

Table 32
Participants' Teaching Confidence

Groups		Pre % (SD)	Post % (SD)	Delayed % (SD)
All TAs (n=14)		4.06 (.46)	4.13 (.54)	4.19 (.51)
Gender$^+$	Male (n=8)	3.98 (.33)	4.17 (.36)	4.30 (.46)
	Female (n=6)	4.16 (.61)	4.07 (.76)	4.05 (.58)

Note. $^+$ = non-parametric testing performed. Likert scale averages reported where 1=not at all confident and 5=very confident. No significant differences for All TAs (all ps>.05). One participants' post-survey score and one participants' delayed-survey score were missing, and mean imputation was used to deal with missing data.

Analyzing average responses for individual questions related to teaching confidence revealed participants initially felt the least confident about facilitating in-depth discussions about chemistry (M=3.57) (Table 33). While their confidence appeared to somewhat improve following processional development (M=3.85), facilitation was still the aspect of instruction participants felt the least confident about going into teaching. By the end of the semester participants improved their confidence in facilitation (M=4.08), and they felt the least confident about promoting student participation in the lab (M=3.85). This suggests facilitation as a whole may have become something participants felt more confident with; however, the more nuanced details of involving all students in these discussions was something participants struggled to implement during the semester.

Table 33

Participants' Teaching Confidence Likert Question Responses

	Pre (SD)	Post (SD)	Delay (SD)
Implement guided inquiry in the lab	3.93 (.73)	3.92 (.47)	4.08 (.73)
Promote student participant in the lab	4.00 (.78)	4.00 (.88)	3.85 (.77)
Make students aware I have a personal investment in their learning	4.07 (.47)	4.08 (.62)	4.15 (.66)
Create a positive laboratory climate for learning	4.15 (.77)	4.38 (.74)	4.46 (.75)
Think of my students as active learners	4.00 (.78)	4.23 (.70)	3.92 (.83)
Encourage students to ask questions during lab	4.14 (.77)	4.23 (.70)	4.54 (.50)
Actively engage students in the learning activities included in the lab manual	3.93 (.62)	4.08 (.73)	4.54 (.50)
Promote a positive attitude toward learning in my students	4.07 (.83)	4.31 (.82)	4.38 (.62)
Provide support to students who are having difficulty learning	4.43 (.65)	4.23 (.70)	4.08 (.62)
Provide encouragement for students who are having difficulty learning	4.36 (.74)	4.31 (.61)	4.08 (.47)
Encourage students to interact with each other	3.71 (.83)	3.92 (.92)	4.08 (.47)
Show my students respect through my actions	4.71 (.47)	4.38 (.74)	4.54 (.63)
Let students take initiative for their own learning	3.71 (.83)	4.00 (.68)	4.15 (.66)
Facilitate in-depth discussions about chemistry	3.57 (.76)	3.85(.66)	4.08 (.73)
Discuss in-depth chemistry content with students	4.07 (.73)	4.00 (.68)	4.38 (.49)

Note. Likert scale averages reported where 1=not at all confident and 5=very confident.

Participants entered the professional development with the most confidence in showing students respect (M=4.71), and while their confidence decreased somewhat following professional development (M=4.38) this was still one of the aspects of teaching participants were most confident about at the end of the year. Participants were also most confident about creating a positive climate for student learning (M=4.38) following professional development. By the end of the semester, participants had the highest confidence in showing students respect (M=4.54), encouraging students to ask questions (M=4.54), engaging students in learning activities (M=4.54) and promoting a positive climate (M=4.46).

Interview participants were explicitly asked what they were most and least confident about in lab, and these data revealed further information about participants' confidence in content knowledge, facilitation, and interactions with students. This more nuanced view of confidence elucidated from the interviews illustrated both high and low confidence about these topics and may help explain the lack of change observed in the overall quantitative data.

Confidence in knowing content. At the beginning of the semester all six interview participants (100%) indicated they were most confident about the content knowledge related to the lab. When asked about what he was most confident about, Jack indicated, "I feel pretty comfortable with the content knowledge. I don't feel too terribly concerned that they'll pop up with a question that I'm just completely lost on" (Jack, TA, 9/10/14, Interview 1). He perceived he had more content knowledge than his students and he felt confident that there was not a topic related to general chemistry that he would not have some understanding of. This view was shared by all interviewed participants. Lawrence and Jeremy were the only participants who had conflicting thoughts on their content confidence at the beginning of the semester. When asked about what he was least confident about at the beginning of the semester, Lawrence stated, "In this lab it's mostly ionic compounds, and I don't do a whole lot with ionic compounds. That can be tough, but content wise it's not difficult" (Lawrence, TA, 9/24/14, Interview 1). He did not perceive the overall content to be difficult, but he did not feel comfortable with certain topics that he had less experience with. Post-survey Likert survey response revealed participants were confident in engaging students in in-depth content discussions (M=4.00), suggesting more participants may have had reservations about their content similar to Lawrence and Jeremy.

By the end of the semester five of the six participants (83%) remained confident in knowing their general chemistry concepts. Similar to his statement at the beginning of the semester, Jack expressed his confidence about chemistry, "I felt pretty good with the content knowledge, honestly. There was really nothing that came up over the course of this semester that I really felt uncomfortable with as far as the content. I felt pretty good about that" (Jack, TA, 12/10/14, Interview 2). Other interview participants who had high confidence related to content became more aware of their weaknesses in their content knowledge, but this did not seem impact their confidence. When asked about the content associated with the lab, Ellen stated, "It was fine. It was gen chem. Statistics were not my forte but it was still very simple, straightforward stuff. Just find standard deviations" (Ellen, TA, 12/2/14, Interview 2). She did not feel intimidated by her lack of knowledge about the concepts associated with the projects because they were not in-depth topics. This end-of-semester view of the content was held by Lawrence, Jack, and Stephanie as well. Likert data showed an increase in confidence in discussing in-depth chemistry content with students at the end of the semester (M=4.38). In combination with the interview responses, this suggested participants who had reservations about their content going into teaching may have felt their weaknesses did not impact their ability to discuss the general chemistry concepts with students.

Confidence in facilitating student learning. Three of the six interviewed participants (50%) discussed their confidence in being facilitators in the laboratory context during both interviews. The differences observed in these three examples may provide insight into the lack of change observed overall for all participants. Ellen was the only participant who consistently described facilitation as the component of the lab in which she was least confident (Table 34). On the other hand, Martha and Jack were initially conflicted about their ability to facilitate student learning, and their confidence became more solidified by the end of the semester. Martha's facilitation confidence appeared to shift toward less confident by the end of the semester, whereas Jack's appeared to shift toward more confident.

Table 34
Participants' Facilitation Confidence Across the Semester

TA	Beginning of Semester (Interview 1)			End of Semester (Interview 2)		
	Confident	Mixed confidence	Not confident	Confident	Mixed confidence	Not confident
Ellen			x			x
Martha		x				x
Jack		x		x		

Note. Stephanie, Jeremy, and Lawrence were excluded from this table because they did not discuss facilitation in relation to confidence during interview 2.

At the beginning of the semester Ellen described her lack of confidence in guiding students using questioning, "I'm worried about asking the questions and having them go off and use the ideal gas law to measure volume. It's just hard to get them to a reasonable point" (Ellen, TA, 9/15/14, Interview 1). She did not feel confident that she could use questioning in a way that would help students and felt she might ask questions that would suggest to students that they use a conceptually inaccurate idea (i.e., measuring a liquid volume using gaseous properties) to develop a procedure. By the end of the semester Ellen still felt less than confident in helping students learn; however, this view was more about explaining concepts to students rather than about asking guided questions. When asked what she was least confident about at the end of the semester, Ellen indicated:

> Explaining concepts. You learn it as a gen chem student, and then seven years later you know it backwards and forwards, and people you interact with on a daily basis know it backwards and forwards. You never have to explain it and you never have to dumb it down. (Ellen, TA, 12/2/14, Interview 2)

Her lack of confidence related to taking what she considered to be her extensive content knowledge and breaking it down into more simple components for students to learn the material.

Both Martha and Jack initially had mixed views on their ability to facilitate discussions. When asked about what she was most confident about, Martha stated, "I feel like I can really help the students with breaking that stuff down without directly giving them the answers" (Martha, TA, 9/30/14, Interview 1). Her confidence in facilitation, similar to Jack's, focused on how she could find ways to help students learn without 'giving them the answer'. However, they both expressed low confidence about facilitation at the beginning of the semester as well. For example, Martha explained why she did not always feel confident when guiding students:

> I guess working with students that really have absolutely no idea what's going on and I exhaust myself with coming up with different ways to approach the problem for them and then they still don't get it. I really don't know what to do in that situation. (Martha, TA, 9/30/14, Interview 1)

Her lack of confidence occurred in more difficult situations where she did not feel she had the skills needed to guide students. This view was mirrored by Jack.

By the end of the semester Martha and Jack no longer had mixed perceptions of their own confidence in facilitation. Martha shifted to having less confidence and described her perceptions:

> I don't know that I always give them guiding questions, rather than ... Sometimes I feel like I'm just giving the questions that are going to guide them right to the answer that I want them to get. That's something that's difficult, was knowing what to do. (Martha, TA, 12/2/14, Interview 2)

Her low confidence in asking students appropriate questions was maintained across the semester, and she did not mention her confidence in helping students. Conversely, Jack discussed his ability to facilitate student discussions as something he was confident about at the end of the semester, "The fact that I had a little bit of experience with guided inquiry, I didn't feel quite as uncomfortable during the guided inquiry" (Jack, TA, 12/10/14, Interview 2). His previous experience as a student in an inquiry-based class allowed him to feel comfortable with being a facilitator of student learning through this method.

Likert responses to participants confidence in supporting students who were struggling to learn revealed a pattern of decreasing confidence from the beginning of the semester (M=4.23) to the end of the semester (M=4.08). This suggests other participants may have had similar experiences as Martha and Ellen where they struggled to help students who were having difficulties.

Social constructivism and confidence. Quantitative data revealed the most confident subgroup of participants across all time points were the two former chemistry teachers (Table 35). Participants who had previously been former teachers had the highest confidence coming into the professional development (M=4.47), whereas all other types of teaching experience did not appear to influence participants initial confidence. There was little change in overall confidence for participants with previous tutor/TA experience across the remaining time points. The two former teachers had little change in their confidence following the professional development (M=4.43), and increased in their confidence at the end of the semester (M=4.80). Participants with no teaching experience showed the largest gains in confidence following the professional development (M=4.33) and end of the semester (M=4.73).

Table 35

Participants' Teaching Confidence by Prior Experience

Groups		Pre % (SD)	Post % (SD)	Delayed % (SD)
Teaching Experience	None (n=3)	3.98 (.41)	4.33 (.20)	4.73 (.24)
	Tutor/undergrad TA (n=3)	3.98 (.21)	4.07 (.67)	3.93 (.13)
	PBGI TA (n=6)	4.00 (.51)	3.96 (.58)	3.85 (.37)
	Chemistry teacher (n=2)	4.47 (.09)	4.43 (.33)	4.80 (.38)
Research Experience	Undergraduate (n=6)	4.10 (.42)	4.43 (.41)	4.62 (.39)
	Graduate (n=6)	4.00 (.51)	3.96 (.58)	3.85 (.37)
	Full time lab tech (n=2)	4.10 (.05)	3.73 (.47)	3.93 (.19)

Note. Likert scale averages reported where 1=not at all confident and 5=very confident. Inferential statistics not performed due to the small size of sub-groups.

Examining participants' confidence based on their prior research experience revealed similar initial confidence for participants. By the end of the semester, participants with less research experience had the highest confidence (M=4.62), whereas participants with graduate or full time research experience had similar, lower confidence (M=3.85 and M=3.93, respectively). Interview data may elucidate reasons for these differences.

Content confidence and social constructivism. Participants' prior experiences and social interactions appeared to shape their confidence in content knowledge. Both prior research and prior teaching experiences were provided by participants as reasons for their confidence in their content knowledge. For example, Stephanie explained her understanding of the chemistry concepts, "I'm truly confident about the content at this point, especially having gone through it a year already" (Stephanie, TA, 10/1/14, Interview 1). Being a TA in the guided inquiry general chemistry labs the previous year improved Stephanie's comfort with the content because she had taught it before. Ellen also explained how her previous experiences shaped her understanding of chemistry content. When asked about what she was most comfortable with in lab, she responded, "I've been in the lab almost daily for like 7 years, so lab techniques and the basic knowledge, I think I've got it down by now" (Ellen, TA, 9/15/14, Interview 1). Ellen perceived her previous experience in a research setting provided her a solid foundation of content knowledge and lab techniques she felt were relevant to the general chemistry laboratories. Likert data suggests participants with previous teaching and research experience have little change in their confidence, which aligned with the initial high confidence perceived by Stephanie and Ellen.

Participant interactions with other TAs during TA training appeared to facilitate high content knowledge confidence. When asked what he did to prepare for lab, Lawrence discussed TA training as preparation for interacting with students about content knowledge:

> All the TAs did all the labs before the students did so we had the chance to fight through our own content knowledge to make sure that we were prepared for what they would be going through. I would say I was fairly confident in all of them. (Lawrence, TA, 12/7/14, Interview 2)

Lawrence's experience doing the labs gave him the opportunity to construct knowledge about the chemistry concepts related to the lab, which he felt improved his confidence in knowing the content.

However, both Lawrence and Jeremy felt less confident when they had an interaction that brought into question their content knowledge. When asked about his content, Lawrence stated, "Yeah, there are moments when a student asks you a question and you just have no idea. Luckily in this lab it's a very valid response to tell students to look it up and find that answer." (Lawrence, TA, 9/24/14, Interview 1). He realized there were limitations in his content knowledge but did not perceive them as being an issue related to the depth of content. Lawrence later contradicted this statement by indicating, "Most nervous about is generally the idea of not having an answer for them" (Lawrence, TA, 9/24/14, Interview 1). Taken together, it appeared Lawrence became aware of weaknesses in his content knowledge through interactions with students, and his response to his lowered confidence was to put the learning on the students.

Jeremy had a similar experience of becoming aware of content knowledge deficiencies when he received a cheat sheet of in-depth concepts related to the labs made specifically for TAs:

> Yeah, so I've been taught that uncertainty is pretty much always precision, and that's not the case, as I found out on the cheat sheet. So I was like, "Okay. Well, I need to go back and make sure that everything-- that students understand that, because I need to correct my misinformation." If my ideas of something, if maybe somehow I passed it on to them, I needed to fix that. Sometimes when you go and look back, what you think you know is the answer might not exactly be the answer. (Jeremy, 9/25/14, Interview 1)

Jeremy thought what he knew was accurate content knowledge, and it was only when he received conflicting information that he realized the limitations of his content knowledge. He understood that his misunderstanding had the potential to influence students' understanding and wanted to find ways to remedy the error. These various interactions appeared to influence TAs content knowledge confidence, and for Lawrence and Jeremy helped them acknowledge deficiencies in the depth of their content understanding.

Facilitation confidence and social constructivism. Interview data suggested three of the four participants with prior inquiry experiences as either a student or teacher used this experience to boost their confidence with facilitating student learning in an inquiry-based setting. Stephanie's prior teaching experience in the PBGI labs helped her feel confident in facilitation. She explained differences in her instruction from the previous year:

> It's easier for me to ask particular questions or dig deeper because I've seen students already go through it and I know they're capable of understanding what the lab is asking pointblank and I can push it further, I know they'll get it. (Stephanie, TA, 10/1/14, Interview 1)

Her previous experience interacting with students provided her knowledge that students can indeed learn through TAs use of questioning. Thus, she felt confident asking more probing questions because she had experience that it worked.

Lawrence also had previous teaching experience with inquiry. When asked about what he was confident about he stated, "I would say there's not very much I'm nervous about guided inquiry. It was something I did a lot with my high school students so I was very used to it" (Lawrence, TA, 9/24/14, Interview 1). Similar to Stephanie, Lawrence had previous experience implementing inquiry and felt comfortable with this style of teaching.

Jack had no previous teaching experience but he indicated he was confident in facilitating student learning through inquiry. When asked about his confidence implementing inquiry, he stated:

> The fact that I had a little bit of experience with guided inquiry, I felt pretty good about that because I'd kind of seen the way guided inquiry was done when I had done it. We had done it in a little bit different setting. More of ours was done in lecture, although we had a little bit in lab. Because I had a general idea of what was going to happen, I didn't feel quite as uncomfortable during the guided inquiry. (Jack, TA, 12/10/14, Interview 2)

Jack's experience with inquiry as a student allowed him to understand what that meant and what it might look like. This in turn made him more confident in implementing inquiry and facilitating student learning through inquiry.

Conversely, Jeremy's lack of prior teaching experience made him less than confident in how he interacted with students. When asked about what he was least confident about, Jeremy discussed his interactions with students:

> Sometimes the students will throw you something that's so convoluted that I don't even understand what they're asking, but maybe they're asking something that might be right, but I've never heard it said that way. Sometimes I'll just kind of do a double take and be like, "What?" Then they'll think, immediately, right then, that they've done something wrong. They'll just be like, "Oh, that's completely wrong if he doesn't understand what I'm talking about," which then maybe they had a good idea about what they were talking about but they didn't know how to express it...I don't know if I've had enough teaching experience to really be able to diffuse what they're saying sometimes. (Jeremy, TA, 9/25/14, Interview 1)

Jeremy acknowledged his response of 'what?' did not produce a positive result in facilitating student discussion in lab. His lack of teaching experience limited his confidence in interacting with students as he struggled with understanding student questions and responding to those questions. Thus, the similarities in Likert confidence scores observed for participants with no prior teaching and more prior teaching experience may have more to do with previous inquiry experience than just teaching experience.

Interaction confidence. Participants' confidence related to their interactions with students inductively arose out of the data. Participants' descriptions of interactions with students suggested some lacked confidence in dealing with confrontational situations in the laboratory whereas others confronted difficult situations that improved their confidence.

Five of the six participants (67%) initially lacked confidence in interacting with students in difficult or confrontational situations. These views appeared to decrease over the semester, suggesting participants increased their confidence in dealing with these types of situations. The most prevalent interaction in which participants lacked confidence related to students not listening or being disrespectful with the TA. Jeremy expressed his lack of confidence in dealing with a situation in which students pushed back on his attempt to facilitate their learning:

> [Students] kind of get a little sassy - not disrespectful - but just they'll be like, "Come on, can't you tell us this?" and I'll be like, "You know, no." Then they'll kind of be like, "Well, what's the point of really asking you?" kind of stuff. It's kind of frustrating. (Jeremy, TA, 9/25/14, Interview 1)

Jeremy did not know how to deal with students' desire for direct answers and felt uncomfortable and unconfident in responding to this type of situation. Similar situations participants described as feeling the least confident about included: students 'freaking out in the middle of class' (Jack and Ellen) and students not listening to the TA (Stephanie and Martha).

Participants indicated their lack of confidence related to student confrontation became a non-issue by the end of the semester. Jack described his experience, or lack thereof:

> I was least confident about was negative reaction from students, to where I had heard horror stories of a student just like breaking down and crying in lab because they got so frustrated. I wasn't really sure how I was going to deal with that. I actually didn't have that happen at all over the course of the semester. Nobody really freaked out or anything. It just ended up being a non-issue. (Jack, TA, 12/10/14, Interview 2)

He initially had low confidence related to interacting with students who were frustrated with the laboratory structure, and he realized by the end of the semester that he did not have to deal with this situation.

Stephanie was the only participant who expressed a continued lack of confidence across the semester. Stephanie explained her confidence in expressing her concern for her students:

> I just would feel bad when they didn't do well and would have to reiterate or reassure them that I want them to succeed. I felt like I had to express that a lot more because I was really not confident in their feelings toward that. (Stephanie, TA, 12/12/14, Interview 2)

She did not feel able to interact with students about their grades in such a way that they understood her desire to want them to do well in the course, and this was something she struggled with throughout the semester.

Other participants felt their interactions with students improved their confidence in interacting with students. In her second interview Martha discussed how her confidence as the TA increased across the semester:

> I think it's hard, because they're so close in age with me, so they definitely ... I don't think so many of them thought of me as an authority, so that was difficult; but as I went on in the semester, I just asserted myself as an authority, so I felt more comfortable with giving them instructions and knowing that they'd follow them. (Martha, TA, 12/2/14, Interview 2)

Martha went on to describe how she felt confident in making sure students were safe in lab. She desired for her students to see her as the person in charge, and she did not have confidence in taking on this role initially. However, she made the effort to take on this role, despite her lack of confidence, and by doing so she found students actually listened to her. This interaction with students appeared to change how confident she was in this regard.

Confidence summary. Overall quantitative data showed no significant changes in participant’s teaching confidence across the professional development or semester. A more nuanced view of these data combined with interview data suggest the lack of differences may be due to participants’ confidence on a variety of different aspects of teaching. Interview data revealed three categories of confidence; content knowledge, facilitation, and student interactions. Participants consistently felt confident in their content knowledge, despite their awareness of possible limited content knowledge, which helped explain the Likert scores indicating participants had moderate confidence on the content question. Interview participants initially had mixed confidence in their ability to facilitate students learning and in interacting with students more generally. While some participants' shifted toward more confident by the end of the semester, others shifted toward less confident. The shifts in opposite directions may explain the overall lack of change observed in the Likert data.

Likert teaching confidence data organized by prior experiences revealed participants with extensive teaching experience had higher confidence than all other participants, and participants with the least amount of prior research experience made the most gains in confidence across the semester. Interview data suggested not only prior teaching experience but prior inquiry-based experiences as a student or teacher increased participants' confidence in both content and facilitation. Experiences with other TAs during TA training helped participants' content confidence, whereas interactions with students in the laboratory appeared to lower participants' confidence. Only a few instances of student interactions appeared to be related to higher confidence.

Relationship between TA content knowledge, beliefs, and confidence

Analysis of the qualitative and quantitative data across different participant characteristics revealed both qualitative and quantitative relationships between these variables. These relationships are detailed in each subsection below. The significant correlations between the quantitative data are presented first (Table 36), then supporting evidence is provided from the qualitative data that help explain these relationships or provide further insight that the quantitative data may not have captured.

Content knowledge and beliefs. There existed no significant correlations between participants' content knowledge and teaching beliefs (Table 36). These results suggested participants with reform-based teaching beliefs may have had high or low content scores. Similar relationships were observed when comparing interviewed participants' quantitative content scores to their teaching and learning beliefs (Table 37). Martha, Stephanie, and Jack had the highest content scores at the end of the semester, and their beliefs ranged from traditional to reform-based. The change in content knowledge also had no relationship to the changes observed in the interviewed beliefs. For example, Martha improved her content score by 8.3% and reverted to all traditional beliefs by the end of the semester, whereas Jack improved his content score 14.3% and retained his transitional/reform-based beliefs. There existed no additional qualitative data relating participants' content knowledge and beliefs.

Table 36

Correlations between Participants' Characteristics

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.Pre-content	x								
2.Post-content	**.574***	x							
3.Delayed-content	.464	.369	x						
4.Pre-T belief	-.251	.037	-.072	x					
5.Post-T belief	-.047	.116	.064	**.739****	x				
6.Delayed T-belief	-.104	.195	-.311	**.688****	.507	x			
7.Pre-confidence	.029	.011	-.308	.182	.370	.254	x		
8.Post-confidence	-.172	-.026	-.252	**.615***	**.836****	**.566***	**.584***	**x**	
9.Delayed-confidence	.083	.043	-.402	.284	.385	**.650***	.363	**.546***	x

Note. Laboratory beliefs excluded from the analysis due to non-normality of the data. * indicates significance p<.05, ** indicates significance p<.01. Correlations for each variable (i.e., content) across time points (i.e., pre/post/delayed) are presented in the sections above.

Table 37

Comparison of TAs' Quantitative Content Knowledge and Qualitative Beliefs

	Content %		Teaching/learning beliefs*	
	Post	Delayed	Interview 1	Interview 2
Ellen	71.43	78.57	Traditional	Traditional
Martha	85.71	92.86	Traditional/Transitional	Traditional
Jeremy	78.57	85.71	Transitional	Traditional/transitional
Stephanie	92.86	92.86	Transitional	Transitional
Jack	85.71	100.00	Transitional/reform-based	Transitional/reform-based
Lawrence	85.71	71.43	Reform-based	Reform-based

Note. * Qualitative teaching/learning beliefs from Table 26.

Content knowledge and teaching confidence. The quantitative data also did not reveal any significant correlations between content knowledge and teaching confidence (Table 36). This suggested that participants who had high confidence may have had either high or low content knowledge scores. Examining the qualitative teaching confidence data confirmed the lack of relationship between content knowledge and confidence. Interviewed participants were confident about their content knowledge because they did not think the general chemistry content was challenging and felt they would be able to answer all students' content questions. From this explanation, participants should have content scores on the survey reflecting their self-perceived depth of content knowledge. This was not the case as most interviewed participants had average or lower than average content scores at the beginning and the end of the semester.

Regardless of their actual content scores, almost all interviewed participants indicated they were confident with their content knowledge at corresponding times (Table 38). At the beginning of the semester, three of the six participants (50.0%), Stephanie, Lawrence, and Jeremy, had confidence aligned with their content knowledge scores. Stephanie had a higher than one standard deviation post-survey content score, suggesting she knew her content knowledge and was justified in feeling confident about it. Lawrence and Jeremy had average and lower than one standard deviation post-content scores, respectively, and their confidence reflected these scores. Both Jeremy and Lawrence discuss some reservations they had with their content knowledge related to the laboratory experiments, which aligned with some limited content knowledge understanding measured on the post-content survey. The remaining three participants (50.0%), Ellen, Martha, and Jack, had scores on content knowledge and confidence about their content knowledge that did not align. All three participants had average or lower than one standard deviation content-knowledge scores on the post-survey but indicated on their interview that they felt confident with their content knowledge.

Table 38
Comparison of Participants' Quantitative Content Knowledge and Qualitative Confidence about Content Knowledge

TA Name	Post content (%) (M=81.63, SD=6.70)	Delay content (%) (M=85.20, SD=8.62)
Lawrence	85.71	**71.43**
Ellen	**71.43**	**78.57**
Jeremy	78.57	**85.71**
Stephanie	**92.86**	**92.86**
Martha	**85.71**	92.86
Jack	**85.71**	**100.00**

Note. **Bolded** scores indicative of reported high content knowledge confidence during the corresponding interview (i.e., Post-content=Interview 1; Delay-post content=Interview 2).

By the end of the semester only two of the six participants (33.3%) had confidence about their content knowledge that aligned with their actual content knowledge. Stephanie maintained her high content knowledge and her strong confidence in her content. Jack increased his content knowledge and maintained his confidence in knowing his content knowledge. At the beginning of the semester his confidence may not have been justified; however, a perfect score at the end of the semester supported his high content knowledge confidence. The remaining four participants (66.7%) had content knowledge and content knowledge confidence scores that did not align. Martha's increase in delayed-post survey content score was not aligned with her confidence in her content. When asked about her confidence with the content, Martha indicated, "Yeah, there are some things that I don't totally understand" (Martha, TA, 12/2/14, Interview 2). She went on to explain she was most confident about, "Making sure my students were safe, that was probably the thing I'm best at" (Martha, TA, 12/2/14, Interview 2). Martha appeared to have a strong content knowledge by the end of the semester; however, she did not feel this was her strength. Jeremey, Ellen, and Lawrence all indicated they were most confident with their content knowledge at the end of the semester; however, their delayed-post content scores did not reflect a solid understanding of chemistry content. Jeremy and Lawrence had similar explanations for their confidence, indicating they did not have any situations where students asked questions that went beyond their content knowledge. The disconnect in Ellen's content knowledge and confidence appeared to be different. When asked about implementing guided inquiry, she responded, "It was easy. I just had to ask them questions. I didn't even have to know what was going on. Just let them figure it out" (Ellen, TA, 12/2/14, Interview 2). Ellen may have acknowledged her limited content knowledge, but it did not seem to be important to her due to her perceptions of how guided inquiry should be implemented.

In summary, both quantitative and qualitative data reveal a lack of alignment between participants' content knowledge and confidence in perceived content knowledge. Some participants had high content knowledge confidence but low measured content knowledge, whereas others had high confidence in content knowledge and high measured content knowledge. Qualitative data suggested participants whose confidence did not align with their content knowledge scores tended to have a false sense of perceived content knowledge.

Beliefs and teaching confidence. There were significant correlations between participants' quantitative teaching beliefs and post-survey teaching confidence (Table 36). A strong, positive relationship existed between participants post-teaching confidence and pre-teaching beliefs (r=.615, p=.019), post-teaching confidence and post-teaching beliefs (r=.836, p=.000), and post-teaching confidence and delayed-post teaching beliefs (r=.566, p=.035). There was also a significant, strong, positive correlation between participants delayed-post teaching beliefs and delayed-post teaching confidence (r=.650, p=.012). These data suggest participants with high confidence about their teaching tended to have reform-based teaching beliefs.

Analyses of qualitative and quantitative beliefs and teaching confidence data provided limited insight into the relationships between teaching beliefs and teaching confidence. Only 2 of the 6 participants provided enough detail in their interviews to make connections between beliefs and teaching confidence at the beginning of the semester. Both Ellen and Stephanie's initial interview revealed a positive relationship between beliefs and confidence about teaching. Ellen held traditional beliefs about teaching in an inquiry-based laboratory and had low confidence in facilitating student learning through inquiry. At the beginning of the semester when asked about implementing inquiry, Ellen referenced the first project and her struggle helping students learn:

> We were asking them to tell us the difference between accuracy and uncertainty, which a lot of people use interchangeably. They didn't know the resources and they didn't understand the difference between the concepts. That was difficult to explain without telling them what it is....It's so easy just to answer a question directly and have the kids understand it, so it's a conscious decision like, okay, ask questions, guide them to it. It's a little rough start but it's getting easier. (Ellen, TA, 9/15/14, Interview 1)

Ellen grappled with how to use questions to facilitate student learning for two reasons; 1) she felt students were unable to learn on their own, and 2) she did not feel confident in guiding students. Ellen went on to further discuss students as barriers to their own learning, “I don't want to say it's too advanced, but they think it is so therefore it becomes too advanced” (Ellen, TA, 9/15/14, Interview 1). Thus, Ellen’s beliefs that students’ difficulties in learning through inquiry put the responsibility on her, and she struggled with her confidence in helping students learn without telling them what to do.

On the other end of the spectrum, Stephanie appeared to have reform-based beliefs about teaching in the inquiry-based laboratory and high confidence related to implementing inquiry in the laboratory. At the beginning of the semester Stephanie was asked what the benefits were to guided inquiry, she responded, “It's prepping them to be more susceptive to their other chemistry classes and problem solving” (Stephanie, TA, 10/1/14, Interview 1). She was the only participant who believed the laboratory helped prepare students for future work in chemistry, a more reform-based belief about student learning than Ellen’s and the other TAs. Stephanie also shared her beliefs about inquiry compared to more traditional laboratory approaches, “I thought that the topics that I learned with that method were learned a lot better than just being told what to do in cookbook lab” (Stephanie, TA, 10/1/14, Interview 1). She believed inquiry enhanced student learning, which was in contrast to Ellen’s beliefs that inquiry hindered student learning.

In her initial interview, Stephanie went on to discuss her confidence in implementing inquiry:

> Confident. I'm more confident this year about not giving them the answer. I think I was pretty easy last year and sometimes I wouldn't know how to ask them many more questions to get them there, so I would just tell them the answer. This year, I'm a little more tougher and I don't tell them the answers and I'll just yeah, I'll keep asking them questions . (Stephanie, TA, 10/1/14, Interview 1)

Having experienced the inquiry laboratories the previous year as a TA, Stephanie felt more confident in being able to help support students through the use of questioning. When combined with her belief about inquiry and student learning, Stephanie’s laboratory beliefs about inquiry facilitating student learning and preparing them for future chemistry classes may provide motivation to continue using questions rather than answers to engage students in the laboratory. This practice in turn helped improve her confidence in doing so.

TA Characteristics Summary

In summary, only TAs’ content knowledge indicated significant improvement from pre to delayed-post survey. No other significant differences existed in the quantitative data for participants overall or for participants based upon gender. The per-question quantitative data and correlations revealed possible trends in and relationships between participants' content knowledge, beliefs and confidence. The qualitative data helped explain why these trends may have presented themselves in the quantitative data.

While the quantitative suggested participants held reform-based teaching beliefs, qualitative data suggested participants actually held a range of teaching and learning beliefs. The qualitative data illustrated more extreme beliefs were resistant to change and may have been influenced by participants' prior experiences and interactions with students. Likert scale data also suggested participants held reform-based laboratory beliefs. Participants believed chemistry concepts should be the most emphasized learning outcome for the guided inquiry general chemistry laboratory over all time points, and by the end of the semester participants believed evaluation of evidence should be emphasized just as much. Qualitative data support these trends as most interview participants expressed a more complex understanding about what students could learn in the laboratory context.

The quantitative data revealed high teaching confidence for participants across all time points. Descriptive statistics of the Likert questions suggested participants were initially the least confident in facilitation and improved their facilitation confidence over the semester. Participants were most confident about more general teaching practices such as showing students respect. Qualitative data both supported and conflicted with these results. Interviewed participants were most confident about their content knowledge across the semester, which was not illustrated in the quantitative data. Interview participants revealed their reservations in facilitating student learning in the laboratory context that supported the Likert data, suggesting facilitation was an aspect all participants were the least confident about. Participants' confidence appeared to be informed by their research experience and their experience with inquiry as either a student or a teacher.

Comparing these TA characteristics (e.g., content knowledge, beliefs, confidence) revealed significant correlations between participants' teaching beliefs and teaching confidence but no significant correlations between beliefs and content knowledge or confidence and content knowledge. Examining interviewed participants' content knowledge, beliefs, and confidence more in depth elucidated no clear trends between content knowledge and beliefs; however, there existed some misalignment between participants' confidence in their content knowledge and their actual content knowledge. Some participants had high confidence in their content, whereas their content knowledge scores did not reflect this knowledge. How these characteristics relate to student learning is examined next.

TA Characteristics & Student Outcomes

Student content scores significantly improved from pre-survey (M=52.48, SD=12.22) to post-survey (M=73.29, SD=12.07) ($p<.001$), and the effect size was large ($d=1.7$) (Cohen, 1988). Correlation data explored relationships between student and TA measures, whereas multiple regression identified which, if any, of these measures predicted student content scores at the end of the semester. Correlation data revealed student post-survey scores were significantly correlated with almost all student-related demographics; while no TA characteristics were significantly correlated with student post-survey scores (Table 39).

Of the significant correlations, it appeared students' pre-survey content scores (r=.474, p=.000) and students' prior chemistry courses (r=.406, p=.000) were moderately (Cohen, 1988) and positively correlated with student post-survey scores. In other words, students who entered into the course with AP chemistry tended to have more chemistry knowledge both at the beginning and the end of the semester as measured by the content survey. A moderate negative correlation existed between students' concurrent enrollment in lecture and the pre-survey scores (r= -.232, p=.000), implying students who were not enrolled in the general chemistry lecture course concurrently with the laboratory course tended to score higher on the pre-survey. Concurrent enrollment was not significantly correlated with students' post-survey scores, suggesting students, regardless of their enrollment in lecture, tended to perform similarly on the post-survey. Small, negative correlations existed between student survey scores, gender, ethnicity, and year in college. Female students tended to have lower pre-survey scores than male students (r= -.119, p=.013), and these differences became more significant and more strongly correlated at the end of the semester(r= -.182, p=.000). Upperclassmen (i.e., third- and fourth- year students) tended to have lower pre-survey scores than incoming freshmen (r= -.161, p=.001), and this relationship persisted across the semester (r= -.130, p=.009).

Table 39

Correlation Table Relating Student and TA Data

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. S Pre-content	1												
2. S post-content	__.474**__	1											
3. S Gender	-.119*	__-.182**__	1										
4. S Caucasian	-.023	__.148**__	-.039	1									
5. S African-American	__-.127**__	__-.128**__	.052	-.358**	1								
6. S Asian	.099*	.019	.042	-.483**	-.118*	1							
7. S Hispanic	.039	-.034	.064	-.192**	.086	-.026	1						
8. S Middle east	-.027	-.040	-.093	-.227**	-.057	-.031		1					
9. S Indian	.023	.015	-.083	-.319**	-.077	-.126**	-.050	.052	1				
10.S Other ethnicity	-.110*	-.101*	-.008	-.226**	-.051	-.050	-.033	.037	-.046	1			
11. S year	__-.161**__	__-.130**__	.060	__.148**__	-.020	-.114*	.006	-.090	-.101*	.000	1		
12. S chem experience	__.406**__	__.314**__	.073	-.109*	-.032	.127*	.040	.078	.117*	.001	-.173**	1	
13. S Lect. enrollment	__-.234**__	-.074	-.061	.023	.041	.005	-.020	.025	-.005	.014	-.103*	-.222**	1
14. TA pre-content	.030	.043	.077	.027	-.042	.009	.073	-.104*	-.028	.021	.030	.040	.037
15. TA post content	.098*	.057	.101*	-.070	.011	.080	.055	-.025	-.002	.019	-.064	.106*	-.019
16 TA delay content	-.013	-.019	.087	-.025	-.057	.066	-.020	-.090	-.041	.055	-.001	-.002	-.093
17. TA pre- conf.	-.079	.000	.011	.057	-.056	-.034	-.075	.029	.040	.026	-.031	-.078	.157*
18. TA post conf.	-.094*	-.013	-.061	-.049	-.019	-.019	-.104*	.073	.072	.067	-.009	-.046	.058
19. TA delay conf.	-.006	.007	-.043	-.080	.067	-.003	-.074	.056	.079	.057	.022	.029	-.005
20. TA pre T belief	-.013	-.009	.081	-.107*	-.002	.067	-.044	.046	.046	.004	-.089	.025	.048
21. TA post T belief	-.085	-.039	.115*	-.068	-.008	.026	-.110	.029	.049	.048	-.013	-.013	.028
22. TA delay T belief	.058	.030	.048	-.097*	.029	.048	-.044	.072	.084	-.031	-.037	.071	.035
23. TA gender	.038	-.026	-.040	.055	-.007	.004	-.020	-.006	.006	-.106*	-.057	-.020	.076
24. TA prior research	.017	.006	-.010	.159**	-.048	-.069	.060	-.029	-.085	-.065	.020	-.047	.019
25. TA prior teaching	.060	.026	-.081	-.020	.031	.005	.048	.0063	.006	-.014	-.150**	.015	.060
26. TA international	-.003	-.015	.097*	-.023	.113*	-.022	-.028	.046	.054	-.063	-.106*	.027	-.001

Note. Correlation between TA data removed due to duplicity with Table 36. TA laboratory belief excluded due to non-normality of data. * are significant at p<.05. ** are significant correlations at p<.01. Pre and post-surveys reported as % scores. Gender coded as male (0) and female (1). Ethnicity coded as Caucasian (1) and non-Caucasian (0), for example. Chemistry experience coded as regular (1), honors (2), and Advanced Placement (3). Concurrent enrollment coded as not currently enrolled (0) or concurrently enrolled (1) in General Chemistry lecture. TA prior research and teaching coded from least experience (1) to most experience (3). **Bolded** correlations appear to be related to student content scores.

Whether a student was Caucasian or non-Caucasian was not a factor related to student pre-survey scores; however, it became significantly, positively correlated to student post-survey scores (r=.148, p=.002). African-American students tended to score lower on the pre-survey that non-African-American students (r=-.127, p=.008), and this correlation persisted on the end-of-semester survey (r=-.128, p=.008). This indicated that students of all ethnicities tended to score similarly on the pre-survey except African-American students who tended to score lower. Caucasian students tended to score higher on the post-survey compared to their non-Caucasian counterparts, and African-American students continued to score lower than students of other ethnicities. There also existed a significant, weak, positive correlation between students' year in college and whether they were Caucasian (r=.148, p=.003). This suggested that students who take General Chemistry lab later in their undergraduate course-work tended to be Caucasian.

Using a conservative p-value (p<.01), none of the TA's characteristics were significantly correlated to student survey scores. This suggests differences in TAs' gender, prior experiences, beliefs, confidence, and content knowledge as measured by the quantitative instruments did not relate to student content knowledge as measured by the post-survey. Some TA characteristics were significantly correlated with student demographics (i.e., TA prior teaching experience and student year); however, these do not appear to be directly related to student content knowledge.

Regression analysis revealed student pre-survey scores (grand mean centered), student high school chemistry experience, gender, and Caucasian were significant predictors for student post-survey scores (Figure 9, Eq. 1). A students' year in college, concurrent enrollment in the General Chemistry lecture course, or other ethnicities were not significant predictors of students' post survey score. The regression equation in Figure 9 accounted for 29.9% of variance in student post-survey scores and predicted that non-Caucasian, male students in the course with an average pre-survey score (M= 52.48) and no high school chemistry would receive a 67.05% post-survey score (Eq. 2). Female, non-Caucasian students with a pre-survey would score one standard deviation below the mean who completed a regular chemistry high school would receive a post-survey score of 61.45% (Eq. 3), whereas a Caucasian, male student with a pre-survey score one standard deviation higher than the mean who took AP chemistry in high school would receive a higher post-survey score of 84.41% (Eq. 4).

$$S_{post\%} = 67.05 + .38S_{precentered} + 2.85S_{HSChem} - 3.81S_{Gender} + 4.17S_{Caucasian} \quad \text{(Eq. 1)}$$

$$S_{post\%} = 67.05 + .38(0) + 2.85(0) - 3.81(0) + 4.17(0) \qquad \text{(Eq. 2)}$$
$$S_{post\%} = 67.05$$

$$S_{post\%} = 67.05 + .38(-12.22) + 2.85(1) - 3.81(1) + 4.17(0) \qquad \text{(Eq. 3)}$$
$$S_{post\%} = 61.45$$

$$S_{post\%} = 67.05 + .38(12.22) + 2.85(3) - 3.81(0) + 4.17(1) \qquad \text{(Eq. 4)}$$
$$S_{post\%} = 84.41$$

Figure 9. Regression equation predicting student post-survey scores. All prediction variables were significant to $p<.001$. $S_{post\%}$ = student post-survey % scores. $S_{pre\%}$ = grand mean centered student pre-survey % score. S_{HSChem} = students' high school chemistry course coded as regular (1), honors (2), and AP (3). S_{gender} coded as male (0) and female (1). $S_{Ethnicity}$ coded as Caucasian (1) and non-Caucasian (0).

Disaggregation of student post-survey scores by TA helped further understand any latent relationships between student and TA not observed in the overall data set

(Table 40). Visual examination of student data by TA revealed TA participants had students with varying background experiences and demographics. For example, Stephanie's students entered into the course with the highest pre-survey scores (57.94%). Her students, on average, had the most advanced chemistry background experiences (M=2.53), were 95% female (n=20), and 62% Caucasian (n=13). Her students maintained high post-survey scores by the end of the semester (M=73.81%). Conversely, Todd's students came into the general chemistry laboratory course with the lowest average pre-survey scores (M=46.63%). Of these students, 67% were female (n=14), 76% of his students were Caucasian (n=16), and on average had taken general chemistry or honors chemistry (M=1.83). By the end of the semester his students did better on the post-survey (M=73.41) than most of the students with other TAs.

Table 40

Student Survey Scores and Demographics by TA

TA	# student	Presurvey % (SD)	HS Chem (SD)	% Female	% Caucasian	Postsurvey % (SD)
Todd	21	46.63 (12.19)	1.83 (.71)	.67	.76	73.41 (15.84)
Jeremy	33	49.24 (12.99)	2.09 (.82)	.76	.45	72.35 (11.87)
Chris	41	50.20 (12.00)	2.15 (.76)	.85	.73	73.48 (12.60)
Yvonne	33	51.01 (10.52)	2.09 (.78)	.82	.64	73.23 (13.98)
Susan	38	51.21 (11.70)	2.06 (.86)	.58	.61	72.48 (10.81)
Jack	27	51.23 (12.65)	2.24 (.78)	.78	.44	72.69 (11.10)
Ellen	31	51.75 (14.30)	2.11 (.80)	.58	.74	71.24 (12.79)
Kelly	36	52.89 (14.32)	2.18 (.76)	.67	.67	72.34 (10.92)
Stanley	34	52.94 (14.08)	2.21 (.82)	.59	.53	72.92 (12.45)
Jason	30	53.33 (11.13)	2.07 (.75)	.77	.77	73.47 (12.26)
Martha	36	54.63 (8.44)	2.16 (.77)	.67	.64	74.65(9.52)
Cameron	16	55.21 (12.12)	2.53 (.83)	.88	.50	71.88 (14.47)
Lawrence	36	57.64 (10.75)	2.37 (.73)	.61	.58	77.08 (11.38)
Stephanie	21	57.94 (10.11)	2.53 (.77)	.95	.62	73.81 (12.30)

Note. HS Chem scores are average student self-report of high school chemistry course taken; 1=regular, 2=honors; 3=AP. 1-% Caucasian=non-Caucasian.

To further understand potential differences in student content knowledge by TA, the predictor variables in Table 40 were used to calculate students' predicted post-survey scores compared to actual student post-survey scores for each TA (Table 41). Comparing TAs' beliefs to the differences between actual and predicted average post-survey scores provided additional insight into TAs' characteristics as non-significant predictors of student post-survey scores. Ellen and Lawrence were on opposite ends of the beliefs spectrum and also had larger or largest differences in predicted and actual student post-survey scores for their students. Ellen held the most traditional beliefs, and her students performed much lower on their actual post-survey than her average student characteristics predicted. Lawrence held the most reform-based beliefs, and his students performed much higher on the post-survey than his average student characteristics predicted. However, those in between did not follow general trends in how their students actually performed on the post-survey compared to how they were predicted to perform. These comparisons suggest more extreme beliefs (i.e., Ellen and Lawrence) may have related to student learning outcomes but were muted by the lack of relationship between moderate beliefs and post-survey scores.

Table 41

Average Predicted and Actual Student Post-survey Scores and TA Beliefs by Participant

	Predicted Post-survey	Actual post-survey	$\Delta_{act-pred}$	TA beliefs*
Ellen	73.54	71.24	-2.30	Traditional
Cameron	74.08	71.88	-2.20	---
Stephanie	75.57	73.81	-1.76	Transitional
Susan	73.72	72.48	-1.24	---
Kelly	73.49	72.34	-1.15	---
Stanley	73.33	72.92	-0.41	---
Jason	73.58	73.47	-0.12	---
Jack	72.36	72.69	0.33	Reform-based
Martha	74.04	74.65	0.61	Traditional
Lawrence	75.95	77.08	1.13	Reform-based
Chris	72.12	73.48	1.36	---
Yvonne	71.80	73.23	1.43	---
Jeremy	70.53	72.35	1.82	Transitional
Todd	70.44	73.41	2.97	---

Note. *Beliefs obtained from interviews only. --- indicates a non-interviewed participant.

In summary, students' demographic and prior experiences were significantly correlated to their survey scores and were the variables that predicted how well students performed on the post-survey. The 29.9% variance predicted by the regression equation suggested other variables not included in the equation may predict student post-survey scores. Organizing average student demographics and differences in actual and predicted student outcomes by TA revealed potential relationships between extreme TA beliefs and student post-survey scores. However, the lack of trends observed for TAs with more moderate beliefs may explain why quantitative TA beliefs were non-significant predictors.

TA Practice

To better understand TAs' laboratory practice, five TAs were videotaped for two lab periods during the semester. Three inductive assertions arose from the analysis of the videotaped observations: 1) General trends existed in TAs laboratory practice, 2) Students' level of engagement in scientific practices varied based on the types of TA interactions, and 3) TAs' prior experience played a role in their depth of interactions with students. These assertions aligned with social constructivism and focused on the interactions between the TA and students as well as the role prior experiences play in this meaning-making process. The assertions are organized in increasing complexity and build upon each other. First, the data revealed similarities in the TA responsibilities and interactions with students chronologically throughout the two lab periods. Second, further examination of the TA-student interaction revealed differences in the methods TAs used to engage students in scientific practices. Third, these interactions appeared to be influenced by the TAs prior and current experiences.

Assertion 1: General trends existed in TAs laboratory practice

Overall there existed commonalities in TA practice during the experimental and presentation days of the calcium supplement project. The many TA responsibilities, including safety, lab techniques, grading, and student learning were consistent across all observations for all TAs. The general order of the labs was also similar across TAs, and the TAs engaged in analogous interactions with students during the experimental and presentation days.

TA responsibilities. TAs' responsibilities identified during experimentation and presentation days were categorized as logistic, laboratory, and student learning responsibilities (Table 42). Logistical responsibilities for TAs included grading, reminding students of future assignments, getting students to complete the experiment in a timely fashion, and helping students locate materials in the lab. Laboratory responsibilities included ensuring students' safety, providing student's feedback on feasible procedures, and troubleshooting when unexpected laboratory results were observed. TAs also took on the responsibility of ensuring students learned proper lab techniques, completed appropriate calculations, used correct chemical language, had a good understanding of the chemical concepts, and made evidence-based claims. All of these different responsibilities were observed for all TAs during the experiment and/or presentation days.

Laboratory chronology. Observed TAs engaged in interactions with students during lab in similar chronological order that are detailed below with supporting evidence (Table 43)[5]. To overview the chronology, at the beginning and end of the experimental lab period TAs focused on more logistical interactions about grading, safety, and location of equipment. As groups began experimenting, TAs interacted with students on their lab procedures and techniques. As students progressed in their experiments, they started obtaining unexpected results. TAs provided students troubleshooting support; however, students became frustrated with the lack of results. In response, most TAs' interactions with students became more directive, and some TAs became frustrated when they could not explain student results as described below.

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[5] See Appendix F for details regarding the Designing a Calcium Supplement project that served as the context for the observations.

Table 42

Overview of TA Responsibilities Observed During Lab

	Responsibility	Examples	Representative Quotes
Logistic	Grading	Returning/submitting assignments, grade feedback	"Everybody did a great job [on the reports] explaining the purpose and reasons for doing the experiment. You might want to explain the chemical and mathematical equations" (Todd, Obs 2)
	Assignments due	Reminders about future assignments	"Have you set up a time to meet to do your presentations?" (Chris, Obs 1) "Take pictures, you have your group presentation next week." (Susan, Obs 1)
	Time management	Making sure students complete experiment within the allotted 3 hour time	"Come on! Come on! Come on! By 2:30 you guys should be done making your solutions." (Susan, Obs 1) "I have a quick announcement to make since we're getting close to the time. All glassware has to be back by 5, so you have 20 minutes to complete your experiment." (Todd, Obs 1)
	Materials location	Location of equipment	"The location of the droppers are usually in the A drawer" (Todd, Obs 1).
Lab	Safety	Goggles, Chemicals	"Goggles on anytime you've got the chemicals out" (Chris, Obs 1) "Keep the EBT in the hood" (Martha, Obs 1).
	Procedures	Verifying and providing feedback on procedures,	"You can do that and maybe if you do subsequent trials you can try a different size [volume of calcium] and that would help confirm your concentration" (Lawrence, Obs 1)
	Troubleshooting	Directing students when they are stuck	"If you reach what you think is the equivalence point and you don't see a color change, check the pH, and if it is too low add base" (Martha, Obs 1)
Learning	Lab techniques	Making stock solutions, pipetting, titrations, testing pH with pH paper	"It might be easier to use a watchglass or something smaller [to weigh] if you're just going to pour it into your flask' (Chris, Obs 1)
	Calculations	Concentration, % error, number of moles	"How many moles of calcium do you expect to have in your aliquot?" (Chris, Obs 1) "We calculated our error, and you can see our experimental is definitely not our theoretical" (Todd's student, Obs 2).
	Chemical language	Aliquot, titrant/analyte, equivalence point, chelation	"An aliquot means a sample or a small amount" (Chris, Obs 1). "So what does equivalence point mean?" (Martha, Obs 1).
	Concepts	Chemistry of titrations, aqueous/solutions chemistry, pH/buffers	"We got the endpoint when the solution turned blue, and the reason why it turned blue was EDTA would chelate with the calcium ions, leaving the EBT free in solution which turned the solution blue" (Martha's student, Obs 2).
	Evidence-based claims	Use of observations and chemical concepts to support claims	"You can throw the first [titration] out because you have experimental evidence for why you can throw the first one out" (Martha, Obs 1). "Since we were using a strong acid we had to add a base, NaOH, to increase the pH" (Chris's student, Obs 2)

Note. More details about TAs roles are provided in the quotes below describing the chronology of lab.

As groups started observing expected results, both students and TAs became excited. Students continued experimenting and recording their data, and TAs began reminding students about finishing in the time constraints. The end of lab was marked with TAs helping students perform calculations to answer the experiment's summary questions.

Observation of the presentation day also revealed similarities across TAs. TAs started by going over the day's agenda, and then had students present their projects. After student presentations, TAs held small group and/or whole group discussions related to experimental errors/limitations, relevance of the project, and areas of future research. The presentations provided TAs opportunities to connect chemistry concepts and applications of chemistry to the project.

Table 43

Overview of Laboratory Practice for Each Observed TA

		Chris	Martha	Lawrence	Susan	Todd
Experimental	Whole class introduction	x	x	x	x	x
	Safety, materials location	x	x		x	x
	Introductory questions	x	x	x	x	
	Lab techniques/procedures	x	x	x	x	x
	Troubleshooting/understanding	x	x	x	x	x
	Student frustration	x	x	x	x	x
	Directive help	x	x	x	x	
	TA frustration		x	x	x	
	Excitement	x	x	x	x	
	Time management		x	x	x	x
	Summary calculations and logistics	x	x	x	x	x
Presentations	Agenda	x	NA	x	x	x
	Student presentations	x	x	x	x	x
	TA clarification questions	x		x		x
	Small group discussion	x	x		NA	
	Whole class discussion	x	x	x	NA	x

Note. NA indicates TA did not record this portion of the lab period. x indicative of one or more instances of this practice during the observation.

Experimental. On the experimental day, four of the five observed TAs started the lab period by having a brief whole class lecture or overview of lab. These lectures lasted less than five minutes and included important safety, lab technique, or timing issues for the lab period. For example, before students began experimenting, Martha walked students through the general order of the lab schedule, "So today you're going to be doing the EDTA titration with the EBT indicator. So because EDTA takes a little bit of time to dissolve, make sure you start with that first, and then make the calcium supplement solution" (Martha, TA, Observation 1). Martha was directive with more students than other TAs about what students should be doing as it related to lab procedures and techniques. Lawrence was more focused on waste and safety in his pre-lab talk:

> When you weigh out either calcium or EDTA, make sure that you put solid waste in the waste container and not back in the bottle itself. Because you could easily put calcium, which is a white powder, into the EDTA container, which is also a white powder and therefore we would have to throw them out. (Lawrence, TA, Observation 1)

All TAs also handed back graded assignments and/or discuss grading as a whole group. After Martha went over the lab schedule for the day, she discussed the reports students turned in the week before, "There was significant improvement this time....That's why I'm so hard on you guys on the first reports, you're doing significantly better so good job" (Martha, TA, Observation 1). Two other TAs explicitly discussed lab reports, whereas the remaining TAs focused on handing back students' graded plans so they could execute these plans in lab.

While students set up their experiments, the TAs answered logistical questions about the location of equipment and chemicals and reminded students to wear safety goggles. For example, when a student asked Chris where the volumetric flask was located, Chris stated, "That's something you get from the stockroom because that's the specialized glassware" (Chris, TA, Observation 1). TAs also made whole group announcements about the location of equipment. Lawrence directed the students to buret stands to be used for the titration, "Everybody. The buret stands are over here" (Lawrence, Observation 1) and showed students the location of these stands in the back of the lab. Four of the five TAs reminded students to put on goggles at the beginning of the experiment and typically stated, "If glassware is out, goggles are on" (Susan, TA, Observation 1).

As students located equipment and got started with their experiments, four of the five TAs circulated around the room and asked students questions such as, "How are you guys?" (Susan, TA, Observation 1) or, "What steps are you doing right now?" (Chris, TA, Observation 1). This initiated the conversation between the TA and the students in each group. The TAs continued interacting with students, responded to questions about students' procedures, and provided suggestions for improving lab techniques. A student in Todd's section asked him how the buret stand held the buret, and Todd responded, "It locks in place, like that" (Todd, TA, Observation 1) and showed the student how to properly set up the buret in the stand. In Martha's lab, a group asked how they could get rid of an air bubble in the tip of the pipet they were using to measure out their calcium solution. Martha responded, "I think when you pull the solution up it should just move up above the line, and make sure you're holding the pipet high on the pipet so you don't stab yourself" (Martha, TA, Observation 1). Martha explained to students that the air bubble should go away once they used the pipet, and she gave them a suggestion for being safe when using the pipet.

TAs continued to monitor students' progress as they made their solutions and started their titrations. All of the TAs helped groups troubleshoot when they ran into unexpected situations and tried to engage students in understanding what was going on. One of Martha's groups determined they needed to add sodium hydroxide, NaOH, to the EBT-calcium solution in order for the titration to work, and they observed a precipitate forming that they thought was worrisome. They called Martha over to ask what they should do:

> "We added NaOH to raise the pH and now it's....will it eventually dissolve or am I wasting my time?" Oliver asks. "Does it need to dissolve?" Martha asks. "Well it's going to affect the calcium ion concentration" Oliver counters. Martha responds, "So what's going to happen when the EDTA binds with the free calcium in solution? Where will the calcium hydroxide go?" "Ah, back into solution," Oliver says with a nod. "Yeah, so it doesn't matter" Martha say. Oliver responds, "Cool." (Martha, TA, Observation 1)

Oliver originally concluded that this precipitate formation would be an issue with the titration because the number of calcium ions in solution would not be the same as when there was no precipitate in the solution. The group did not want to continue using the solution if it was not going to yield accurate results in the titration, so they asked Martha for help. Martha understood that as EDTA was added to the solution, the calcium bound to the EBT would bind with EDTA instead, and the insoluble calcium (i.e., calcium hydroxide) would dissolve to form more EBT-calcium complexes which would form more EDTA-calcium complexes. She used questions rather than answers to help students come to that conclusion. This general type of responding-to-questions-with-questions interaction was evident for all TAs and appeared to benefit the students in two ways; 1) it helped the students continue on with their procedure, and 2) it facilitated a deeper understanding of the experiment.

As students worked through their titration, many did not get the expected color change and began to get frustrated because they could not understand why their experiment was not working. During a frustrating point in lab Susan went up to a group and realized they were struggling:

> "What's wrong?" Susan asks. Sherry responds in a teary voice, "We always mess up. It's just a rough life." Susan says, "Rough life?" and focuses on another student in the group. She asks, "What are we doing?" to Joshua, who is working on the titration. Joshua says, "Trying to figure out what the issue is but we're all stuck." (Susan, TA, Observation 1)

Students in this group were clearly frustrated with the experiment to the point of tears, and Susan struggled to find a way to help support them. Other student comments included, "Chemistry hates me; all facets of it" (Chris's student, Observation 1) and, "I thought it would be easy today" (Martha's student, Observation 1). Hitting a road block in the lab was difficult for students to handle, and TAs responded to the frustration in similar ways.

While some TAs were more reactive than others, all TAs became more directive in their interactions with students to deal with student frustration. Rather than responding to student questions with questions as they all had done earlier in the lab, the TAs took on the role of explaining concepts and telling students what steps to do. A group of students in Martha's lab struggled to get red to blue color change they expected for the titration even though they were adding base to maintain the required high pH. The students had a purple color rather than pink and could not figure out how to remedy this:

> "So make sure you're keeping it at a red/pink color" Martha says. "We've been testing the pH the whole time" Judy says. Martha responds "It's still pretty purple." "It's purple and we're at 10mL which is over our equivalence point, so we're a little confused" Judy states. "Okay, so add some base and see if you can get it to go back to more of that wine color" Martha tells the group. "We can get it to go to [pink], but it keeps going back to purple" Judy counters. Martha tells them again "So I think what is happening is you're not making it basic enough. So use excess base and see if you can get the color change." The group adds three more drops of base to their calcium solution as Martha watches. Martha observes a precipitate forming and asks the students "So what does it mean if you're adding base and you're seeing a precipitate? What's still in that solution?" Sonya says "The calcium ions?" "So you're not at your equivalence point yet. So keep going" Martha states. (Martha, TA, Observation 1)

Martha took a directive approach with students to tell them they needed to continue adding base in order for their titration to work. The students were hesitant at first, insisting they had added enough base, but Martha was persistent that this was the issue. Once students added the base, Martha pointed the students to the formation of the precipitate. This helped convince the students that there was still calcium in solution that was not complexed with EDTA, indicative of an incomplete titration. Martha then directed the group to continue on with their titration given this evidence.

Three of the five TAs also became discouraged when students did not observe a color change despite the directions they had given on how to go about the titration. This frustration appeared to stem from the TAs inability to explain why the students were not getting predictable results. A group of students in Lawrence's lab did not observe a color change, even though they had added base to keep the pH high. He approached the group to help them troubleshoot:

> "So how many milliliters have you added [of EDTA] at this point? A lot?" Lawrence asks as he approaches a group of students. "A lot" Kate responds. Lawrence asks "How much [EDTA] were you expecting to add?" "About twenty-five [milliliters]" Greg states. Lawrence asks "And what's the pH right now? Add um.....bump up your pH range a good bit and see what happens." Lawrence watches as Kate adds base to the calcium solution. "Like a really good bit" he comments. Kate adds three pipets of base. "And stir it" Lawrence states. Jenny stirs. Kate continues to add more base and Jenny stirs while Lawrence and the other two group members watch. "Huh. No...." Lawrence comments when there is no color change. The students continue to add more and more base. Rachel tests the pH of the solution on pH paper, and they all observe the color. Lawrence says "I am not sure....the problem is when you're spotting on your pH paper you're getting that purple. That's the Eriochrome black T [EBT], and so you're having trouble seeing what is actually happening. So it's kind of, the thing is it might not be telling you the right pH because you've got something else reacting on there. But I mean that looks pretty darn basic....but maybe it's not." He shrugs. (Lawrence, TA, Observation 1)

Lawrence attempted to help the students get their titration to work by suggesting they continue adding more base to the calcium solution. He tried to explain the lack of color change as a result of a low pH, but this was not what was observed when the pH was tested. What he expected to see happen in response to his suggestions and what he actually saw conflicted, and he was not able to reconcile these differences. Lawrence ended up going back to the group later and suggested they try titrating a new sample rather than trying to make the other one work.

At this point in lab it was clear that both the student and TA morale was low in all of the labs; however, some students began to observe color changes in their titrations, giving the lab a renewed sense of energy. When a group got their pink to blue color change they clearly got excited, and Lawrence said, "Make sure you take a picture to remember this day" (Lawrence, TA, Observation 1). Susan observed a group getting a color change and she threw up her arms and said, "Yes! Yay! Do a happy dance" and she danced around (Susan, TA, Observation 1). When a group asked Chris if their solution looked blue, he said, "Oh yeah!" and held up the groups solution to show to the class and stated, "Dark blue." The group of students who got it to work said, "Yes. Yay!" (Chris, TA, Observation 1).

More and more groups were able to get a clear color change for the titration and began to clean up their workspace. Some groups continued to work, and the TAs reminded these students of the time limit for laboratory work. Todd reminded a group of students, "Well all glassware's supposed to be back by five o'clock" (Todd, TA, Observation 1) and Lawrence said to students, "Cool you got something. Now clean glassware and make sure you read your buret" (Lawrence, TA, Observation 1). Students who continued working but were not able to get a clear color change for the titration before the glassware was due lacked the data needed to calculate the experimental calcium concentration. These groups were worried that they would be penalized for this, and all TAs emphasized to students, "It's not dependent upon how well you do; it's did you do it and do you understand" (Chris, TA, Observation 1). Stressing learning over correctness eased students' worry and focused their attention on making sense of what they had observed.

Finally, students finished the experiment and worked on their summaries. All TAs answered logistic questions and helped students with calculations. In Martha's lab students asked, "Do we need to show the standard deviation equation?" and, "Will you sign our summary?" (Martha, TA, Observation 1). Martha also helped her students with calculating the experimental concentration of calcium from their data:

> "Can we use MV-MV to compare [EDTA and calcium concentrations], or is that only acid-base [titrations]?" Amy asked. Martha responded "As long as the moles are equivalent at the equivalence point." Amy confirms "So this is what we use?" pointing to the $M_1V_1=M_2V_2$ equation in her notebook. Martha explains "You use the moles of EDTA and the volume of...." "Right" Amy responds. "So you just divide the moles by the volume" Martha states. Amy and the two other group members work on the calculation and Martha walks away. (Martha, TA, Observation 1)

The students in this group needed clarification on how to calculate the concentration of calcium ions in solution from the titration data. Martha told them what assumptions to making (i.e., that the moles of calcium and EDTA are equivalent at the equivalence point) and what values to use to obtain the calcium ion concentration (i.e., moles of calcium and volume of calcium). This directive help was evidenced for three of the five TAs and may have been related to the time constraints of lab. While not all students were able to collect enough data to calculate a calcium ion concentration, all groups had data that they could use to present how they approached the project.

Presentations. The presentation day followed similar patterns for all observed TAs. Four of the five TAs started the presentation day reviewing the agenda for the lab period and then having students present. Students were required to email their groups presentation and a set of discussion questions to their TA 24 hours in advance, and all TAs had PowerPoint^{TM} slides organized and ready to go at the beginning of lab. The order of the presentations was pre-determined by the TAs and each group presented based on that order.

All groups included the same information in their presentation as identified in the presentation rubric for the course: experimental, results, and limitations. The organization of student presentations differed slightly. Some groups presented all experimental information first, followed by their results and error/limitations. Some groups presented their experimental and results chronologically and concluded with the errors/limitations for both days combined. And other groups presented the experimental, results, and errors/limitations for each day separately. These presentations lasted five minutes or less, and all students in each group talked during the presentation.

In between presentations three of the five TAs asked clarifying questions or prompted students to ask clarifying questions. For example, when one of Chris's groups finished presenting, Chris indicated he had a couple of questions:

> "I didn't see your actual results, what concentrations of calcium did you guys find experimentally?" Chris asks. Sally replies "We found .009 molar," and Chris asks "And what were you expecting?" ".4 molar" Sally states. Chris responds "Okay, so that was the high percent error that you had?" and Sally confirms "Yes." Chris wraps up the groups presentation by stating "Okay cool. Thank you" and the next group comes up to present. (Chris, TA, Observation 2)

Chris observed that the students reported their percent error but failed to report the actual values used to compute that error. He asked students what those values were so he was clear on what data students gathered in lab. Todd and Lawrence were the only other TAs who asked clarifying questions in between student presentations.

This process of presenting and opportunities for questions continued until all groups had presented, and the TAs then led a group discussion focused on errors/limitations, relevance, and future work related to the calcium project. Prior to coming into lab, each group submitted one question for each of these three categories.

The TAs chose the questions that were most appropriate and included them on the PowerPoint^{TM} slides to guide the class discussion. How this discussion portion was organized varied by TA. Some TAs had small group and whole group instruction whereas others only engaged students in whole group discussion. Some TAs interacted with students during the small group discussions whereas others did not. The two classroom examples below illustrate these differences.

Classroom Example 1

Chris had students get into small groups of students from different experimental groups to have discussions on each topic before discussing the topic as a whole class. The following student-created limitations/errors questions were posted on the PowerPoint^{TM} for discussion: 1) Why did some titrations start with a vibrant red color while others were more purple? and 2) Why did it take a varying amount of acid and base per group in order to reach the desired pH if everyone used the same amount of calcium?, and 3) What is a more accurate way of determining the equivalence point in a titration? Chris rotated around to each group during this time, and he listened and asked questions to facilitate student discussions:

> “What’d you guys come up with?” Chris asks as he approaches a group. Kyle says “We’re on number three right now.” “Alright” Chris probes further, “Any ideas on how we can improve the titration?” Kyle responds “I feel like there is a piece of technology out there...” “There are a couple, yeah. Another group brought up a pH meter, so that would give you continuous monitoring. How would that help the titration?” Chris asks. Kyle responds “It would tell you when it’s neutral.” Chris replies “It would tell you when it’s neutral, but how would it help with, maybe, the first question? About your starting color?” “It would tell us if it’s acidic or basic” Kyle says. Chris responds “Right, so you need to start pretty basic, right? So if you had a pH probe throughout the entire titration....” “You’d know where you’re going, you get your cool little graph” Kyle finishes. “Yeah, a titration curve” Chris confirms. (Chris, TA, Observation 2)

Chris joined in the group's conversation by first asking the students what they were discussing. He shared ideas from other groups to help facilitate a discussion about the use of pH probes instead of pH paper. When Kyle did not illustrate a solid understanding of how the pH probe could be used in the titration, Chris made connections to a previous discussion question to prompt a different response. This approach appeared to help Kyle better understand how a pH probe could be used and what it would produce during the titration.

After interacting with students during small group discussions, Chris brought all of the groups together to discuss each topic. Chris started the errors/limitations whole group discussion by asking for a student to share what they discussed in their group about the first question:

> Chris calls on Carly to answer the first question. She states "They started at different colors because of the varying pH. If it was more basic it would be more red, and if it was more acidic it would be more purple." "Right" Chris confirms. "Does anyone know what the target pH range for EBT is? Where you want it to be for an EBT titration?" Chris asks. "Is it 10?" Jackie asks. Chris verifies her answer "Yeah. Anywhere from 8 to 11 is a good range for this indicator. I think a couple of you kind of added base until it turned red. Did anyone actually monitor their pH in the beginning or throughout the titration to make sure you were in that range?" No students respond. "So that may have been a way to improve the titration to make sure you guys got successful endpoints" Chris explains. He then moves on to the second question. (Chris, TA, Observation 2).

During the whole group discussion Chris made sure students understood what different EBT colors meant in terms of pH as well as what the appropriate pH range was for an EBT titration to be successful. While he did not address everything that he discussed in the small groups, he made larger connections across discussion questions and compared what the students did during the experiment to what they could have done to confirm the pH range. This process of small group-whole group discussion repeated until they discussed all three topics. Todd used a different approach than Chris and went through each question as a whole group, as illustrated by the classroom example below.

Classroom Example 2

After students presented, Todd posted the first two student-created discussion questions: 1) Why was the EBT indicator used? and 2) What factors affect the color of EBT? Todd facilitated a whole class discussion and let students respond to the two questions:

> Everly raises her hand to respond to the first question "When the EDTA is attached to the calcium ions you can't see it, so the EBT indicator is necessary to actually see what's going on." Rachel chimes in to answer the second question "So the point of the specific EBT indicator was that it bound to the metal ions. And so the EBT indicator turned red when it was in the presence of metal ions like calcium and it was blue when we finished titrating it. So the factors that affect the color would be the metal ions and the pH. So it works best when you have a pH is 10 and then gauge its color by how much EDTA you use to get the calcium ions down." Walter responds "She said most of what I was going to say. Also, one of the things that changed it was since EDTA was slightly acidic, so what we did is we added NaOH to make sure they were basic, and we had to make the solution really obnoxiously basic." (Todd, TA, Observation 2)

During the whole class discussion students illustrated their understanding of what EBT does and how pH affected the titration. Todd allowed students to talk and respond to each other's answers rather explaining the chemical concepts to the students. Later in the whole class discussion Todd took a more active role to help students gain an understanding of how metal ions other than calcium may have affected the titration.

Regardless of the methods used to facilitate the discussion portion following presentations, it was clear these discussions were fruitful and provided a venue for TAs to help students make connections between concepts and for students to express their understanding of the project.

Assertion 2: Students' level of engagement in scientific practices varied based upon the types of TA interactions.

There existed evidence that students engaged in similar scientific practices during the experimental and presentation days of the calcium supplement project. These practices include carrying out investigations, analyzing and interpreting data, using mathematical thinking, constructing explanations, communicating information, and evaluating information. Some practices were evidenced specifically during experimentation or presentations, and the level of engagement of students in different scientific practices varied based upon the types of interactions the TAs used (Table 44). Four different types of interactions inductively arose from TAs' practice that ranged from more to less teacher-centered: directive, didactic, facilitative, and student-driven. A *directive* approach was the most teacher-centered and involved the TA explaining concepts or telling students what to do with little to no involvement of the student. *Didactic* approaches were characterized by TA-directed questions requiring one-word student responses (i.e., close-ended questions) with some interaction of students with the TA. *Facilitative* interactions included the use of varied types of questions, both close-ended and open-ended, to promote students engagement that reflected their understanding of an idea. *Student-driven* was the most student-centered interaction in which the TA listened to students, allowed them to interact with each other to construct ideas, and used students' responses to guide the discussion. TAs' interactions will be discussed for each practice in the sections below.

Carrying out investigations. The five observed TAs used different types of interactions to engage students as they carried out the calcium supplement experiment. These interactions appeared to promote or inhibit students' ability to justify their own procedures. Susan, Lawrence, and Martha utilized strategies that limited students' engagement in carrying out investigations, whereas Chris and Todd employed approaches that promoted active participation of students in understanding the purpose of the steps of their experiment. Vignettes of Susan and Chris's interactions illustrate these differences.

Table 44

TAs Interactions for Different Scientific Practices

	Carrying out investigations	Mathematical thinking/ Analyzing Data		Constructing explanations		Communicate information*	Evaluating information**
	Experiment	Experiment	Presentation	Experiment	Presentation	Presentation	Presentation
Susan	Didactic	Directive	N/A	Absent	N/A	N/A	N/A
Lawrence	Didactic, directive	Directive	Didactic	Absent	Didactic, directive	Infrequent/ incomplete	Absent
Martha	Directive	Student-driven	Facilitative	Facilitative, directive	Facilitative, directive	Frequent/ accurate	Facilitative
Chris	Facilitative, directive	Student-driven	Absent	Absent	Directive	Frequent/ inaccurate	Absent
Todd	Student-driven, facilitative	Student-driven	Facilitative	Student-driven, facilitative	Student-driven	Frequent/ incomplete	Student-driven, facilitative

Note. * = the construction of explanations was not directly observed but was inferred from the effectiveness and accuracy of students' explanations of chemical concepts during presentations. ** = includes interactions beyond those observed during the required limitations/errors discussions

Classroom Example 3

During the calcium experiment, Susan returned to a group of students to follow up on a previous conversation. Rather than using the entire volumetric flask full of calcium solution for one titration, Susan prompted the group to think about using just a portion of their calcium solution. She came back to check on what approach they had come up with to obtain this portion from the larger solution:

> "Our theory is we could take this, put it into here" Keith points to a piece of glassware, "and divide it by three" he says. "You could..." Susan responds. "But you want to know an easier way?" Susan asks. Keith states "Yes, please." Susan points to the 10 mL volumetric pipet "Think of this one. What is this one again?" "That's a volumetric pipet" Keith says. "How many milliliters is it?" Susan asks. "10.00" Keith responds. "So, what did you find out about this in project 1? Was it to contain or to deliver?" Susan asks. "To deliver" Keith says. Susan confirms "To deliver. So, how would you make your little solution? Do you know what they're called?" Wilma chimes in "What?" Susan asks again "The little solutions that you're making?" Keith unsurely answers "Samples?" "Eh" Susan responds. "It starts with an A." The students do not respond, so Susan says "We can play a fun game. I love this game." She gets a piece of paper and writes the letter A. "Start saying words" Susan prompts the students. She wants them to guess the word for making little solutions. "Asinine" Larry says. "Antelope" Wilma says. "No" Susan giggles, and she adds the second letter L. No one responds and Susan says "You have to say a word." "Alum....Alum-in-ium?" Keith says and giggles. "Oh, you're close" Susan responds and adds I. Wilma says "Uhhhh." "Uhhhh, a-liquidation?" Keith says. Susan finishes writing out the word and says "It's an aliquot." Keith says "I've never heard that word" as Susan walks away to another group. (Susan, TA, Observation 1)

The initial goal of the interaction was to have the group explain their method for obtaining just a portion of their calcium solution; however, Susan did not feel their method was appropriate and told them to use the volumetric pipet. The conversation then shifted to knowing the chemical word used to describe a portion of a solution, called an 'aliquot'. While the game appeared to be enjoyable, Susan's use of a game to get students to say the word aliquot resulted in students throwing out unrelated words without thinking. This tactic may have allowed students to be able to define the word aliquot; however, there were no opportunities for students to explain aliquot in their own words, apply this word to what they were doing, discuss their approach with each other, or justify why using an aliquot was important for a titration.

Lawrence used a similar approach to Susan that focused on the use of close-ended questions to engage students in discussions, whereas Martha was more directive in her approach to facilitating students' carrying out investigations. For example, when a student commented on EDTA taking a long time to dissolve Martha responded, "That's why I told you to do it first" (Martha, TA, Observation 1). She clearly told students the order to approach the experiment. The didactic and directive approaches used by TAs to interact with students about procedures and experimentation appeared to limit students engagement in the process.

Classroom Example 4

Chris used a different approach to help students understand the importance of using an aliquot in their titration. He initiated the conversation with a group who appeared to be focused on using a beaker to make one of their solutions:

> "So I heard you guys talking about what glassware to use. What are you thinking is the most appropriate?" Chris asks. "For what?" Henry asks. Gabby chimes in "We want it to be this at the end" she points to a beaker, "To do the actual titration. We're debating what we want to make [the calcium supplement solution] in." Henry asks about the beaker, "Can we do it in that?" Chris responds "Ah, look at the first step of titration" Chris points to the displayed PowerPoint, "Use an aliquot of your supplement, not the whole thing." Henry asks "What is an aliquot? It's a fun word." "It is" Chris replies, "An aliquot means a sample, or a small amount. So when you titrate....basically what I'm saying is don't use your entire calcium supplement to titrate." "Right" Henry says. "Can you think of any reason why that might be a good idea?" Chris asks the group. Henry responds "We'd need a lot of the indicator, the stuff in the top,"

> pointing to the buret. “Right” Chris confirms. “You’d need a lot of EDTA to cancel it out. Right. Any other reasons?” Chris asks. “Ummm” Henry says. “Is it going to go perfectly the first time?” asks Chris. “No. So you’re going to have to do multiple trials” Henry states. “Exactly. So you don’t want to remake your supplement every time if it goes wrong” Chris elaborates. “How many trials should we be trying to do? Three?” Henry asks. “That’s up to you guys” Chris tells the group. “So the trials, that’ll depend on if it works. That’ll indicate that you need more trials. Or maybe you’re experimental calcium is way off from your theoretical, then you may want to do a second trial. But that’ll be up to you guys. So, getting back around to it, is this what you want to make your supplement in?” Chris asks as he points to a beaker. “No” Henry says. “Right. You probably want to make it in something else and pour a little bit in” Chris says. (Chris, TA, Observation 1)

Chris initiated the conversation with students by asking them to justify what glassware was most appropriate to be making their calcium solution. This question prompted both Henry and Gabby to enter into the conversation, and Chris guided the discussion through a mix of open-ended and close-ended questions to promote student responses. Chris also used some of his own knowledge, such as what an aliquot was and the reasons multiple trials might be necessary; however, he encouraged the group to make their own decisions about their procedure. In his approach to interacting with students, Chris found it more important to focus on students providing explanations and making their own educated choices rather than defining words such as ‘aliquot’. This appeared to facilitate students understanding of the overall goal Chris had; that the beaker was more appropriate for completing one titration trial rather than making the solution.

Todd also used facilitative interactions, similar to those observed in Chris’s vignette; however, Todd took on more of a student-driven role than Chris to promote students’ engagement in carrying out investigations. For example, when a student said, “How do we figure [the calcium ion concentration] out with a titration? Because I don’t exactly know how a titration works" Todd allowed other students in the group to explain the process of titration, "So we're using the concentration of EDTA, and we use that to figure out the concentration of our solution. But we can't see it with the EDTA, so that's why we have to put in the indicator" (Todd, TA, Observation 1). Todd provided students opportunities to interact with each other to help explain the purpose of the titration and the purpose of the indicator in the titration. Thus, both facilitative and student-driven approaches appeared to enhance students' understanding of this scientific practice.

Using mathematical thinking & analyzing data. The scientific practices of mathematical thinking and analysis of data were both observed in TAs' practice. TAs engaged students in mathematical thinking as a form of data analysis during the experimentation, whereas a more qualitative and systematic approach to facilitating students' engagement in data analysis occurred during presentations. Differences in TAs' level of involvement when interacting with students regarding mathematical thinking and data analysis appeared in their practice.

Mathematical thinking. During experimenting, Lawrence and Susan took a much more directive and active approach to interacting with students, which limited students' ability to use their own mathematical thinking. Todd, Martha, and Chris took on more of a student-driven role when interacting with students about their calculations, which allowed students to work their way through problems on their own. Below are examples of Lawrence and Todd helping students understand how to determine the molarity of

EDTA needed for their titration. These examples illustrate differences in the interactions related to students' engagement in mathematical thinking.

Classroom Example 5

At the beginning of the experimental day, Lawrence worked with a group on how they were going to make their EDTA solution. The group struggled to understand how to determine the concentration of EDTA needed. Lawrence asked the students to think about the purpose of EDTA and what they were doing:

> "This is a titration, right," Lawrence says. "So in order to do the titration, you need to know the concentration of what you're titrating with, the EDTA, so you can find out the concentration of...." Lawrence waits for Linda or Roger to respond. "Ummm, of our solution" Linda says. "Right" Lawrence confirms and continues, "Because you have in your plan that the EDTA and the calcium bind in a one-to-one ratio, so that's how it's going to work. So, in order to do that, you do have to know the concentration of your EDTA solution. Which is why you have to make a solution and go from there first."
>
> Linda asks "So does it matter if it's a particular concentration?" "It matters in the sense that....so imagine you have a very concentration solution of calcium ions and you used a very dilute solution of EDTA. Why would that be a problem?" Lawrence asks. Linda states "It wouldn't react." Lawrence corrects her "Well it would react eventually, but..." Linda interjects "there would still be...." Lawrence interrupts, "Well think about it. So you have a lot of calcium ions in your beaker and not many ions in your EDTA solution, how much of that EDTA solution are you going to have to use?" "A lot" Linda says. Lawrence continues "A lot. So you don't want the concentration of your EDTA to be very different than your calcium solution. It doesn't mean it has to be the same. So you told me your calcium solution was going to be roughly what concentration?" ".164 molar" Linda states. "So .164. So the closest even molarity of EDTA that you could make would be what?" Lawrence asks. ".15?" Linda asks. ".15." Lawrence repeats. "Or you could even do .1, and that would be close enough. So just calculate how much EDTA you'd need to make that solution. Now in order to do that you need to know what glassware you want to be using. So you have what size volumetric flask?" Roger says "100 milliliters." "You have 100 milliliters. So you have to calculate how much EDTA you need to make .1 molar in 100 milliliters. So I'll come back around. Work on that, and we'll get you started" Lawrence concludes and walks away. (Lawrence, TA, Observation 2)

Lawrence took an active approach when interacting with students to help them understand the concentration of EDTA needed for their titration. He used fill-in-the blank type questions to engage students in the conversation, and he provided the explanations with little input from either Linda or Roger. This teacher-intensive interaction limited opportunities for Roger or Linda to have mathematical-based interactions with Lawrence or each other. As a result, this group of students knew they needed to make a solution of EDTA similar to their calcium supplement concentration, and that it should be made in a 100mL volumetric flask. Lawrence provided the explanation for why these two concentrations should be similar, but there was no evidence the students had a mathematical understanding of the titration.

This approach was also observed in Susan's interactions with students. For example, when Susan interacted with a group about their calculations for the EDTA concentration she asked, "Who did your math?" The student responded, "You did it. I know for a fact that you said 'you're good to go" (Susan, TA, Observation 1). This student perceived that Susan did all of their calculations and suggested that students in Susan's section had limited input in their mathematical thinking.

Todd used a different level of involvement to interact with students about mathematical thinking during lab. As illustrated in the classroom example below, his student-directed approach to interacting with students provided more opportunities for students to engage in mathematical thinking.

Classroom Example 6

Todd returned to a group who was struggling to get an endpoint in their titration to follow up:

> "Have you gotten to an endpoint?" Todd asks. "Uh, no. We used all of [EDTA in the buret]. We might add more, or we were thinking we could dilute our calcium solution and increase the molarity of [EDTA] solution so they were closer. So we just kind of figured out the point of a titration. So we're a little bit less confused. But it still doesn't answer the question I've been having the whole time, and you've been trying to answer it but I don't know why I can't wrap my mind around it. Why do the molarities need to be similar, do they need to be similar at all? Between the titrant and the calcium? Do they need to be the same? I know they're the same molar ratio. But if they're different volumes then they're molarities would not have to be the same amount of moles" Paul says.
>
> Todd responds "So let's take a situation like this. You're trying to figure out what the calcium concentration is. So let's say you don't know what it is but say someone knows what it is. And they know it's one molar. And then you have a one molar EDTA solution. So the calcium is one molar and the EDTA is one molar. You know that there is 10 milliliters of one molar calcium here, and you have one molar EDTA. How many milliliters of the EDTA would you expect to completely react with the calcium?" Paul answers "Uhhh. One milliliter? Because it's one to one. Or is it ten? It's ten?" Todd confirms "Yeah. Okay same situation. Ten milliliters, one molar calcium here. Then you have a .5 molar EDTA. How many milliliters of the EDTA would you need to get to the endpoint?" Paul immediately responds "Twenty. So then..." Sharon interjects "So having them similar just means you don't have to add as much." "Correct" Todd confirms. "Alright. Alright. Cool" Paul says. Todd elaborates "So from the amount of calcium that you had in your supplement, can you estimate what the molarity of your supplement should be?" Sharon says "Yeah, but when we're using the volume...I think I made a mistake. Are we using the 5 milliliters amount that we're using here? Or the total volume of solution in general?" Todd responds with a question "How many grams of the calcium carbonate did you add to that?" "2.992" Sharon answers. "And what was the total volume of liquid?" Todd asks. "60.3 milliliters" Sharon says. Todd asks "So do you know what the molarity of that is?" "Yes. I just calculated that" Sharon responds. Todd continues asking questions "So do you expect the molarity of the 5 milliliters that you have here to be similar to the one in the bulk?" "I would think not, because you can't use the 60.3 it's only 5 milliliters" Sharon states." Theresa chimes in "But we don't have all the moles." "Shouldn't it be the same?" Paul says. "It should be the same" Theresa states. Paul explains to Sharon "You just took it to a smaller container." "Okay. Because I'm sitting here thinking I did it wrong." Sharon responds. Todd brings them back to the titration situation "So this is the

> molarity of the calcium that you predict it should be. Do you know the molarity of your EDTA? Roughly?" Paul responds ".02." "So in 5 milliliters of about .5, and this is about .02. So through estimation, about how many milliliters would you suspect to...." "500" Sharon responds. "A lot" Paul responds. They all giggle. "Okay, let's change that concentration and maybe dilute [calcium] a little bit" Paul states to his group. "Let's just go with EDTA first" Theresa suggests. "If we can just get that to .1 then that would be much better. The concentration was twenty times different, so that's going to take a lot. Okay." Paul says. The group gets to work and Todd leaves. (Todd, TA, Observation 2)

Todd's limited verbal interaction with students promoted a student-driven conversation and helped their understanding of the relationship between concentrations of analyte (i.e., calcium supplement) and titrant (i.e., EDTA). He allowed students to talk out their ideas with him, which helped Todd gauge students' problems. When Todd initially asked if they had reached an endpoint, Paul gave a detailed explanation of what the group understood and where they were still struggling. After using the scenario, Todd realized Paul did not quite understand the relationship, so he used another scenario to assess Paul's understanding.

Todd also allowed students to talk with each other, which helped them realize further ideas they did not understand and allowed them to work through them as a group. Later in the conversation Paul, Sharon, and Theresa talked with each other about the difference in the molarity of the stock solution and the aliquot. Together they came to the conclusion that the molarity of the stock and their aliquot were the same. Todd's limited verbal interaction provided students' opportunities to be active participants in their own mathematical thinking.

Martha and Chris also limited their interactions with students regarding mathematical thinking to promote students' active engagement in understanding calculations related to the EDTA titration. For example, students in Martha's section struggled to understand the equivalence point and asked about calculating the concentration of calcium from the concentration of EDTA. Rather than telling students how to do the concentration calculations for the titration Martha said, "I want you to look up what the equivalence point means in a titration" (Martha, TA Observation 1). Martha, Chris, and Todd used this approach and suggested what students could do to gain a better understanding rather than facilitating or directing students through the mathematical calculations. These passive methods, as evidenced in Todd's classroom example above, helped students learn mathematical thinking.

Whole class data analysis. Only three TAs, Lawrence, Martha, and Todd, were observed engaging students in the analysis and interpretation of data during presentation discussions, which took the form of analyzing data across groups. Differences existed between Lawrence's interactions with students compared to Martha and Todd's interactions with students during data analysis. These differences in the TAs' approach elicited different responses from students that illustrated their varied abilities to apply this scientific practice to novel situations.

For example, after presentations Lawrence began a whole-group discussion on data analysis by showing students their experimental results across groups. He asked students to come up with explanations for the differences:

> Peter says "We all chose different concentrations. For example, we just randomly decided, oh, let's make our EDTA .1 molar. So another group could have chosen something else." "Who did .1 molar EDTA?" Lawrence asks. Two groups raise their hands. "Who did .2 molar?" One group raises their hands. "Who of you who did .1, how many milliliters did it take to titrate?" "40 something" Peter responds. "And it took you about 40 mils as well?" Lawrence asks the second

> group. “Both of you used a 10 mil sample?” Lawrence confirms with both groups and continues, “So if you compare those, do you think that helps confirm the trials you got?” Peter responds “Either we’re both doing it right or we’re both doing it wrong.” Lawrence chuckles “That’s the other possibility.” (Lawrence, TA, Observation 2)

Lawrence went on to have students discuss reasons why the group who used 0.2 molar EDTA had a slightly lower calcium concentration, but no consensus was reached. By presenting student data across the entire section, Lawrence used a didactic approach to help students to analyze similarities and differences across groups and come up with possible explanations for these differences. Initially, Peter thought the variety of results was due to the arbitrary choice of EDTA concentrations, and Lawrence used close-ended questions to get students to think about similarities across groups and what this might mean for the experiment overall. Peter’s comment, “either we’re both doing it right or we’re both doing it wrong” illustrated his ability to think about alternate explanations for the similarity in the results. Lawrence ended the conversation with a lack of consensus and did not force students’ data into a direct relationship; however, he did not explicitly discuss or promote divergent thinking during this discussion.

Martha and Todd used a facilitative approach to engage students in data analysis across groups. For example, Martha started the whole group discussion by comparing and contrasting experiments:

> “Who are the groups that had double the volume?” Martha asks. Three groups raise their hands. “Did any of you guys come up with any ideas?” Martha asks. Irma responds “I calculated to see how much it would take to titrate 20.8 milliliters of the calcium, and I got really close to the volume we got to titrate the 10 milliliters. Maybe we had half molarity” Martha replies “Yeah. Maybe. Did any of you guys go back through your calculations to make sure it wasn’t the stoichiometry?” Students nod. “Yea?” Martha confirms. “Did you find the error in there?” Martha asks and students shake their heads no. “Okay, I’m just

> curious" Martha responds. Parker asks "Is it possible that, because we were all drowning in a base to make sure the pH was high enough, maybe us three groups just drowned it in way too much base relative to other groups and that affected it." Martha replies "Yup. So a lot of times in science, when you learn the most is when something happens when you don't expect it to. It'd be interesting to figure out what happened." (Martha, TA, Observation 2)

Martha initiated the conversation by asking which groups had similar results. This prompted Irma to explain her data and describe discrepancies in her results, illustrating her ability to analyze her groups' data. Parker took it a step further and considered what common titrations conditions existed for the groups who obtained concentrations double the expected concentration, demonstrating his ability to synthesize new ideas by analyzing data across groups. Martha also took the opportunity to explicitly discuss the nature of science to explain the lack of consensus between groups.

In summary, Martha, Todd, and Lawrence incorporated opportunities for students to further engage in the analysis of data across groups. Each TA interacted with students differently during the discussion, which promoted different responses from students. Lawrence used a didactic approach, which allowed for one student to provide alternate explanations of the results. Martha and Todd utilized a more facilitative approach to data analysis that resulted in students making evidenced-based claims, providing alternate explanations for results, and synthesizing new ideas. Thus, more facilitative interactions promoted varied responses in students; however, this claim was limited by the small number of TAs observed interacting with students in this type of data analysis discussion.

Constructing explanations. TAs also used different approaches at different times to engage students in constructing chemical explanations for what they observed in the experiment. Martha and Todd were the only TAs who emphasized chemical explanations during the experimental day, whereas the all TAs used the presentation discussion to promote students' construction of explanations. Regardless of when the TA emphasized chemical concepts, the methods employed to interact with students differed by TA. Chris used directive methods to tell students about the concepts, Lawrence used directive and didactic approaches to teach students concepts, Martha utilized facilitative and directive approaches in helping students construct explanations, and Todd took on a student-driven role as students constructed concepts[6].

Experiment-based explanations. Only Martha and Todd emphasized student participation in constructing explanations during the experimentation day. Both TAs employed a facilitative approach to help students actively construct chemical explanations for the EDTA titration. Martha tended to provide direct responses and Todd tended to allow other students to provide those responses.

Classroom Example 7

During the experimental day Martha interacted with students about the pH of the aliquot. Martha checked in on a group of students on their solution making:

> "Did you guys make your EDTA solution? And you've made your calcium yeah?" Martha asks. Victoria says "Yeah. And [the calcium supplement] has to equal 10, right? The pH?" Martha responds, "What's going to happen when you put base in there?" "The pH is going to go up" Victoria says. "Yeah. The pH will go up, but will you get any chemical reaction?" Martha asks. Victoria replies "Well I thought the EDTA, it has to be at pH of 10 because that's where it's going to actually show. Indicate." "Right. That's true" Martha confirms. She

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[6] Susan did not engage students in chemical explanations during experimentation and was not observed during her calcium presentation. Therefore, no claims can be made about her students' ability to construct explanations.

> continues, “But do you want to change the pH of your entire stock solution?” “No. We just want to change however much we need.” Victoria says. “So the 10 mil aliquots.” Martha states. Victoria replies “Oh. So we should measure out 10 milliliters of this first, and then get it to a pH of 10.” “Right. Because if you add sodium hydroxide to this, for example, I think that’s what you guys planned to use, what’s going to happen to the solution? What’s going to happen to the calcium in the solution?” Martha asks. “Mmmmm” both Victoria and Monica mumble. Martha waits. Monica replies “The calcium is going to change, the molecule that it’s in is going to change. Because it’s going to be a different reaction.” Martha confirms “Right. So what is it going to change to?” Victoria and Monica take a second before replying “With the OH?” Monica says. “Mmmhmm” Martha confirms. “It’s going to be calcium hydroxide, which isn’t soluble and it’s not good for you either” Victoria adds. “Ohh” Monica says. “It would be different depending on what we took out” Victoria says. “Right” Martha confirms. “So that’s why you want to wait” Martha says. Monica recaps “So get it alone and then get it to a pH of 10, and then we can do our titration.” “Right” Martha confirms. “Okay, thank you” Monica says. Martha moves on to another group. (Martha, TA, Observation 2)

Martha initiated the conversation with students by checking on their progress. Victoria posed a question to Martha, which prompted the discussion about whether to change the pH of the stock solution or the aliquot. Martha used a mix of close-ended and open-ended questions to facilitate students’ explanation of the chemical reactions that occur when sodium hydroxide is added to a solution containing calcium. Martha also used some explanation and directive responses to students to move along the conversation. The conversation concluded when Martha felt the students had an understanding of the concept of solubility.

Presentation-based explanations. All four TAs observed during the presentations emphasized the construction of explanations about the chemical processes that occurred during the titration. Each TA used a different approach to engage students in the process of explanation. Chris was the most teacher-centered with a directive approach to instructing students about the concepts, whereas Todd was the most student-centered and used a student-driven role to facilitate student-student interactions to construct explanations.

Classroom Example 8

At the end of the presentation discussion, Chris took a directive approach to constructing explanations:

> Chris has a picture of the EDTA structure on the PowerPoint and explains "So [EDTA] has a carbonyl bonded to an -OH. So in this situation [of low pH] the free oxygens are bound to an H, and they can't bind our calcium. So this is why it's really important to have a high pH. Because what happens at a high pH?" Chris asks. A student responds and Chris confirms, "Right. You'll break that -OH bond as that hydrogen gets pulled off to form that hydroxyl group, because you've got all that free -OH minus floating around. So that will free up your oxygens to bind to the calcium. And it's slightly stabilized by the lone pairs of the nitrogen. It's not a true bond, but they do stabilize. And you see that carboxylic acid groups kind of flip around to present the oxygens, and it sequesters the calcium into the middle of the molecule. And that's why this is such as stable final complex when it's bound to calcium. Any questions?" (Chris, TA, Observation 2)

Chris explained to students about the structure and function of EDTA and why the high pH was important. Lawrence utilized a similar approach with more use of close-ended questions; however, the result was the same. Both TAs used a directive method of instruction that did not allow students to construct their own explanations.

Classroom Example 9

Conversely, in part of Todd's whole group discussion, he focused students on providing chemical explanations for their observations. He started the conversation by asking:

> "So if you start with a red color and all of the calcium is bound to the EDTA, why wouldn't have there been a blue color change?" Olivia responds "I know for us during our first titration we didn't make our solution more basic because we used a weak acid and thought it wasn't that acidic and we didn't think we needed to

> make it more basic. Additionally, we didn't consider how acidic the EDTA was. And so when we titrated it, we titrated between 100 and 150 milliliters of EDTA and it didn't turn. It wasn't basic enough for EBT to change color. So because we didn't make our solution in a way that EBT would have been affected, there was no color change because we didn't have the right mixture of base and acid to get the pH." Todd calls on Gillian, "I know with the addition of potassium hydroxide, EDTA will find potassium as well as calcium, so if you had potassium ions in solution the EDTA and EBT will react with the potassium ions and that could have affected your concentration." (Todd, TA, Observation 2)

Todd posed a hypothetical situation to his students that prompted their thinking about reasons why there may not have been an observed color change when there should have been. Olivia used her experimental evidence to provide an explanation for the lack of color change. Gillian provided an alternate explanation based upon outside research she performed. Both of these explanations illustrated students' ability to provide conceptually accurate explanations for a phenomenon.

In summary, only two TAs, Martha and Todd, engaged students in constructing explanations during the experimentation day. They both used similar approaches that promoted students' active involvement in the process of explanation. All TAs provided opportunities for construction of explanations following student presentations; however, the amount of student talk differed greatly between the directive approaches and the facilitative/student-driven approaches used by TAs. Lawrence and Chris chose more directive approaches to help students learn about the chemical concepts of the titration. This resulted in students' passive participation in the construction of knowledge. Martha and Todd chose facilitative and student-driven methods, respectively, to help students learn the concepts. This promoted students' active engagement in the construction of knowledge.

Communicating information. The presentations allowed for students to demonstrate their skills in communicating information. Students had similar abilities communicating their procedures and results, whereas differences existed in their frequency and ability to explain communicate their understanding of chemical concepts[7]. Differences in the accuracy and frequency of students' communication of their conceptual understanding related to differences in TAs' emphasis in lab. TAs who did not focus on chemical explanations during experimentation (i.e., Lawrence and Chris) had students who infrequently or inaccurately communicated chemical concepts. TAs who emphasized students' active construction of explanations during experimentation (i.e., Martha and Todd) had students who communicated these concepts most frequently and accurately/completely during presentations.

For example, in Chris's section, Gary presented his group's errors, including an error related to addition of sodium hydroxide to their aliquot:

> When we added the EBT to the calcium carbonate solution, it was a purple color to begin with so we needed to add NaOH to make it more into that deep red color. For that we didn't actually count how many drops we put of NaOH into the solution so that would affect our volume in the end. (Chris, TA, Observation 2)

The group perceived the volume of sodium hydroxide added to their aliquot as important in calculating the experimental concentration of calcium from the titration. This was an inaccurate understanding of how a titration works, as the endpoint of a titration is dependent upon the moles of analyte, not the concentration (which is volume dependent).

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[7] It is acknowledged that these differences may illustrate limited ability to communicate or limited understanding of the concepts. The observational data gathered was not sufficient to differentiate the two.

In Lawrence's section, most of the groups did not discuss the chemical processes occurring during the titration in their presentation, and those that did appeared to have a limited understanding of this process. Hank presented his groups day 2 experimental procedure:

> "We added a drop of EBT indicator. If there were any calcium ions present, then the solution would turn red from the EBT indicator." Hank goes on to explain how they went about the titration process with EDTA and explains what occurred at the endpoint. He states "Once we reached the endpoint, the solution turned blue, indicating that all the calcium ions formed with the...uh...calcium ions. Also EDTA is a hexaprotic acid, so when it binds with the calcium ions then four hydrogens get released into the solution, so we have to add a little bit of 1 molar sodium hydroxide to keep it in the pH range. (Lawrence, TA, Observation 2)

Hank appeared to understand the reason for the red color observed in solution but was unable to describe the endpoint process. He also attempted to describe the process by which EDTA binds with calcium; however, he illustrated a limited understanding of the process. Rather than the four hydrogens being released because the calcium binds, the four hydrogens are released due to the basic conditions, then the calcium binds.

In Todd's section, Kristen explained the chemical reasons for the different colors observed in the titration:

> And our titration was successful in that the color change was evident. It was a reddish to begin with, which shows the calcium ions are still present, and then it turned to purple, which shows that the EDTA caused the calcium to be unreacted. (Todd, TA, Observation 2)

Kristen understood the color change observed during the titration was due to a reaction occurring with the calcium ions that involved EDTA. However, she was not prompted by Todd to elaborate on the involvement of EBT in the color change and did not describe the relationship between EDTA and calcium in accurate chemical terms.

During a presentation in Martha's section, Kim also explained the chemical processes of the observed color change of the endpoint:

> We got the endpoint when the solution turned blue. Of course this is after continually adding sodium hydroxide. The reason why it turned blue was because EDTA chelates with the calcium ions, leaving the EBT free in the solution, which turned the solution blue. (Martha, TA, Observation 2)

Kim explained the role EDTA, calcium, and EBT played in the endpoint color change her group observed in their experiment. Kim was able to describe the processes occurring at the endpoint and used appropriate chemical language. However, she did not elaborate on what chelation meant or the chemical reactions occurring in solution when different substances were added.

There existed clear differences in Chris, Todd, Lawrence, and Martha's students' chemical explanations of an EDTA/EBT titration[8]. Martha's student had the most complete explanation of the endpoint process as she explained the relationship between calcium, EDTA, and EBT. She also used 'chelate' to describe the binding of EDTA and calcium, an accurate description of the chemical process occurring at the endpoint. No clear misconceptions were stated by Martha's student, but she did not elaborate on the chemical reactions. Todd's students also had similar descriptions as Lawrence's student's, suggesting both groups of students had some understanding of the chemical processes but lacked the ability to explain their knowledge. Todd's student also described the color change as a result of the 'EDTA causing the calcium to be unreacted',

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[8] Susan was not included as her calcium presentation was not recorded.

whereas Lawrence's student described the color change as a result of the 'when EDTA binds with the calcium ions then four hydrogens get released into the solution'. It appeared the intent of these statements was to explain how EDTA, which loses its protons in the basic solution, causes calcium to unbind with EBT to then bind with EDTA; however, their word choice illustrated an incomplete understanding of this process. While the depth of understanding was similar for Todd and Lawrence's students, Todd's students more frequently communicated their understanding of the chemical phenomenon. The incorrect and infrequent use of words to communicate understanding as observed in Lawrence's students may be due to the lack of engagement by the TA in discussing the concepts before presentations.

The limitation Chris's student presented that related to the unknown volume of base added to the calcium solution illustrated a lack of understanding of titrations in general. While Chris's student understood that volume was important in calculating concentration, he did not grasp that additional volume added to the aliquot did not impact the volume used in the calculation. Thus, the most accurate and complete explanations illustrated by students in the presentations occurred in Martha's section, where students were provided opportunities to explain the underlying chemical processes as they were observing the phenomenon.

In summary, Martha and Todd were the only TAs who promoted students' construction of explanations during the experimentation day, and their students most frequently and accurately communicated their understanding of the chemical processes that occurred during the titration. Chris and Lawrence emphasized construction of explanations following presentations, and their students showed infrequent or inaccurate ability to communicate their understanding of the chemical phenomena.

Evaluating information. Whole group discussions related to the student-developed questions about limitations/errors allowed TAs to promote students' engagement in evaluation of information. While the questions differed, these interactions were similar across TAs. Todd and Martha were the only two TAs who additionally emphasized evaluation. Thus, the curriculum played a more important role than the TA in promoting students' engagement in evaluation.

Classroom Example 10

This example illustrates how TAs used the group discussions to engage students in evaluating information. Chris posed a student-developed question during the limitations/errors discussion:

> "If you all added the same amounts of calcium [to the calcium supplement], why did it take different amounts of acids and bases?" Chris calls on Nancy "Well we talked about how it was hard to get the same amount of calcium, depending on what you used for your RDA [recommended daily allowance] and also it was...we got a really precise number, .997. So it was kind of hard to measure out. And then even with the volumes, everyone has different eyes, so it's hard to be precise. And the pH range was so wide that it had to be between 4 and 10, so it depended on what pH you were aiming for." Chris comments "Right. Excellent point. So variance in measuring. And one group wanted to get [the pH] to 4 while another group wanted to get it exactly to 7. Good points. Anyone else have another reason?" Paula responds "People could have overshot it?" Chris confirms and elaborates "Right. If your first measurement, even if you measured it exactly right but added too much, then you could have had to compensate." (Chris, TA, Observation 2)

Chris asked students to think about similarities and differences in the ways students approached making the calcium supplement solution. Nancy provided various different procedures that could have affected the masses and volumes of the calcium and water, respectively. However, there was no elaboration on how these differences (i.e., a low or high pH) affected the experimental results. This type of TA-student interaction and lack of follow-up was present for all four observed TAs. This suggested students engaged in evaluation, but the absence of TAs promoting student evaluation of the results of subsequent experiments limited students' ability to fully evaluate information.

Only Todd and Martha went beyond the student-created questions to further students' evaluation of the experiment. Both used similar facilitative approaches as illustrated in previous examples of these two TAs; Martha was directive in her interactions whereas Todd allowed students to drive the interaction.

Classroom Example 11

After students had discussed all of the student-created questions, Todd posed a final question to his students to promote further discussion:

> Todd asks "What might you have done differently if you had to do it again?" He calls on the first group, "Probably use less calcium" Hannah says. Kelly, her team member elaborates "We started the titration with 25 milliliters of calcium solution, and we didn't add any base. And we ended up adding 100 milliliters of EDTA without solving any of the problems. So doing it on a smaller quantity would have helped." Todd calls on another group and Qian shares, "Originally we didn't look at how hazardous nitric acid was. So we definitely would have changed to see how hazardous the various acids were and pick the least hazardous one." Her team member Gillian shared other suggestions "And also, our calculations were all over the place, and we had so much glassware out we didn't know what was in it. And for the experiment, I think, it didn't help us. It made it more frustrating and much more stressful." (Todd, TA, Observation 2)

The question Todd asked his students prompted them to evaluate the experiment as a whole to come up with ways they would improve what they did. Students responded in a variety of ways that illustrated their ability to evaluate their experimental procedures and lab techniques. But again, there was no follow-up discussion on how these changes would impact students' data or results.

Summary. Between and within TA differences seemed to impact students' ability to engage in and effectively do certain scientific practices. TAs differed in the methods used to facilitate students' engagement in scientific practices. Lawrence tended to use more didactic approaches in his interactions with students across most scientific practices, whereas Todd tended to use more student-driven approaches in his interactions. Observations of Susan suggested her approach was similar to Lawrence; however, without observations of her presentation, these trends are unverified. The more teacher-centered approach utilized by Lawrence and Susan limited students' ability to actively engage in scientific practices, whereas Todd's student-centered approach promoted student-student interactions that allowed for active construction of knowledge and ability to do scientific practices.

Differences within Martha and Chris's practice suggested some TAs utilized different approaches to interact with students depending upon the scientific practice. Martha was directive in her interactions when engaging with students about procedures, mixed her approaches when interacting with students about constructing explanations, and was the most facilitative in interactions involving students' analysis of data and evaluation of information. Conversely, Chris was facilitative in his interactions with students about procedures but was the most directive in his interactions about chemical concepts. These differences observed within and across TAs may be related to their experiences.

Assertion 3: TAs' prior experiences played a role in depth of interactions with students.

TA experiences may have influenced the level of interactions TAs engaged in with students; current experiences related to TA responsibilities and prior experience related to research. First, all TAs had similar responsibilities in lab, and their varied roles limited the interactions they could engage in with students. Second, TAs with more research experience appeared to have more accurate content knowledge that translated to their students. TAs with more research experience also engaged students in discussions about how science works.

TA responsibilities. All TAs engaged in logistical, laboratory, and student learning responsibilities, to varying degrees at various times. The plethora of diverse roles pulled TAs in multiple directions and made it challenging for some TAs to engage in in-depth discussions with students.

Classroom Example 12

For example, at the end of lab when some students were still titrating and some students were working on their summaries, Susan interacted with four groups simultaneously. She initially worked with group 1 as they completed their titration when group 2 came over to get help on a calculation:

> "So we got this" Sonya, from group 2, says and shows Susan her lab notebook with her calculations. Susan's attention was on group 1, but she takes her attention away from group 1 and focuses her attention on group 2. Susan asks "Where's your calculator?" Susan works with group 2 on the mathematical calculations. Susan looks at group 1, then group 2, then turns around and shouts to Candice across the room in group 3, "Candice, check my math on the milliliters, because I think it should be .109 for you guys." Susan returns her attention to group 2, then looks up and says to group 1, "No that's not red." "She

> wants fire truck red" Lance, a member of group 1, says. Susan repeats "Fire truck red." Sonya in group 2 says "so then we do .188 moles per 1 liter." Susan confirms "Yes." Teddy in group 4 shouts as Susan from across the room to ask a question "Susan, so we....." but he cannot be heard over other students in the room. Susan nods and responds "Into a beaker." Susan looks back to group 1 who is still titrating "You're getting there." (Susan, TA, Observation 1)

Susan's interactions with four different groups required her to provide lab technique and procedural feedback to groups 1 and 4, and calculation help to group 2 and 3. The interaction with groups 3 suggested Susan completed the calculations for the group, but did so incorrectly. These various responsibilities she engaged in limited her time and focus with any one group.

Presentations were another example of split responsibilities for TAs. During presentations TAs were responsible for grading students on the components of the presentations, visual representations, and delivery. At the beginning of a group's presentation, Chris was observed completing the previous group's presentation grade sheet, suggesting he may not have been able to pay full attention to the presenters. The lack of student understanding or misconceptions illustrated in student presentations was not addressed by any of the observed TAs. Thus, it is possible the multiple responsibilities TAs took on during experimentation and presentations, sometimes simultaneously, limited their ability to assess all student learning outcomes (i.e., laboratory techniques, content, calculations, evidence-based conclusions).

Prior research experience. All TAs illustrated accurate chemical conceptions in the majority of their interactions with students; however, there existed some misunderstandings or lack of content knowledge about certain topics. Chris, Susan, and Lawrence all had undergraduate and summer research experiences as well as bachelor's degrees in chemistry to shape their understanding of the concepts. Martha and Todd had similar previous research experiences to Chris, Susan, and Lawrence but had additional research experience as graduate students. Those TAs with less chemistry research experience (i.e., Chris, Susan, Lawrence) illustrated instances of inaccurate or incomplete understanding of the EDTA/EBT/calcium titration compared to the TAs with the most chemistry research experience (i.e., Todd, Martha).

There was no observable overlap in the types of incomplete or inaccurate understandings observed for Susan, Lawrence, and Chris, as illustrated in the examples below. Susan demonstrated the most limited understanding of all TAs, believing the titration color change should go from blue to red. The lack of understanding of the titration process was evident when she interacted with Terrence, who discussed his confusion on the pH and color of the calcium supplement aliquot:

> "The [calcium supplement] solution is blue, so it is basic now" Terrence says. "Yes" Susan confirms. "So this is basic as well" Terrence says, pointing to the buret full of EDTA/NaOH. "It should be, because you added NaOH didn't you?" Susan asks. "So we are adding something basic to a base. So why?" Susan does not answer and sighs. She hears Orion say across the room "So this should be red?" Susan walks away from Terrence without answering his question and responds to Orion, ""Fire truck red." (Susan, TA, Observation 1)

Susan believed the titration should start blue and go to red, and directed her students to continue adding base their calcium solutions until they turned blue. When a student asked the purpose of adding two basic solutions together, Susan was unable to respond. She had confused her students to the point where her background knowledge was not able to help her understand or explain to students what was going on or why they were doing what they were doing. This was evident when a student at the end of the lab stated, “I know what we did but I don’t know why we did it” (Susan, TA, Observation 1).

Chris had limited chemical knowledge, and his interactions with students suggested he was unable to answer more in depth questions about related concepts. When he walked around during small groups discussions following presentations a student asked:

> “Are we wrong to say that calcium is just kind of basic, period?” Tori asks. “Yeah. Basicity is determined by hydroxyl groups and hydrogens. Right? Either OH or H groups. And inherently calcium doesn’t have any hydrogens on it. Calcium hydroxide would become basic but calcium itself is not inherently acidic or basic.” (Chris, TA, Observation 2)

Chris used the fundamental definition of acids and bases, as defined with hydrogen and hydroxyl (OH) groups present. However, he did not illustrate a more in-depth understanding that salts, such as the calcium chloride in the calcium supplement, have a pH and would be ‘acidic or basic’.

During the group presentation in Lawrence’s section they discussed the different ways to keep the calcium solution aliquot basic. Lawrence asked if any group added base to the solution at the beginning and got the titration to work. A student responded:

> “Well when we added so much base in the beginning it was like a milky purple solution. And I think it was very basic, as in out of the range of EBT. So after adding EDTA, it then became the starting red color, and then from there we could keep going. But I think it would have been interesting to try adding NaOH dropping it in as the titration was going on. At the same time.” “Okay. Hmm. Let’s go on” Lawrence responds. (Lawrence, TA, Observation 2)

The student illustrated a lack of understanding of what the cloudiness indicated in his solution, and Lawrence did not address this. His ‘Hmm’ response suggested he may not have understood the formation of the precipitate himself, and he missed an opportunity to deepen students' understanding of the chemical reactions occurring when sodium hydroxide is added to a calcium solution.

Martha and Todd, who had more research experience, illustrated more in-depth understanding of chemical principles, and no clear misconceptions were evident as shown in the following example.

Classroom Example 13

During experimentation, a student asked Todd a question about adding sodium hydroxide and getting a precipitate. Todd responded:

> "So it does precipitate out. So what happened when you added acid to calcium carbonate?" Todd asked. "It ended up forming a gas and the calcium carbonate dissolved more because of the equilibrium which converts it to products and the gaseous products left the system." Andrea states. Todd asks "So what would you expect to happen with EDTA reacting with calcium hydroxide?" Andrea responds, but it is not the respond Todd was looking for, so Todd states "So you mentioned something about equilibrium being shifted in one direction, right? So with the compound that's slightly soluble....does it partly dissolve?" "So we should add more solution?" Andrea asks. Todd asks for clarification. Andrea rephrases "Should we add more of our calcium acetate solution?" "You could" Todd replies. Pattie chimes in "The thing about adding more solution is its just going to make it more acidic, so we will need to add more base so it will just balance itself out in the end." Todd confirms "Right. So with the two insoluble compounds you have encountered so far, calcium carbonate and calcium hydroxide. So the acid reacting with the calcium carbonate, there was a gas formation reaction, the gas left and it forced the equilibrium in one direction. But if the calcium carbonate was solid, and the calcium and the carbonate were locked to each other, how did the acid break those two apart?" The student replies and Todd confirms. "Right. So is there any way to tell whether or not the EDTA binds to calcium stronger than the hydroxide? It would be worth testing." (Todd, TA, Observation 1)

Todd exhibited an accurate understanding of the chemical processes occurring when creating the calcium supplement solution and when titrating the calcium supplement solution. His last question to the students might be interpreted as a misunderstanding about the process of solubilizing calcium hydroxide; however, taken with the previous statements about equilibrium, the intent of this statement was likely about the shift in equilibrium to EDTA-calcium over calcium hydroxide.

Martha also illustrated an accurate understanding of chemical concepts beyond the EDTA titration performed in lab. During the presentation discussion, Martha explained to a small group what buffers were:

> A buffer solution is a combination of a weak acid and it's conjugate base so that it'll maintain a pH near the pKa of that solution. So buffer solutions, the idea is because it contains an acid and a base, when you add either acid or base the pH doesn't change very much. (Martha, TA, Observation 2)

Martha provided a detailed definition of buffers based on the idea of pKa, a concept students may not have been exposed to. She rephrased her definition to explain what occurs when an acid or based are added to a buffer. Martha was the only TA who accurately discussed the use of buffers as a way to control the pH during the titration, suggesting she had a much more in depth understanding of the EBT/EDTA/calcium titration than other TAs.

Differences clearly existed between TAs own content knowledge about the EDTA/EBT/calcium titration. Both Lawrence and Todd had situations arise where students could not explain or understand the formation of a precipitate when sodium hydroxide was added to the calcium supplement. Lawrence responded with a 'Huh', illustrating he did not understand what was going on. Conversely, Todd understood what compounds were forming in solution (i.e., calcium hydroxide), how the precipitate would dissolve (i.e., add EDTA), and how this compared to other processes the students had seen (i.e., solubilizing calcium carbonate by adding acid).

Susan, Chris and Martha all had situations where students asked questions that were more atypical and required an extended amount of content knowledge not directly related to the experiment. Susan responded to the difficult question by walking away from the student, Chris attempted an explanation that was inaccurate, and Martha provided students with an accurate explanation to their question about buffers. Differences in the responses provided by TAs illustrated differences in their understanding chemical concepts; Lawrence, Susan, and Chris had inaccurate or incomplete understandings whereas Todd and Martha had accurate understandings. The main difference between these two groups of TAs was their previous research experience, suggesting TAs experience in a scientific laboratory may have promoted a deeper understanding of concepts related to the calcium supplement project.

Assertions Summary

In summary, there existed similarities in the general TA responsibilities and chronological order in the laboratory. TAs took on logistical, laboratory, and learning responsibilities as they interacted with students during experimentation and presentations. Four types of interactions were observed in TAs practice – directive, didactic, facilitative, and student-driven – and these different types of interactions influenced the depth and breadth of student involvement in different scientific practices. Analysis of these interactions across observations revealed some TAs continued to use the same types of interactions with students whereas some TAs modified how they interacted with students during experimentation and presentations. The variety of responsibilities required of the TAs limited their ability to fully engage with students, and TAs' prior research experience provided one explanation for the difference between varying levels of their chemical understanding illustrated in interactions with students. To better understand the role TAs' beliefs, confidence, and content knowledge played in their practice, a more in-depth look at two TAs, Martha and Lawrence, follows.

A Case Study of Two TAs

Martha and Lawrence were selected as two 'cases' to examine further in depth. Their entire data sets helped provide a comprehensive picture of Martha and Lawrence as TAs as well as the context in which they taught. Each participant's characteristics and practice will be reviewed first, then examination of the relationship between these characteristics and practice follows. How participants' beliefs, experiences, and practice impact student learning is discussed next, and the case study concludes with a summary.

Martha

Martha was a returning PBGI TA who was undertaking chemistry research in addition to taking a few classes and being a TA for the labs at the time of the study. Martha taught two sections of general chemistry lab; a Monday section with 18 students and a Wednesday section with 23 students.

Martha had traditional beliefs about teaching and learning that persisted across the semester. She believed the purpose of the laboratory was for students to apply concepts they had previously learned, and she believed her role was to be an active, directive participant in student learning. However, her beliefs about student learning conflicted with the goals of inquiry, and she struggled with this. Implementing inquiry was challenging for Martha and she felt she experienced situations where she was unable to support students learning through guidance and facilitation. Thus, her confidence in her content and ability to effectively interact with students decreased across the semester. Student frustration was perceived as a negative experience for Martha, and she used these negative experiences to confirm her beliefs that students should learn concepts first and verify them in lab.

In Martha's practice, she used open-ended and close-ended questions along with more directive interactions to facilitate student learning. Martha's content survey and explanations of concepts to students suggested she had extensive content knowledge, and this content knowledge translated into her practice. Martha was one of only two observed TA who emphasized that students engage in a conceptual understanding of the titration process during experimentation, and she encouraged students to explain this process to her. During presentations her students illustrated more complete understanding of the concepts than other TAs, which may have been related to how she approached her interactions with students on the experimental day. She also engaged students in analyzing data across sections and discussed how science really works with students following presentations.

Lawrence

Lawrence was a former high school chemistry teacher who was taking full-time graduate level classes and teaching the general chemistry lab for the first time. He taught two sections of lab; 23 students in his Monday section and 16 students in his Thursday section.

Lawrence had reform-based beliefs about teaching and learning and believed lab was a venue for grappling with information to create new knowledge. He perceived his role as developing alongside students in their construction of knowledge and felt his previous teaching experience helped him do so. Student frustration for Lawrence was a positive experience as he understood this enhanced student learning, and his experience appeared to confirm his reform-based beliefs. However, he struggled with balancing facilitating student learning and getting them back on track when they were going in an unproductive direction.

At the end of the semester, Lawrence had high confidence in his content knowledge and ability to facilitate student interactions, which conflicted with his actual content knowledge and ability to facilitate. As evidenced in his survey and observations, Lawrence had a limited understanding of the concepts associated with the laboratory projects, and this appeared to impact his interactions with students. In practice, Lawrence directed the conversations using didactic questioning where students responded with one-word answers and experienced little opportunity to ask questions or engage in explanation or justification. During the presentation discussions he continued using didactic questioning but allowed for more student input and encouraged students to analyze data across sections. However, Lawrence illustrated misconceptions in his own explanations of chemical processes during these discussions and was unable to facilitate discussions to deepen students' understanding because he did not appear to understand the concepts himself.

Cross-Case analysis of Martha and Lawrence

TA content, beliefs, confidence, and practice. The guided inquiry context appeared to limit both Martha and Lawrence's ability to enact their beliefs in practice. Martha's traditional belief of a more directive approach to learning was present but limited by the expectation of TA-as-guide rather than TA-as-disseminator. Lawrence's reform-based beliefs of a student-centered construction of knowledge were present but limited by his understanding of guided inquiry and the open-ended nature of related chemical knowledge students could pursue.

Beliefs. Martha maintained the belief that students learn best through, "A combination of lecturing and having them try things on their own because I don't really feel like they have the foundation" (Martha, TA, 9/30/14, Interview 1). This belief appeared in her practice at various times. Martha's emphasis on knowledge focused her interactions with students on explaining concepts and encouraging students to explain concepts as they completed the experiment, rather than connecting concepts after making sense of the experiment. Since Martha did not have control over what students learned in lecture, she felt she needed to ensure students' conceptual knowledge as they went along. Her content knowledge was such that she was able to engage in deeper conceptual conversations with students than the other TAs.

She also directed students as much as she could through lab procedures, which may have been a response to her beliefs about students' lack of foundation. At the beginning of lab Martha told her students:

> So because EDTA takes a little bit of time to dissolve, make sure you start with that first, and then make the calcium supplement solution. Watch the video for

> cleaning and conditioning your buret, because that will affect your titration results. And then when you're doing your titration in your calcium solution just use 10 mil aliquots of your solution that you make, not the entire supplement. Because you'll probably have to do multiple titrations, and also you'll have to use a lot of the EBT solution. (Martha, TA, Observation 1)

Martha felt it was important to make sure she told students ahead of time the order of procedure and the volumes they should be using rather than allowing students to figure this out as they went. Such a directive approach was not observed in other TAs practice and illustrated how Martha's beliefs presented in her practice.

Lawrence's beliefs similarly translated into practice in a limited way. He believed:

> Students learn by making mistakes, but being taught through them, or shown new methods or knowledge from those mistakes. Learning by doing is very important and of course appropriate prior knowledge is also a must. But self-taught knowledge from experience and trial/error is often the best way to seat information deep in the mind. (Lawrence, TA, Pre-survey)

His beliefs aligned with the guided inquiry approach in which students learn through the analysis of data collected in lab. In practice Lawrence attempted to facilitate students' construction of knowledge by initiating conversations that would promote active engagement in these discussions. For example, Lawrence asked a group of students about the volumetric flask, "What's the advantage of making EDTA in that?" (Lawrence, TA, Observation 1). As the conversation continued, Lawrence proceeded to explain to the students why the volumetric flask was more precise than other pieces of glassware. This shift in the conversation from open-ended questions to close-ended questions to TA answers was evidenced in most of his interactions with students.

This focused interaction conflicted with his beliefs about students' construction of knowledge and may be a result of two factors: his epistemological beliefs and his content knowledge. Lawrence's constant question-asking suggested he was looking for one particular piece of knowledge he wanted students to construct. If he found students deviating from his original goal, he would focus the questions so much that he did the opposite of what he intended - to facilitate students own construction of knowledge. Lawrence discussed this corrective approach in his interview:

> When they are reaching in the wrong direction and the guiding inquiry that you're providing is not, it doesn't seem sufficient to get them to come back around, and they really need to be told exactly what they're doing wrong do that then they can make a primary adjustment, and then maybe from that primary adjustment then they can be guided through the secondary things that they have to do. (Lawrence, TA, 9/24/14, Interview 1)

He was unable to find appropriate questions to ask students to refocus their learning, and this resulted in his more didactic approach.

Lawrence also did not appear to be able to use students' misunderstandings or unexpected responses as a learning opportunity. This may have been due to his limited content knowledge. There existed few instances in Lawrence's practice when students had the opportunity to ask him in-depth conceptual questions. Lawrence tended to close the conversation by directing exactly where he wanted students to go. For example, a group of students asked Lawrence about the endpoint color change during their titration:

> "It's supposed to turn blue. Yeah." Lawrence states. He continues, "It turns to blue because...The EDTA does what?" "Binds with the calcium" Thomas replies. Lawrence confirms, "Binds with the calcium. Which means the EBT indicator..." Kelly says "Reacts with..." And Lawrence interrupts, "No longer..." "Is there?" Kelly answers unsurely. "It's still there. It can just no longer interact with the..." "Ummm" Kelly says. "Calcium" Thomas says. Lawrence confirms "Calcium. Yes." He moves on to another group. (Lawrence, TA, Observation 1)

Lawrence's command of the conversation through mostly one-word answer questions left little room for students to ask further questions about the concepts. This approach may have been due to his need for control over the conversation as a result of his limited content knowledge.

Teaching confidence. Martha and Lawrence's interactions with students influenced their teaching confidence and provided evidence for discrepancies between their content knowledge confidence and measured content knowledge. While Martha was directive about laboratory procedures, she engaged and encouraged students to interact with her about the content. These more open-ended, in-depth discussions challenged her content knowledge. For example, in one observation a group of students discussed with Martha a possible reason for the discrepancy between their experimental and calculated calcium ion concentration:

> James says "Okay. .9356 grams of H_2O, based on this" pointing to his reaction equation for dissolving calcium carbonate in acid. James continues "And we can't use the fact that we added 80 mils of acid. Right?" "What do you mean?" Martha asks. "To make this solution, we combined acid with $CaCO_3$, and a reaction occurred. And the solution that resulted was water." "Mhmm" Martha confirms. James continues "But there's not as much water as acid we added." "...Yup." Martha states. "Right? And so when we were figuring out the initial concentration, we assumed that we had 100 mils but we didn't. That's why our concentration's wrong." James says. (Martha, TA, Observation 1)

Martha continued to discuss with the group about this assumption, and she determined that the group had added excess acid, meaning it did not all react to form water. She used this evidence to help students realize their total volume was not the reason for the difference in the calculated and experimental. Martha's pauses and need for clarification to James' questions suggested this was a challenging conceptual conversation for Martha.

These types of conversations, which Martha promoted, pushed her own understanding and challenged her ability to facilitate students' understanding of these difficult concepts. So even though she had a depth of content knowledge and initially felt confident in her facilitation, the interactions she engaged in made her unsure of her content knowledge and ability to help students learn the concepts.

Conversely, the interactions Lawrence promoted in lab were not focused on deep conceptual understanding, and he did not call into question his conceptual understanding or facilitation ability. Lawrence commented on the content for the lab, "There are just certain topics that you can't really prepare for. There's not stress involved as far as whether the content is too much" (Lawrence, TA, 9/24/14, Interview 1). He understood students may bring up unanticipated ideas, but this did not seem to concern him. Lawrence's interactions with students suggested he reacted to these unanticipated scenarios by using the shift-to-didactic-teaching approach or allowed questions to go unanswered. These shifts in practice meant he did not have to deal with challenging conceptual situations, which in turn confirmed his self-perception of high content knowledge and facilitation ability.

TAs' impact on student learning. Both Martha and Lawrence had distinct content knowledge, beliefs, confidence, and practice, yet there existed no significant differences in their students' pre or post-survey scores (Table 45). This suggested their students learned similar concepts despite the TAs disparate characteristics and instructional approaches. The quantitative student survey data showed no differences in student learning for Martha and Lawrence, but this conflicted with the observational data indicating students in Martha's lab obtained a more accurate conceptual understanding of the calcium supplement project. Both Lawrence and Martha engaged students in similar discussions following presentations and focused on analysis of data across groups, evaluating lab techniques, and understanding the real-world implications of the calcium supplement project. This suggested the presentations have influenced student learning of concepts the most.

Inductive categories arose from students' self-reported survey responses of what they learned in the lab and provided further insight into the relationship between the TA and student learning (Table 46). Based on these data, students learned much more than just chemical knowledge, as measured by the pre/post survey. For example, when asked what she learned, Penelope, a student of Martha's stated:

> I learned how to write lab reports, how to use certain equipment such as pressure sensors and pH probes. I also learned how to plan, conduct and summarize experiments. Not only that, I also learned to cooperate with group members due to group write-ups. (Penelope, student, Post-survey)

Penelope felt she learned scientific writing, lab techniques, laboratory skills, and group work. This type of multiple learning outcomes response was also evidenced in Lawrence's students' responses.

Table 45

Overview of Student and TA Data for Case Study Participants

	TA characteristics			Interactions in TA practice				Student Content	
	Content	Beliefs*	Confidence**	Focus	Type	TA perception	Influence	Pre-survey	Post-survey
Martha	In-depth, accurate, 92.86%	Traditional	Low	Concepts, Data analysis	Open-ended, directive	Frustration is bad	Research, content	54.63%	77.08%
Lawrence	Limited, inaccurate, 78.57%	Reform-based	High	Procedures, Data analysis	Didactic	Frustration is good	Teaching, content	57.64%	74.65%

Note. * = teaching and learning beliefs. ** = Content and facilitation confidence.

Table 46

Students' Self-reported Learning by TA

	Martha	Lawrence	Example
Scientific writing	8	10	I also learned how to effectively deliver my results in my lab reports (Martha). I learned how to write more concisely, especially for scientific writing (Lawrence).
Group work	8	5	How to work as a team without getting frustrated with each other. (Martha) I learned how to be a better collaborator and work more effectively in a group setting. (Lawrence)
Lab skills	7	11	I learned how to conduct experiments without a given protocol (Martha). I learned about standard deviation (which I had also never used at all). Learned how to calculate things like ion concentration in a solution, which I had always had trouble with before (Lawrence).
Lab techniques	5	2	How to use certain equipment such as pressure sensors and pH probes (Martha). I learned how to do a titration; something that I was never previous exposed to (Lawrence).
Work ethic	4	2	I learned that is it necessary to completely understand what you are doing before you come into the lab. Always come prepared! (Martha). Answers aren't going to just pop up when questions are asked. Extensive research and investigation is often required to achieve the proper understanding of many concepts (Lawrence).
How science works	3	3	I learned about specific chemical processes and was given a more accurate representation of how labs work (Martha). How scientists work on a day to day basis (Lawrence).
Data analysis and conclusions	3	0	The experiment is not the biggest part of lab. It's being able to explain what occurred and why you go the results you did while also analyzing errors (Martha).
Connecting concepts	3	3	I learned about specific chemical processes and was given a more accurate representation of how labs work (Martha). This lab was helpful in helping me understand the application of certain activities and equations that I learned in lecture (Lawrence).
Application	3	1	I learned how many real world applications that do not seem to relate to chemistry actually do relate (Martha). Application of concepts learned in chem lecture and what they mean in the real world (Lawrence).
Negative	2	5	We focused way too much on the writing, yet the writing itself is a long process, and we should've spent more time honing our lab techniques (Martha). That I dislike chemistry and dislike the set-up of chem. lab (Lawrence).
Communication	2	1	[Group work] was great for communication skills. (Martha). How to present scientific information and results (Lawrence).
Implicit skills	2	6	It will all be okay just stay calm and work the problem out (Martha). I learned the necessity for patience in lab (Lawrence).
Failure is okay	1	1	I Learned that even if everything looks like it has gone completely downhill and there is no coming back after a failure in the lab, it is possible to do at least okay (Martha). If you fail, try, try again (Lawrence).

Note. **Bolded** categories differ for Martha and Lawrence by three or more student responses.

Students most frequently discussed scientific writing as the one thing they learned in the course, and this was evident for both Lawrence and Martha. Kyle, another one of Martha's students reported:

> From my experience in the lab this semester, I believe the most important thing I got was a very strong idea as to how to write lab reports. At first, the harsh grading on the semantics of the report frustrated me to a great degree. However, as I realized what mistakes I made, I understood where to correct them and what I should include for subsequent labs. That was the most helpful thing regarding the reports (comments on them). I learned how to write a lab report and focus on the details of the report being written. (Kyle, student, Post-survey)

Kyle illustrated his initial frustration with Martha's strict grading; however, he came to understand and appreciate her expectations for scientific writing and felt he learned from the experience.

The differences that existed between Martha and Lawrence's students' reported learning outcomes occurred in the categories of group work, laboratory skills, data analysis/conclusions, negative perceptions, and implicit skills. These differences aligned with differences in Martha and Lawrence's observed practice. Martha emphasized conceptual understanding and data analysis over understanding laboratory procedures, which aligned with her students less frequent mention of lab skills and more frequently mentioned analysis and drawing conclusions. The more frequent mention of lab techniques from Martha's students confirmed her directive approach to laboratory procedures and telling students to condition glassware or use a specific piece of glassware.

Lawrence utilized didactic questioning during experimental time that limited students' ability to engage with each other and explain concepts. This aligned with students' less frequent mention of learning how to work as a group and no mention of drawing conclusions. Lawrence's students were more negative about their lab experience and more frequently expressed implicit skills such as patience and persistence as things they learned in lab. This was illustrated by Lawrence's student, Homer, who stated, "I learned that working in a lab is extremely hard and I never want to do it again" (Homer, Student, Post-survey). These experiences were noted less frequently for Martha's students, suggesting her more direct approach may have received a less negative reaction from students. The challenges students experienced may not have been liked or appreciated by all students.

In summary, the importance students placed on scientific writing as a learning outcome for the course and the various outcomes students mentioned as what they learned indicated measuring chemical understanding may not have captured all that students learned from the course. Differences in student's self-reported learning aligned with differences in Martha and Lawrence's practices and provided evidence that the content assessment may not have captured the entirety of student learning as influenced by the TA's practice.

CHAPTER 5: DISCUSSION & IMPLICATIONS

Researchers in chemical education and science education have called for additional research on TAs and TA training programs (e.g., Hammrich, 2001; Garner & Jones, 2011; Luft et al., 2004; Sandi-Urena & Gatlin, 2013), and the present study adds further information to these bodies of literature on how TA professional development impacts TAs. Previous studies on TA training fail to utilize the extensive K-12 body of literature to develop effective TA training as suggested by Luft and colleagues (2004), and only limited TA studies fully integrate a theoretical framework into their research (Addy & Blanchard, 2010; Calkins & Kelly, 2005; Sandi-Urena et al., 2011). This study integrated both the K-12 literature and a theoretical framework in the development and analysis of TA training for an inquiry-based laboratory context, and as a result, provides a more robust and in-depth understanding of TAs' learning to teach inquiry than is currently present in the literature.

Despite the number of studies examining student learning outcomes in the undergraduate laboratory context (e.g., Brickman et al. 2009; Chatterjee et al., 2009; Russell & Weaver, 2011), none of these studies investigate the relationship between TAs' content knowledge, beliefs, and confidence on student learning. The present study explicitly connects student learning to these TA characteristics and provides qualitative and quantitative data to identify these relationships. Further, only two studies in this body of literature utilize observations to understand student learning in inquiry-based laboratories (Krystyniak & Heikkinen, 2007; Xu & Talanquer, 2012). This dissertation addresses the gaps in the literature and provides a more complete and complex view of student learning in an inquiry-based undergraduate general chemistry laboratory. Few studies of student learning use a theoretical framework for understanding how students learn (e.g., Chatterjee et al., 2009; Russell & Weaver, 2011), and only one study attempts to integrate theory into the data collection and analysis (Xu & Talanquer, 2012). This is the first study to fully integrate theory into a study on student learning in the undergraduate inquiry-based laboratory context and use social constructivism as the theoretical framework.

The results of this dissertation build upon previous research, fill gaps in between bodies of literature, and address limitations of previous studies. How this study adds to the general bodies of literature on TAs and TA training, informs literature on student learning in the undergraduate laboratory, and enhances the understanding of TA learning and student learning through theory-driven research is discussed below.

Teaching Assistants in the Undergraduate Laboratory

This section first examines how TA's content knowledge, beliefs, confidence and practice extend and inform the literature on TAs and the more general literature on science teacher practice. These characteristics are discussed in light of the professional development to provide explanations for changes, or lack thereof, and how these comparisons build upon the TA training literature. A discussion of theory-based research on TAs follows, and this section concludes with a summary.

TA Content Knowledge

Only one study in the TA literature measures TAs' content knowledge (Bond-Robinson & Bernard Rodriques, 2006); however, TA knowledge was assessed through observing pedagogical content knowledge (PCK) in practice using an instrument that measured frequency and depth of questions asked. No studies to my knowledge directly assess TAs' content knowledge, so this investigation is the first of its kind. Some researchers assume TAs' degree illustrates their understanding of content (e.g., Sandi-Urena et al, 2011), which may explain the lack of research assessing TAs' content knowledge. This degree-as-proxy-for-content knowledge assumption is also prevalent in the K-12 science education literature, despite the recent emphasis by researchers on using more direct measures of content knowledge (e.g., Diamond, Mearten-Rivera, Rohrer, & Lee, 2014; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). TAs in this study did not enter the professional development or teaching with high content knowledge, suggesting a degree is not representative of understanding content for these TAs. Thus, researchers should consider assessing TA content knowledge to identify whether content knowledge should be addressed during professional development.

The TAs in this dissertation significantly improved their content knowledge pre- to delayed post-survey, but no significant differences were observed in between. Therefore, these TAs learned significantly more content only when they attended a week-long professional development, engaged with students in learning the concepts, and attended weekly TA meetings. None of these components alone appeared to significantly impact TAs understanding of the content knowledge as measured on the survey. From a situated learning perspective, improving TAs content knowledge requires authentic learning environments (i.e., completing experiments/modeling during professional development, interacting with students in lab), opportunities to increase participation in a community of practice (i.e., discussions at weekly meetings), and reflection on teaching (i.e., peer observations and reflection writing during weekly meetings). Just one of these components of situated learning was not sufficient in improving TAs' content knowledge.

The present study's findings extend the research on social constructivism and situated learning theory from teachers to TAs. Bleicher & Lindgren (2005) measured conceptual understanding of pre-service in a methods course informed by social constructivism and situated learning theory and found that pre-service teachers significantly improved their content knowledge by engaging in similar activities as the TAs in the present study. Thus, using a situated learning theory framework as a basis for professional development may be an effective approach to improve TAs' content knowledge.

TA Beliefs

Only a few studies examine TA beliefs in an inquiry-based laboratory context (French & Russell, 2002; Sandi-Urena & Gatlin, 2013), and these studies use either survey or interview data to identify TA beliefs. Teacher beliefs can be challenging to measure (Jones & Carter, 2007), so the use of surveys, interviews, and observations in this dissertation study to triangulate data provides a more complete and accurate understanding of TA beliefs than is presently found in the TA literature.

In this dissertation TAs' quantitatively measured beliefs revealed no significant changes following professional development or across the semester. These findings add to the body of literature on teaching suggesting teacher beliefs are difficult to change (e.g., Kagan, 1992; Kane et al., 2002). The per-question data showed TAs believed chemistry concepts should be the most heavily emphasized learning objective in the inquiry-based laboratory setting. This builds upon previous literature on traditional laboratories that also found TAs believe content is the most important component of laboratory learning (e.g., Addy & Blanchard, 2010). By the end of the semester, TAs in the present study believed evaluation of scientific evidence should be just as heavily emphasized as chemistry concepts. While there existed no significant shifts in TAs overall laboratory beliefs, the shifts in per question data suggest inquiry-based contexts may promote changes in TAs beliefs about what students can learn in the laboratory.

Qualitative data also revealed shifts in TA beliefs not evidenced in the overall quantitative data. TAs shifted to more reform-based beliefs about laboratory learning, as evidenced in their increasingly complex understanding of what students could learn in an inquiry-based laboratory. However, these reform-based laboratory beliefs conflicted with some TAs more traditional beliefs about teaching/learning (i.e., Martha). In a study of TAs beliefs and understanding in an inquiry-based laboratory context, French and Russell (2002) found that TAs better understood the process of science after teaching. When comparing the results from the present study to French & Russell (2002), changes in TAs' laboratory beliefs may not have changed but their ability to understand and explain the process of science may have improved. From a situated learning perspective, TAs appeared to learn the language of teaching through participation in a community of practice during weekly TA meetings rather than the weekly meetings changing TAs' laboratory beliefs. For example, pairing new TAs with returning TAs for experiments and content-based discussions may have provided TAs exposure to language more representative of a variety of learning outcomes of which they may not have been previous aware.

Both interview and survey data revealed TAs in the present study who were new to teaching had the most resistant teaching/learning beliefs compared to other TAs with more teaching experience. This result differs from research that proposes new teachers' beliefs in K-12 education are more susceptible to change (Luft, 2001). Thus, TAs' beliefs may be even more challenging to modify. One possible explanation for why new TA beliefs are difficult to change may be due to the compounding factors of teaching context and experience. TAs in the present study did not make curricular decisions as K-12 teachers do and could only make changes to their practice based upon how they interacted with students within the project-based guided inquiry curriculum. Some researchers have found a relationship between teacher practice and beliefs (e.g., Anderson, 2002), so the limited amount of change TAs could make in their practice may have limited how this practice influenced their beliefs. Further, TAs with no teaching experience may have been unable to find ways to change how they interacted with students in a manner that may have positively affected their beliefs.

The present study also adds to the literature on teaching beliefs by illustrating a possible relationship between TAs' prior research experience and beliefs. Participants such as Ellen, who had extensive research experience and unchanging traditional beliefs, may have experienced research in such a way that it confirmed their traditional beliefs. Success in traditional instruction and in research by participants may substantiate traditional instruction as the only method of effectively preparing scientists for research. These beliefs may be much more challenging to change as a result.

An alternate explanation for the relationship between beliefs and research experience may be explained by situated learning theory. For example, participants with traditional beliefs and extensive research experience may have conflated research experience with teaching experience. This experience may have modified perceptions of their teaching abilities, making them think they were more of an expert than novice. This may have prevented these participants from engaging in the community of practice as a novice (i.e., discussing her interactions with students and how she could improve her teaching), which may have precluded any changes in traditional beliefs.

TA Teaching Confidence

This dissertation focused on assessing TAs' confidence in their teaching as a subcomponent of the larger self-efficacy construct. A plethora of work in science teacher education has found prior experience and teacher support mechanisms such as professional development shape self-efficacy (e.g., Bleicher & Lindgren, 2005; Fazio, Melville, & Bartley, 2010). The results from this dissertation extend the research on teaching self-efficacy at the K-12 level to undergraduate science teaching by TAs. Prior experiences appeared to influence TAs' teaching confidence in the present study; however, professional development for TAs did not appear to impact their confidence overall. Descriptive statistics examining the per question teaching confidence survey questions revealed participants made some improvements in their confidence to engage students in active learning and confidence to encourage students to ask questions by the end of the semester. While no overall changes existed, the per-question increase in participants' confidence about teaching suggests teaching and/or weekly follow-up meetings may have promoted some changes in overall self-efficacy.

This study builds on the small TA literature focused on self-efficacy of TAs. Research on TAs' self-efficacy suggest TAs with more prior teaching experience have higher self-efficacy (DeChenne, et al., 2012; Prieto & Altmaier, 1994). With the small sample size in the present study no inferential statistics could be performed on sub-groups based on prior experience, but descriptive statistics confirm and extend previous studies that more experience is related to higher confidence in teaching. The qualitative results presented in this dissertation suggest the relationships between experience and confidence may differ when TAs are instructing in an inquiry-based context. The TAs with prior inquiry experience, not just inquiry experiences as teachers, appeared to relate to higher confidence in TAs' content knowledge and ability to facilitate student learning.

TA professional development in the present study appeared to have no overall impact on TAs teaching confidence, which conflicts with the results from other studies on TAs and TA training (DeChenne, et al., 2012; Prieto & Altmaier, 1994). TAs' confidence Likert responses in the present study were consistently high across all time points, suggesting TAs may have been overly confident in their abilities. This supports previous research that TAs have higher self-reported confidence in their teaching than those they work with report of them (Cho et al., 2010). An alternate explanation is the instrument was not sensitive enough to measure changes in TAs' confidence, a limitation of the instrument suggested by the developers (DeChenne et al., 2012).

Situated learning theory may also help explain the changes, or lack thereof, in TAs' confidence in teaching. TAs' completion of the experiments as if they were students, TA-led content discussions, and discussions about teaching that occurred during the professional development and weekly TA meetings may have provided TAs with a false sense of confidence in their practice. The goal of these components was to be authentic experiences for TAs in learning how to teach; however, these experiences may not have been authentic enough to account for student difficulties. As a result, TAs may have felt overly confident in being able to engage students in their learning, and this overconfidence was not addressed in TAs' practice. Further, according to situated learning theory, authentic experiences are situated, relevant and provide opportunities for novices to learn language/skills and the importance of these language/skills. Modeling, sharing, and reflecting may have allowed TAs active opportunities to learn language and skills but may not have allowed for TAs, especially those with more traditional beliefs, to understand the importance of these skills on learning how to teach through inquiry-based instruction.

TA Role

Observations of TAs' practice revealed TAs took on a variety of different responsibilities in the laboratory setting. When examining these responsibilities in light of the literature on TAs, few studies use observational data to characterize TAs' role and responsibilities (Addy & Blanchard, 2010; Goertzen et al., 2008), and most utilize TA self-report of their role (e.g., Golde & Dore, 2001; Sohoni, Cho & French, 2013). None of these studies characterize TA practice within an inquiry-based setting; this study is the first of its kind to do so.

There exists a large amount of overlap when comparing TA roles identified in the literature to the TA roles identified in this study, suggesting that a fundamental set of TA responsibilities span inquiry and non-inquiry laboratory curricula. For example, TAs are responsible for safety, logistics, lab techniques, and helping students learn content regardless of the context. Previous studies indicate TAs perceived their most important role as teaching the content, even in an inquiry-based context (e.g., Herrington & Nakhleh, 2003; Sandi-Urena et al., 2011). While TAs in the present study were in general more reform-based than traditional in their perceptions, most TAs believed their role should emphasize the process of learning rather than content-as-a-learning-outcome as their main responsibility. Only Martha and Ellen emphasized content in their roles. The difference in the perceived and actual role TAs took on in this study compared to previous research may reflect an important step in shifting the focus of instruction to other types of learning in laboratory settings, such as scientific practices and laboratory skills. This shift may be attributed to the professional development TAs received; however, this link is not supported by the data as there were no TAs without professional development as a comparison.

TAs in the present study also took on additional roles in the lab not identified in the literature such as troubleshooting, helping students learn chemical language and how to make evidence-based claims, and knowing and helping students with calculations. In traditional laboratory contexts students follow prescribed procedures with a single solution, which provides little opportunity for TAs to take on these roles in lab. Thus, the differences between observed TA roles in an inquiry-based context compared to observed TA roles in a non-inquiry based context suggest TAs have additional responsibilities due to the curriculum and approach to learning. These added responsibilities have implications for TAs practice, as evidenced in observations of TAs.

TA Practice

Researchers have previously focused on TA-student interactions in a traditional laboratory (e.g., Addy & Blanchard, 2010) and student-student interactions in an inquiry-based laboratory (e.g., Xu & Talanquer, 2012), but no study to my knowledge has examined TA-student interactions within an inquiry-based laboratory. This dissertation bridges the gap between these two types of studies on laboratory practice. Studies examining TAs in traditional laboratories found that the focus in the laboratory is on managerial interactions (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodriques, 2006; Cho et al., 2010; Luft et al., 2004). This dissertation found in an inquiry-based laboratory TAs engaged in managerial, or logistic, interactions at the beginning and end of the experimental and presentation days. TAs' interactions during student experimentation focused more on students explaining concepts, justifying procedures, providing evidence-based claims, and analyzing data. Xu and Talanquer (2012) found student-student interactions in an inquiry-based laboratory shifted to focus on scientific practices, and the observational evidence in this dissertation supports previous work that TA-student interactions also focus on scientific practices.

This dissertation provides a more in-depth understanding of how TAs interact with students in an inquiry-based laboratory through observations and case studies, which is an important addition to the literature. In a similar case study approach of two TAs in an undergraduate physics tutorial, researchers utilized framing, or a “set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she acts” to understand how TAs assess student understanding (Goertzen et al., 2008, p. 119). They observed one TA focus on calculation-based responses as evidence for understanding whereas the other TA focused on student explanations. Observations of TAs in the present study mirror these categories with Susan and Lawrence obtaining one-word responses from students whereas Martha, Chris, and Todd encouraged explanations and justifications. Thus, the TAs in the present study have similar expectations of student responses as observed in a non-inquiry, non-laboratory setting. This suggests factors such as beliefs and confidence may influence TAs’ interactions with students more so than the curriculum or type of course.

Knowledge of how TA beliefs and confidence impact teaching within an inquiry-based context also helps inform the TA literature and the more general literature on science teacher’s beliefs and self-efficacy. A plethora of research on science teachers at all levels suggests a relationship between beliefs and practice can facilitate change (e.g., Anderson, 2002; Kazempour, 2009; Lotter et al., 2006; Sandi-Urena & Gatlin, 2013). Some of the data presented in this dissertation confirm the results of these previous studies. For example, the results of the present study found TAs with more moderate beliefs (i.e., a combination of traditional and reform) shifted their beliefs in response to interactions with students; however, similar to Lotter and colleagues (2006), there were no observable trends in the direction of that shift.

What is unique about this study is the understanding of the relationship between beliefs and practice for TAs with strongly held traditional or reform-based beliefs. Multiple data sources suggest these TAs' experiences in the lab made their beliefs more resistant to change. In other words, similar experiences were interpreted differently based on a TA's beliefs, regardless of whether the beliefs were traditional or reform-based, and these interpretations further confirmed the TA's beliefs. These results are in contrast to the previous literature that shows teaching beliefs promote change in practice or practice promotes changes in teaching beliefs (e.g., Anderson, 2002; Kazempour, 2009; Lotter et al., 2006; Sandi-Urena & Gatlin, 2013). This new understanding of practice-impeding-beliefs for TAs may be useful when attempting to explain lack of change in either practice or beliefs.

Researchers also allude at the importance of TA self-efficacy on their teaching (Kendall & Shussler, 2013; Luft et al., 2004); however, only one study of TAs examines the relationship between self-efficacy and practice (Bond-Robinson & Bernard Rodriques, 2006). The qualitative data presented in this dissertation conflict with the conclusions drawn by Bond-Robinson and Bernard Rodriques (2006) that TAs "lacked confidence to teach the underlying chemical concepts of the lab because he or she needed to understand the chemical topic better" (p. 322). The data from the present study suggest that TAs with inappropriately high perceptions of their content knowledge did not interact with students in ways that elicited any change in their confidence about their content knowledge. Thus, TA's with high perceived confidence did not recognize the need to improve their understanding of topics. Conversely, TAs with falsely low confidence in their content knowledge engaged students in active learning opportunities that extended their own content knowledge, which made them question their own content knowledge. This dissertation provides the first evidence that TAs: 1) may believe they know their content when they may not, and 2) perceived confidence and actual content knowledge may influence practice.

Theory-driven TA Research

When examining the literature on TAs and TA training from a theoretical perspective, the majority of studies discuss TA learning in constructivist terms; that learning is based on prior experiences and social interactions. Much of the literature states TAs teach how they were taught through traditional instruction and that professional development, interactions with students in lab, and relationships with mentors impacts the learning process for TAs (Addy & Blanchard, 2010; Bond-Robinson & Bernard Rodriques, 2006; Calkins & Kelly, 2005; Luft et al., 2004; Sandi-Urena et al., 2011). This dissertation is only the third study to understand TAs learning how to teach using theory-driven research and adds to this body of literature by continuing to build a picture of factors that influence TAs' instructional practices.

Two studies utilize situated learning and cognitive apprenticeship to understand TAs (Bond-Robinson & Bernard Rodriques, 2006; Dotger, 2011), and the use of situated learning in the present study builds upon this work. One previous study emphasized videotaped observations, formative feedback, and reflection in professional development and found these components increased TAs pedagogical content knowledge (inclusive of content knowledge) used in a traditional chemistry laboratory course (Bond-Robinson & Bernard Rodriques, 2006). This dissertation extends the theory-based research on situated learning to inquiry-based contexts and found similar components of professional development promoted change in TAs' content knowledge. Given that content knowledge in a particular course is similar regardless of the method of teaching, the similarities in these findings are to be expected.

Dotger (2011) used a lesson study approach within a situated framework, where TAs reflected on, engaged in collaborative discussions, and developed lessons for their teaching of a science lecture course. The author found this method promoted change in TAs' beliefs about teaching and learning, which conflicts with the results from this study that suggest TA beliefs were not changed through the use of a professional development informed by situated learning theory. The present study did not utilize lesson study, which may be one reason for the conflicting results. An alternate explanation for the conflicting results may be the implementation of situated learning theory compounded by the number of TAs engaged in the professional development. Dotger (2011) emphasized a community of practice and reflection components of situated learning theory model while working with only four TAs. The present study incorporated a community of practice, reflection, cognitive apprenticeship, authentic context, and stories/language with the professional development but had eight times the number of TAs (32 total, 14 in the study) engaged in the professional development. The focus on only some aspects of situated learning may better promote changes in beliefs as observed with Dotger (2011). Alternatively, the limited ability to provide each of the 32 TAs with individualized support in this dissertation through the cognitive apprenticeship model (e.g., model, coach, fade) may have precluded changes in beliefs.

No TA studies examine how situated learning theory impacts TA confidence, so this dissertation is the first to do so. The present study found that the implementation of situated learning theory in the professional development was not sufficient to align TAs' confidence and content. This conflicts with the results of a previous study of elementary pre-service teachers that found a situated learning approach used in a methods course significantly improved both the teachers' content understanding and self-efficacy (Bleicher & Lindgren, 2005). Bleicher and Lindgren's (2005) implementation of situated learning theory focused on authentic practice (e.g., going through hands-on activities similar to students), participation in a community of practice (e.g., discussions of the activities), and reflection (e.g., writing about the activity), similar to the components of situated learning experienced by the TAs in this dissertation.

What differed in the two approaches was the time spent by Bleicher and Lindgren (2005) re-teaching concepts participant's felt the least comfortable with, a practice not utilized in the present study's TA professional development. Formative assessment and re-teaching concepts to TAs through additional hands-on activities may facilitate alignment between content knowledge and confidence about content knowledge by helping TAs better understand their strengths and weaknesses in the content. Another possible explanation for the differences in the present study and the results found by Bleicher and Lindgren (2005) may be that TAs in the present study simultaneously taught while engaging in the situated learning theory-based professional development, whereas pre-service teachers had no opportunities to teach during the methods course. Further, pre-service teachers choose a career in teaching while TAs are required to teach as a component of pursuing a career in research, making them two different populations of teachers. TAs experiences appeared to influence their confidence in teaching, so the differences between TAs and pre-service teachers may suggest that a situated theory framework alone may not be able to change TAs' confidence during the process of teaching.

From a theoretical perspective the perceptions teachers hold of themselves in a particular role is an important factor to consider in undergraduate laboratory instruction (Finson, 2001; Sandi-Urena & Galtin, 2013). The literature review provided an overview of TAs' perceptions (Figure 7), and results from this dissertation provide additional evidence and detail about what may impact TAs' perceptions of their teaching (Figure 10). First, the literature suggests teaching, research, and coursework are all influential factors on the TA, and while not the focus of this dissertation, should be included in the construction of TAs' perceptions of themselves as a teacher. This dissertation examined TAs teaching and found five main factors impact this part of TAs perceptions: prior experiences, current interactions, content knowledge, beliefs, and confidence.

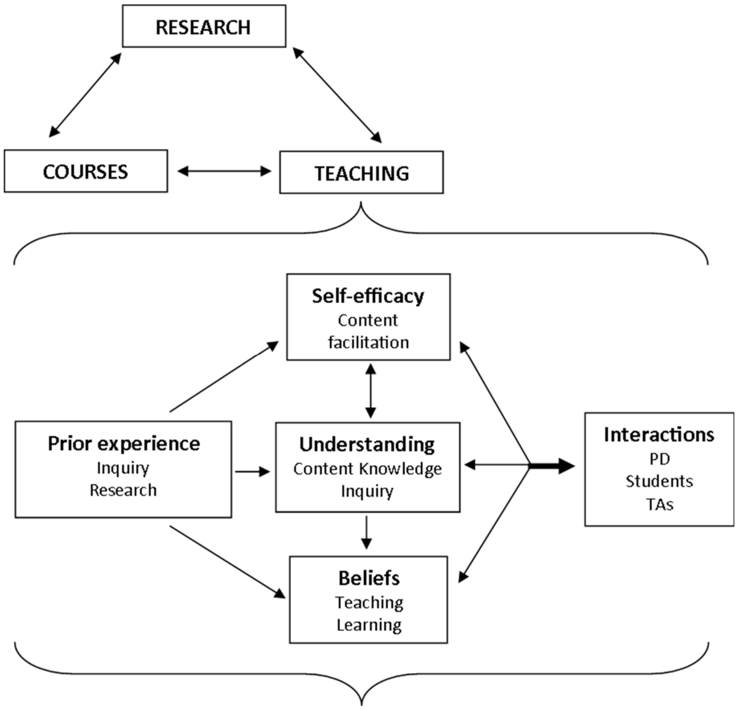

Figure 10. Factors Influencing TA Perceptions of Teaching.
Arrows within the teaching component are proposed relationships based upon evidence from this dissertation.

Evidence from this study indicates that prior experience appeared to inform TAs' confidence, understanding, and beliefs, and all of these characteristics combined in different ways for different TAs to shape their interactions with students. The multiple interactions TAs encountered throughout the semester also influenced TA characteristics, and in this study these interactions appeared to confirm rather than change TAs characteristics. There also existed evidence in this study of recursive relationships between confidence and understanding, but there was not enough evidence to suggest beliefs influenced understanding or confidence. This figure does not address the relationships between factors within the same category (i.e., how the PD influenced TAs interactions), which illustrates the complexity of factors that influence TAs' perceptions of themselves as teachers and ultimately TAs' practice.

Summary

In summary, the present study used multiple data sources to provide a more in-depth understanding of TAs than previously found in the literature. This dissertation is one of only a few studies examining TAs and students in an inquiry-based laboratory and is the first to do the following: 1) directly measure TA content knowledge rather than assume content knowledge from a degree, 2) use multiple data sources to identify TA beliefs, 3) characterize TA responsibilities in an inquiry-based laboratory using observational data, 4) examine TA-student interactions in an inquiry-based laboratory, and 5) use situated learning theory and social constructivism to understand TAs' content knowledge, beliefs, and confidence and how that influences TAs' practice.

This study is also the first to propose that TAs' beliefs may be hindered by their practice and that TAs' confidence and actual content knowledge and/or practice may be at odds. Further, a situated learning theory framework may be sufficient to improve TAs' content knowledge but not necessarily to promote change in their beliefs or confidence in teaching. All of these varied characteristics impact TAs' perception of their teaching, which helps better understand the TA and their role in the undergraduate laboratory context.

Student Learning in the Undergraduate Laboratory

Both qualitative and quantitative data were gathered and analyzed for this dissertation to better understand the impact of TAs' content knowledge, beliefs, confidence, and practice on student learning in the laboratory. This study bridges multiple bodies of literature to build a new area of research that examines the relationship between TAs and student learning in the undergraduate laboratory. The section begins with a discussion of how the student learning outcomes of this dissertation add to current research on undergraduate student learning. Examination of TA characteristics and student learning in light of previous studies follows. The section concludes with a discussion on theory-based research on student learning and how this dissertation informs this body of research.

Understanding Student Learning

Previous studies on student learning in the undergraduate laboratory found students learn more knowledge (i.e., facts, concepts), process (lab techniques, scientific practices), and nature of science (i.e., how science works) in inquiry-based laboratories than in traditional laboratories (e.g., Lord & Orkwiszewski, 2006; Russell & Weaver, 2011; Suits, 2004). The present study does not compare traditional and inquiry-based laboratories but adds to the literature on student learning as it is the first to identify predictors of students' content knowledge survey scores at the end of the semester. For this dissertation, students' gender, previous experience, and ethnicity were significant variables that predicted post-survey scores and may be important for researchers and instructors to consider in students' learning in an inquiry-based laboratory. Further, concurrent enrollment in the general chemistry lecture course was not a significant predictor of students' post-survey scores, suggesting the significant pre/post changes observed for students in the lab may be attributed to their experiences in lab. No other study to my knowledge has illustrated that student learning gains in the laboratory are unrelated to the associated lecture course.

As evidenced in previous studies, content knowledge is not the only domain of knowledge students can learn in an inquiry-based undergraduate laboratory (e.g., Basaga et al., 1994; Brickman et al., 2009). Multiple qualitative data sources in this study revealed that students learned more than content knowledge in the guided inquiry laboratory. For example, observational data of TA-student interactions provided evidence that TAs engaged students in discussions about process skills (i.e., lab skills and scientific practices) and that students could demonstrate their ability to enact these skills. The triangulation of data sources provided strong evidence that content knowledge was not the predominant learning outcome; TAs, students, and my own perception of the most important learning in lab focused on process skills. While content knowledge was the most straight forward outcome to measure, it did not capture the breadth of learning that occurred in the guided inquiry laboratory.

TA Characteristics and Student Learning

This study bridges the literature on TAs and student learning in the undergraduate laboratory and examines how TA characteristics impact student learning. In this study, TAs' quantitative content, beliefs, and confidence scores were not significant predictors of student post-survey scores. The lack of significant relationships between the TA and student contradicts a plethora of K-12 studies suggesting teachers' content knowledge, beliefs, and self-efficacy impact student learning (e.g., Diamond et al., 2014; Geddis, Onslow, Beynon, Oesch, 1993; Goddard, Hoy & Hoy, 2000; Love & Kuger, 2005; Ross, 1994; Salder et al., 2013; Tschannen-Moran & Barr, 2004). This may indicate the role of the TA is not as important to student learning as a teacher is in K-12 instruction.

However, it may be possible that the quantitative TA characteristics used as predictors did not capture TAs' impact on student learning. Examination of the qualitative data as it relates to the literature provides evidence for this claim. Using different instruments to measure TAs' characteristics may provide more complete measures of TA self-efficacy, beliefs, and content knowledge. For example, the use of a card sort for identifying TAs' beliefs (e.g., Harwood et al., 2006) or focusing on chemistry misconceptions to assess TAs' content knowledge may reveal these characteristics may impact student learning. There also existed strong, positive correlations between TAs' confidence and teaching beliefs, so there may be a characteristic undefined in the literature that relates beliefs and confidence. Future work should focus on developing and assessing TAs' characteristics to better understand the possible relationships between TAs and students in an inquiry-based laboratory context.

When comparing the present study to a previous study of 22 high school teachers implementing an ecology curriculum, both studies found student demographics predicted much of the variance and that teachers' beliefs and experiences were not predictors of students multiple choice content scores (McNeill, Pimentel, & Strauss, 2013). This dissertation extends this research to illustrate student characteristics play a more important role in student learning content than teacher characteristics. The authors in that study also quantitatively measured teachers' self-reported time spent on inquiry time and time spent on direct instruction, and found these practices were significant predictors of student outcomes. TA practice was not quantified for this dissertation and was not a factor included in the prediction equation; however, the research on teachers suggests TA practice may play a role in predicting student content knowledge. Correlation and regression data in the present study revealed students' gender, ethnicity, and previous chemistry course work were important factors that predicted students' learning of content knowledge. A focus on understanding and examining socio-cultural factors may also elucidate TA-student interactions that exacerbated these student-related factors and prevented non-Caucasian and female students from performing as well as their counterparts.

Theory and Student Learning

Piaget's Mental Model and Integration of Learning have been used to explain the active construction of knowledge by undergraduate students (Abraham, 2011; Barber, 2012). In the literature review I proposed a model of student learning to better understand how social constructivism influences this process (Figure 6). The results from laboratory observations in this dissertation provide preliminary evidence of how students learn, which suggests the proposed literature-based model is incomplete. I propose that students may construct knowledge differently depending on the domain of knowledge being learned (Figure 11). Further, the proposed model in Figure 11 increases in complexity as the TA-student interactions and other prior experiences influence different parts of the student learning process differently.

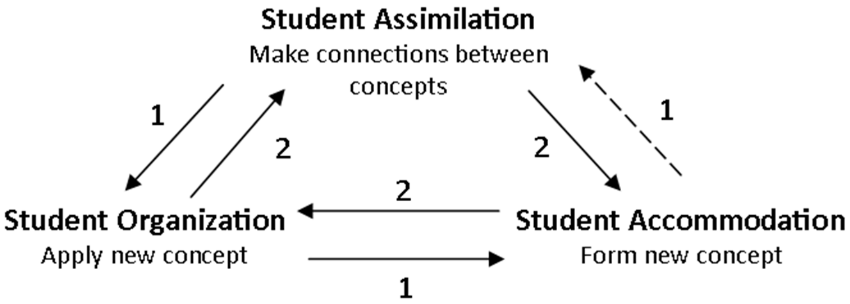

Figure 11. Theoretical and Empirical Understanding of Student Learning in the Undergraduate Inquiry-based General Chemistry Laboratory.
1 = Integration of learning process for concepts and laboratory skills. 2 = Piaget's Mental Model process for scientific practices and nature of science.

Observational data and TA interviews in this study revealed that students may learn chemistry concepts and laboratory skills through an Integration of Learning process (1, Figure 11). Observations and my own understanding of the course suggest students may have successfully learned concepts if they did their own research prior to lab (connection/assimilation) and applied the concepts during experimentation (application/organization) through TA facilitation. Students were observed creating new concepts during presentations and TA-led discussions (synthesis/accommodation). These newly synthesized concepts were meant to be utilized during subsequent experiments, but laboratory observations suggested students did not make these conceptual and laboratory connections. The nature of TAs' interactions during the accommodation and organization process may have facilitated or hindered this process of learning. For example, didactic TA approaches observed in this study prevented students from applying concepts from their own research whereas facilitative and student-directed TA approaches promoted students' application.

Conversely, interview data and students' self-report of learning suggest scientific practices and nature of science may have been learned through a model more representative of Piaget's Mental Model (2, Figure 11). Some TAs were observed helping students make explicit connections between the laboratory and scientific practices and nature of science during experimentation and presentations (connection/assimilation), and students may have created a new understanding of these learning outcomes in their laboratory reports (synthesis/accommodation); however, this was not directly observed. Students built upon their understanding of scientific practices and nature of science by applying these ideas to future projects (application/organization) as suggested by interviewed TAs. Again, TAs' interactions could facilitate or hinder students learning of nature of science and scientific practices.

There exists additional theory-based research examining student learning specifically in undergraduate laboratory contexts, and the present study also adds to this body of literature. However, less than half of the studies that rigorously examined student learning in the undergraduate laboratory mention a theoretical framework, and most use the theory to justify the use of an inquiry-based curriculum (Chatterjee et al., 2009; Hall & McCurdy, 1990; Russell & Weaver, 2011). Only one uses theory to drive the research study; however, they implement the theory in an unintended way (Xu & Talanquer, 2012). The researchers in this study utilized a sociocultural framework to understand the student-student interactions in the laboratory and used live observations, rather than multiple methods, to examine these interactions. Therefore it is unclear whether the claims made by the authors are representative of the inquiry-based laboratory. This dissertation used multiple methods to triangulate data to provide readers confidence in the results presented and is the first study to use theory-drive research in examining student learning in the inquiry-based laboratory.

Summary

In summary, the quantitative results from this dissertation are the first attempt of any research study to connect TA characteristics to student learning outcomes. When comparing the results with the qualitative results as well as previous research in other bodies of literature, it is likely the quantitative measures may not have captured the breadth of student learning or the depth of TA characteristics. The literature provides possible alternative methods for measuring these variables that may better capture teacher characteristics, practice, and student learning outcomes.

Results from the present study add to the literature on how students learn and suggest the learning cycle may differ depending upon the type of learning occurring in an inquiry-based general chemistry laboratory. Previous studies examining student learning in the undergraduate laboratory rarely discuss or effectively use a theoretical framework to drive the research. Social constructivism was the methodological approach used in the present study that was fully integrated throughout the data collection, analysis, and results to better understand student learning.

Implications & Future Research

This dissertation provided an in-depth look at 14 TAs in a mid-sized Mid-Atlantic university who experienced an intensive professional development and taught a project-based, guided inquiry general chemistry laboratory curriculum to 713 undergraduate students. The study is the first study of undergraduate inquiry-based laboratories to bridge the gap in TA and student learning literature to begin a new body of literature that accounts for both the TA and the student within the curriculum.

While these results add to this newly developed TA and student learning undergraduate inquiry-based literature, the context specific examination of TAs and students in this study as well as sub-group sample sizes limit the generalizability of these results beyond the present general chemistry laboratory course. Similar studies of TAs and students in another inquiry-based general chemistry laboratory course are warranted and may reveal relationships between TAs and students that confirm or conflict with the results from this study.

Despite the limited generalizability of this dissertation, there are important implications of this work and possible future directions that may further the research in this field. First, this dissertation informs the use of various quantitative instruments used to measure TA and student variables. Suggestions for modifications and changes to instrumentation are discussed below. Second, results from this dissertation reveal how modifications to a situated learning theory framework for professional development may promote changes in TAs characteristics and practice. Finally, this dissertation provides insight into the original literature-based conceptual framework (Figure 7) for understanding TA and student learning in the inquiry-based undergraduate laboratory context.

Instrumentation. This dissertation's professional development pilot study found TAs perceived many components of the professional development helpful in supporting their implementation of the inquiry-based laboratory curriculum (Wheeler et al., in review). However, quantitative evidence from this dissertation suggests this is not sufficient to change TAs' content knowledge, beliefs, or confidence and that these characteristics may influence TAs' practice as well as student learning, as evidenced by the qualitative data. It may be that the professional development was effective but the instruments were unable to capture the differences. The use of modified instruments to measure these characteristics may be able to better capture quantitative changes over time. These instruments may also be able to measure more nuanced differences between TAs that were not evidenced in the present study.

The use of a multiple choice survey of TAs' content knowledge failed to capture some of the differences in content knowledge found in the qualitative data. This suggests a more robust framework, rather than just science content knowledge, may be able to better capture TAs' content. One such framework is pedagogical content knowledge framework (PCK), which focuses on the curricular decisions teachers make based on their knowledge about teaching (Shulman, 1986). However, this is not appropriate for the context of TAs' teaching as they implement a pre-developed curriculum and have little choice in the materials they use in their instruction.

A more appropriate framework for understanding TAs' content knowledge may be science knowledge for teaching (SKT), which organizes content knowledge specific for the subject separate from pedagogy (Nixon, Campbell, & Luft, 2015). In this framework, three domains are used to understand content knowledge specific for teaching: core content knowledge, specialized content knowledge, progressional content knowledge. Using this framework in future studies for assessing TAs' content knowledge may better identify how different aspects of content knowledge change as a result of professional development and how it impacts student learning. For example, the TA interview protocol used in this dissertation could be modified to include content and scenario-based questions to probe TAs' SKT. Two previously developed SKT interview questions related to 'Conservation of Mass' and 'Chemical Equilibrium' ask participants to describe the phenomenon, and then explain student errors in the related scenario (Nixon et al., 2015). These additional interview questions would help triangulate observational data and elucidate a more nuanced understanding of TAs' content knowledge for teaching.

TAs' quantitative beliefs in the present study were measured using various components of previously validated instruments that may not have accurately captured their beliefs. Open-ended questions and interview data allow for elaboration that cannot be captured in a Likert question and have been suggested as a more appropriate method of accurately assessing TA beliefs (e.g., Luft & Roehrig, 2007). Thus, further modification of the Teaching Belief Interview and rubric developed by Luft and Roehrig (2007) beyond this dissertation is needed to understand how best to capture TA beliefs and transform the qualitative data for subsequent use as a predictor variable for student learning.

The present study focused on measuring TAs' confidence in teaching rather than self-efficacy. Examining TAs' confidence in teaching as well as outcome expectations, or a teacher's outlook on students' ability to learn, may elucidate potential differences in

TAs' quantitative self-reported teaching self-efficacy not found when just measuring teaching confidence. Outcome expectations is a component of the Science Teaching Efficacy Belief Instrument (STEBI-B) (Enochs & Riggs, 1990) that could be added to confidence instrument used in this study and used in subsequent studies.

Using observation protocols to quantify observations and understand the impact of TAs' content knowledge on their interactions with students may illuminate latent relationships between TAs' practice and student outcomes. Instruments such as the Reformed Teacher Observation Protocol (RTOP) (Piburn et al., 2000), Electronic Quality of Inquiry Protocol (EQUIP) (Marshall, Smart, & Horton, 2009), Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith, Jones, Gilbert, & Wieman, 2013), or Science Teacher Inquiry Rubric (STIR) (Bodzin & Beerer, 2003), are possible protocols that would provide quantitative data on TAs' practice that could be used as a predictor variable for student post-survey scores.

Future research should utilize the different observation instruments to assess how TAs and students interact with each other in the inquiry-based laboratory context. For example, using the four different observation protocols on the same set of observations would provide different data about TAs' practice. Comparing and contrasting the data obtained from each instrument may help identify the most appropriate instrument to capture the TA-student and student-student interactions. Use of an observation protocol that best characterizes the TA-student interaction may also be used to capture TAs' interactions of students with differing gender and ethnicity. This may help identify how TAs interact with certain subgroups of students that could then be addressed in professional development to help reduce differences in male/female and Caucasian/non-Caucasian students' content knowledge learning.

A more complete assessment of students' self-reported learning may provide insight into the most appropriate measure of student learning for the inquiry-based laboratory. One area of student learning not extensively studied at the undergraduate level is students' and TAs' understanding of the nature of science and the nature of inquiry. The use of the Views of Nature of Science (VNOS) or the Views of Scientific Inquiry (VOSI) instruments (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Schwartz, Lederman, & Lederman, 2008) may yield different evidence of student learning and different ways TAs impact these learning outcomes. Further, previous research found explicit nature of science instruction is vital for students to understand the construct (e.g., Bell et al., 2011). Analyses of students' self-reported data in the present study suggest engagement in the project-based guided inquiry curriculum may be sufficient to promote an understanding of how science works. Future studies on the undergraduate general chemistry laboratory context that examine TAs' practice of explicit nature of science instruction, students' pre/post understanding of the nature of science, and the use of a validated instrument to measure understandings (e.g., VNOS) are warranted to validate this claim.

Situated learning theory and TA professional development. Results of this study suggest the use of a situated learning professional development was not effective in changing TAs' confidence or beliefs. One way to promote change and alignment between confidence, beliefs and practice may be by introducing cognitive conflict for

TAs as used in conceptual change models (e.g., Posner, Strike, Hewson, & Gertzog, 1982; Windschitl & Andre, 1998). In a study of an inquiry-based professional development for teachers, Rushton et al. (2011) found making explicit links between inquiry and content during professional development made teachers realize they were not teaching inquiry. A more explicit method of connecting inquiry to content in TA professional development may produce cognitive conflict and allow TAs to realize they do not know their content or are not effectively facilitating student learning. The use of peer observations, modeling, discussion, and reflection in the TA professional development during the fall 2014 may have initiated the change process but may not have been enough to overcome the false confidence some TAs held about their own content knowledge. One approach to overcome this lack of change and create cognitive conflict for TAs may be the use of video observation and explicit discussion of areas of strength and weakness in their practice. The use of additional hands-on activities to create cognitive conflict may also be helpful in promoting change in TAs' beliefs or confidence, as observed in Dotger (2011).

Previous research and the present dissertation results provide evidence that the following changes to the situated learning theory professional development may be beneficial for TAs teaching in the guided inquiry general chemistry laboratory context: 1) a smaller head TA to TA ratio (i.e., expert to novice) ratio should be utilized to engage TAs in more frequent and intense cognitive apprenticeship and encourage all TAs to engage in the community of practice, 2) the cognitive apprenticeship model should be modified to support TAs' use of certain types of questions (e.g., open-ended) and to teach

TAs how to encourage student-student interactions during experimentation and discussions (e.g., student-driven role), 3) the TA reflections and debrief discussions should be modified to explicitly assess and reference TAs' beliefs about inquiry-based instruction, and 4) video reflection and hands-on activities that promote cognitive dissonance for TAs should be incorporated. Future research should examine the modified professional development based on TAs' perceptions as well as by changes in TAs' content knowledge, teaching confidence, teaching beliefs, practice, and student outcomes. These results could be compared to this dissertation's results to understand the optimal professional development and TA characteristics that increase student learning. Finally, expanding the professional development to other inquiry-based chemistry laboratory courses and assessing fidelity of implementation may help identify whether the professional development is transferrable and could be expanded across departments and universities.

Conceptual framework revisited. Results from this dissertation have informed the research and literature examining TAs' perception of their role as a teacher and how their students learn. These can be combined into an overall conceptual framework illustrating the complexity of the possible factors that contribute to students' learning in an inquiry-based undergraduate laboratory (Figure 12). From this study and previous studies, a variety of different student outcomes have been identified and measured in the undergraduate laboratory. Applying different theories of student learning within a social constructivist lens to this dissertation revealed that students may learn different domains of science differently; learning scientific practices and nature of science occurs through a cyclical connection, synthesis, application process whereas learning concepts and laboratory skills occurs through a mirror process of application, synthesis, and connection. Qualitative data from a subset of students and observations of the laboratory suggest students may learn more scientific practices and nature of science in the guided inquiry laboratories than concepts and skills, as illustrated by the size of the student learning cycles. Previous studies suggest student attitudes and beliefs shape the learning experience (e.g., Osborne et al., 2003; Pajares, 1996), and the present study found students demographics and prior high school chemistry experience are predictors of students content knowledge understanding.

While TAs' quantitative characteristics were not directly linked to students' content knowledge, the different types of interactions TAs utilized in the laboratory appeared to relate to students' ability to understand concepts and be able to do certain scientific practices. All five observed TAs experienced traditional general chemistry laboratory instruction as a student, which provides little opportunity for experience with scientific practices. Yet all of these TAs engaged students to varying degrees in data analysis, communication of results, and evaluation of ideas. Since instructors typically teach the way they are taught (e.g., Sharpe, 2000; Luft et al., 2004; Dotger, 2011), observation of these scientific practices suggests the change in curriculum may have promoted the observed interactions that differed from traditional instruction.

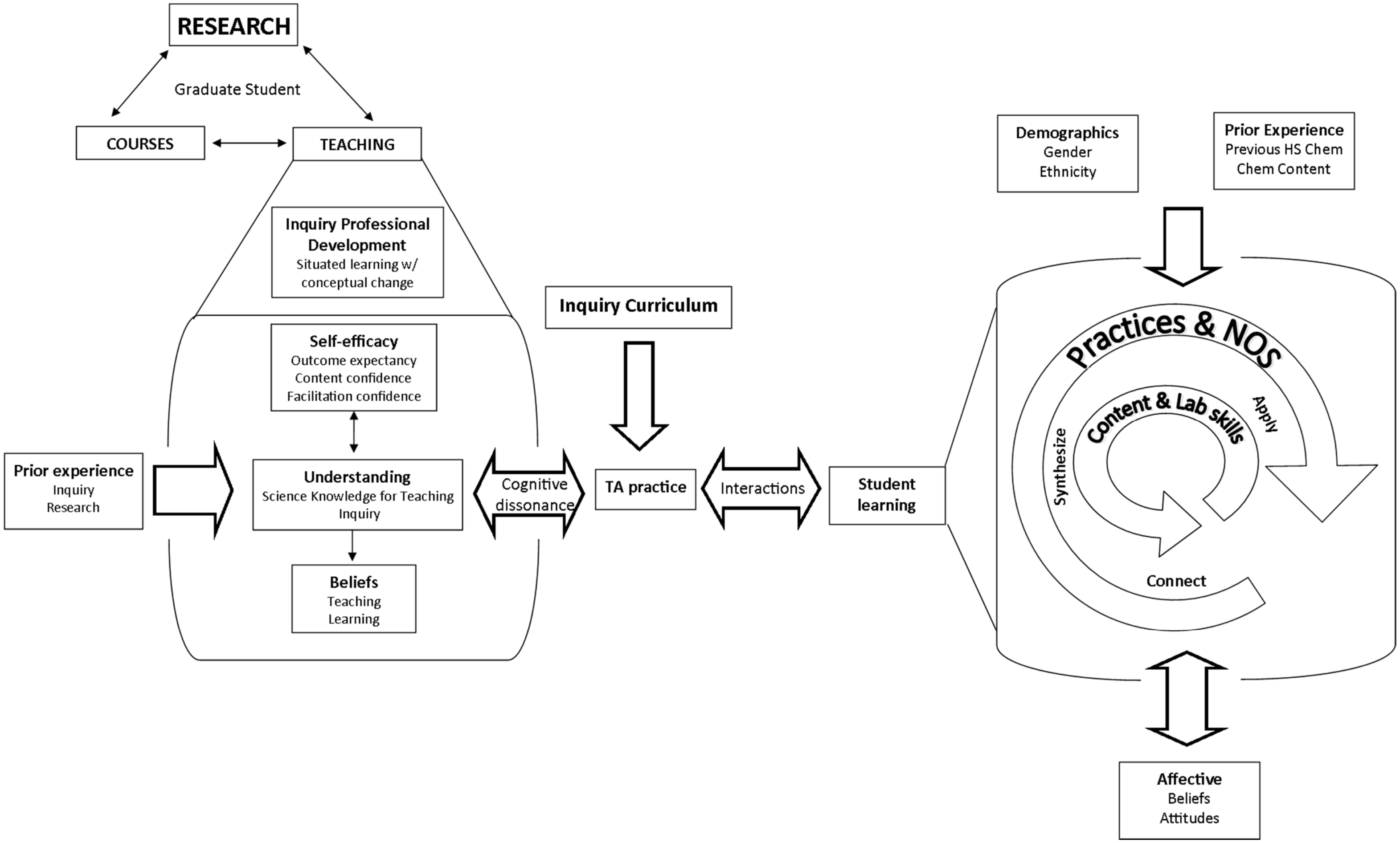

Figure 12. Conceptual Framework for Understanding Relationships between TAs and Students in the Undergraduate Inquiry-based Laboratory. Relationships and arrows based upon previous research and this dissertation's data. Further examination of the direction of arrows and order of relationships is warranted.

TAs' beliefs, confidence, and content understanding are all factors that influenced TAs' practice but were also influenced by prior experiences, the professional development, and their own practice. TAs' understandings may not just relate to content knowledge but science knowledge for teaching (SKT) as well as their understanding of inquiry. The use of an inquiry-based professional development embedded in a situated learning framework that promotes cognitive dissonance may provide the support needed to change TAs' beliefs and confidence. Creating cognitive dissonance between TAs practice and their perceptions of their characteristics may further facilitate changes that align these two.

For TAs, teaching is just one component that contributes to their overall role as a graduate student. Research predominates TAs time and effort in graduate school (Luft et al., 2004; Shannon et al., 1998) and should be a factor addressed when considering TAs as instructors. In addition, those TAs with no prior experience with inquiry had beliefs and confidence that impeded their practice in an inquiry-based laboratory. Future research should attempt to address each connection proposed in this conceptual framework (Fig 12) with research designs and methodological approaches that capture the complexity of the connections between TAs and students.

To bring this dissertation manuscript full circle, the larger goal of undergraduate education is to create scientifically literate citizens[9]. Qualitative data from this dissertation provides evidence that some students may have indeed become scientifically literate, and this learning process may have been enhanced through the inquiry-based curriculum and by TAs' interactions with these students. However, data revealed some TAs as well as students believed inquiry was not an effective method of instruction for the general chemistry laboratory because inquiry is too challenging, a sentiment that continually presents itself in the literature (e.g., Brickman et al., 2009; Brown et al., 2006; Sandi-Urena, Cooper, Gatlin, & Bhattacharyya, 2011). These inquiry-as-too-challenging beliefs may hinder students' scientific literacy gains. Thus, it is not only TAs but also the students that need to embrace the challenges of inquiry as promoting students' scientific literacy, a skill that will serve them in the future.

One promising piece of evidence from this dissertation was that TAs' positive experiences with inquiry as students may have promoted scientific literacy as they encouraged students to persevere through the frustrations and challenges of learning brought on by the inquiry-based curriculum. These undergraduate students may one day become graduate students and possibly TAs for undergraduate laboratories, and those with positive experiences may also perceive student frustration as an important part of the learning process. Therefore, in order to change the inquiry teaching culture, it is vital that

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[9] Scientific literacy is defined as possessing a conceptual understanding of science, having the ability to apply science to their lives, being able to solve scientific problems, and continuing to learn about science (NRC, 1996, pp. 15)

students experience inquiry with a TA who has reform-based beliefs and practices so they are open to teaching through inquiry in the future. Changes in laboratory course curricula and supporting TAs' implementation of inquiry is one small step in changing the state of undergraduate science education. This may help break the cycle of traditional beliefs and practice to make inquiry-based instruction and learning of scientific literacy the norm rather than the exception.

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APPENDICES

Appendix A

GENERAL CHEMISTRY LAB TA EXPECTATIONS
Fall 2014

Welcome to teaching General Chemistry laboratory! With the new guided inquiry approach to lab, your role as the TA has become even more important, and we appreciate all of the hard work you will be putting into working with your students. The purpose of this document is to outline the responsibilities and expectations of being a TA for General Chemistry lab. Please read everything carefully and do not hesitate to contact the head TA or instructor for clarification.

TA meetings

During the semester TAs will be required to attend a weekly TA meeting. Attendance at every meeting is mandatory. You will be responsible for reading over the TA notes and rubrics from Online for the following week's experiment. All TAs will be performing the labs. Each TA will also sign up to lead a discussion on content/student problems associated with a particular project. When you lead the discussion it is your responsibility to be an expert on the content, and we encourage you to attend General Chemistry lecture (if possible), read the textbook, and look up any other relevant information. Details will be discussed in the TA training.

Agenda:

- Discussion of grading issues
- Discussion of any other issues that arise
- TA-led project discussions
- Peer observation debriefs
- Teaching and reflecting on teaching

Time/Location:

TBD in CHEM 313 (time depends upon your schedules)

Laboratory

For any day you are in lab, you should keep in mind that you are a model of appropriate attire for the students (closed toe shoes, long sleeves, lab coat, long pants, safety goggles, hair tied back). You are also responsible for the safety of your students during lab. **Please arrive 30 minutes prior to your assigned lab period every week**. Check online for any last minute changes to the powerpoint slides, etc. Post experiment notes on the monitors for students to reference during lab. Please do not grade or complete other work during lab. Emailing and texting are not allowed for TAs during lab periods.

Each project can be separated into three categories; planning, experimenting, and presenting. In the guided inquiry approach, your role as facilitator is essential, and we encourage you to interact with students. Please reference the "Discourse" booklet used during the TA meeting for further details on how to interact with students during planning and experimenting. Summarized below are the primary activities for which you are responsible during each component of the project

Planning:

- Help students connect their prior and current experience
- Use discourse to facilitate student discussions of the planning questions and development of a procedure
- Give specific feedback, but do not tell students what to do
- Encourage students to use resources/videos on Online and do online research to answer planning questions
- Talk with the "Team Leader" of each team (or read student plan) to ensure students have a detailed plan for the following experimental day
- Only allow students to leave lab if plan is detailed enough (i.e., students must have approximate masses/volumes of reagents listed, as well as steps they will perform for the experiment)
- Your jobs is **not** to check for the correct answer – students may leave lab with a non-viable plan (as long as they aren't wasting chemicals)
- **The "Plan Writer" for each group turns in one plan at the end of the planning period (**all students sign the pledge, and you sign off)

Experimenting:

- Provide feedback to students on lab technique
- Ensure students are being safe in lab [The General Chemistry Teaching Assistant's Guide contains specific information regarding the safety equipment and emergency procedures for the general chemistry labs. *Should a student be injured, it is important that one TA stays with the student in the lab room while the other TA notifies Jan in the stockroom.*]
- Engage in discourse to help students modify their experimental procedures as needed
- Encourage students to run multiple trials, take detailed notes of their experiment, and make sure their data makes sense
- Encourage student-student interactions to obtain a deeper understanding of the underlying concepts associated with the project
- Share with students your own experience and be explicit about how they are acting as scientists
- Students email TA and lab members data (not to be checked by you unless needed, see grading responsibilities below)
- Students will plan for the following day after an experiment, so keep students on track in terms of time
- **After completing the experimental day, sign the bottom of each student's experimental section**
- **The "Summary Writer" for each team turns in one summary of their experiment**
- Before leaving lab, check to make sure all waste containers are closed, gas and water are off, lab benches are clean, etc.

- **Students complete an online post-lab quiz for the prior project before beginning experimental work for the following project**

Presenting:

- Each team emails their presentation and discussion questions to the TA 24 hours before lab
- Have student presentations and discussion questions organized into one powerpoint and loaded on the lab room desktop computer ready prior to lab
- Keep time of presentations to ensure all students present
- Facilitate 1-2 student questions following presentations by calling on students
- Facilitate whole group discussion following presentations (30-60 min)
- Grade presentations and discussion (see grading details below)
- Allow time for planning for the next project
- **Each group turns in a hard copy of their group write-up at the beginning of the presentation day**
- **Each student turns in a hard copy of their individual lab write-up at the beginning of the next lab day**
- **Each student completes an online peer evaluation by the beginning of the next lab day**

Absences:

If you have an emergency and cannot attend lab you are responsible for finding someone to switch with you. You must also let the head TA and the instructor know, preferably at least 24 hours prior to your absence. TA emails and availabilities (based on what people indicated at the beginning of the semester) will be located in the "TA Availability" google spreadsheet. Contact these first before sending an email to the entire group.

Office Hours

The goal of office hours is to facilitate conceptual understanding of chemical concepts, aid students in the analysis of data, and provide feedback for writing a laboratory report. We encourage you to use the TA notes, information from the TA meetings, lecture course textbook, and resources on the Online site to help guide students to the answer through questioning. Please **do not give students the answer directly**.

Location:

The 3rd floor back hallway of the Chemistry Building. Please be prompt to your office hours and plan to stay the entire hour. Office hours can be attended by any student regardless of their section.

Absences:

You are responsible for finding someone to switch with if you have a conflict. TA emails and availabilities (based on what people indicated at the beginning of the semester) will be located in the "TA Availability" google spreadsheet.. In an emergency, please let the intstructor know so that a note can be written on the board. We ask students to notify us if a TA does not show up for office hours.

Grading

There are a variety of assignments students will complete both individually and as a group through the course of the semester. It is your responsibility to grade the assignments in a timely fashion and record grades in an google spreadsheet and on Online (directions will be given on how to do this during the TA meeting). Since there are more than 1300 students enrolled in the lab, so we need to be consistent across sections when grading. Therefore there is an associated rubric at the end of the lab manual for each assignment. Grading sheets to be returned to students will be printed and left in the stockroom for you to use. Please see the Assignments section in the lab manual detailing the assignments for the course.

Returning graded work: You are to upload grades to Online, add them to your google spreadsheet, and pass back graded work the lab period following that in which the assignment is collected. We will be checking Online weekly and will pull data from your google spreadsheet twice during the semester for analysis. **Individual lab write-ups can be returned to students two weeks after they are collected.** See the “TA Calendar” for details on dates for deadlines. If you find you are getting behind on grading, PLEASE notify the head TA immediately. If you do not meet the return deadlines twice during the semester we will need to set up a meeting with Department Chair to discuss the status of employment.

TA Role

Example	Non-Example
Check to make sure students have a detailed enough plan to be executed in lab	Check to make sure students have a "correct" plan or a plan that will work
Encourage students who want to try a different experimental method that you are comfortable with	"Guide" all students into doing the same procedure
Sharing your own experience of how science works so students understand that not everything works perfectly the first time	Telling students "that's life" or blame the experiment for not working
Constantly circulating in order to ask probing questions and make suggestions of being more efficient during lab	Standing and waiting for students to approach you with questions
Remind students to think about their procedural limitations and how their data will help answer the project objectives	Tell students why their procedure will not work or what their data will tell them
Provide feedback on lab technique	Allow students to improperly use equipment
When a student says "I don't understand," asking them what it is they don't understand	When a student says "I don't understand," telling them what they should know
Have students explain to you their understanding of chemical concepts	Explain concepts to students with no student input
Confirm accurate content understanding or ask thoughtful questions to help foster content discussion with the group	Correct student understanding with no student input
Encourage students to look up content and/or lab procedures when content is inaccurate/inadequate and point students to lab manual for key words to search	Allow students to have an incomplete/inaccurate content understanding OR show students exactly what to search for
Have students with accurate content understanding explain to other students	Hold a mini-lecture at the front of the room

Most importantly, the TA's role is to hold students accountable for their own learning

Appendix B
Reflection on Teaching

Beginning of TA Training:

1. What is one thing you are most excited about teaching in the general chemistry labs?
2. What is one thing you are most nervous about teaching in the general chemistry labs?
3. What is one goal you have for teaching in the general chemistry labs?

Reflection on Discourse:

1. What did you learn about discourse?
2. What can you use from this session in your own teaching?
3. How will you integrate discourse into your teaching?

End of TA Training:

1. What is one thing you are most excited about teaching in the general chemistry labs?
2. What is one thing you are most nervous about teaching in the general chemistry labs?
3. What is one goal you have for teaching in the general chemistry labs?
4. How, if at all, have your ideas about teaching in the general chemistry labs changed?
5. What remaining questions do you have about being a TA for the general chemistry labs?

Peer Evaluation:

Reflect on the observation and the discussion of the observation.

1. Describe your experience observing, being observed, and discussing teaching. Was it helpful? Awkward?
2. How, if at all, have your ideas about teaching in the general chemistry labs changed?

End of Semester:

1. Looking back at your goals and what you wanted to improve on in your teaching, did you achieve these goals? If so, how? If not, why?
2. What, if anything, did you learn about teaching from this process?
3. How, if at all, have your ideas about teaching in the general chemistry labs changed?

Appendix C

TA Survey

Please answer the following questions to the best of your ability. For content-based questions you may use a calculator and periodic table if needed. Your responses will not be graded but will be used to guide the TA training and for research purposes if you provide consent. If you do not feel comfortable answering a question, please leave the question blank.

Content Multiple Choice:

1. Which of the following statements is TRUE?
   a. A covalent bond is formed through the sharing of electrons.
   b. Room temperature ionic compounds conduct electricity.
   c. Most covalent bonds are much stronger than ionic bonds.
   d. Once dissolved in water, covalent compounds conduct electricity.
   e. None of the above are true.

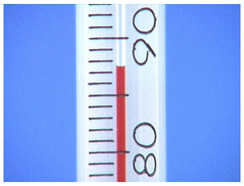
2. What is the concentration of nitrate ions in a 0.050 M $Ca(NO_3)_2$ solution?
   a. 0.025 M
   b. 0.150 M
   c. 0.100 M
   d. 0.050 M
   e. Cannot be determined from the information given

3. Which statement below is TRUE regarding solubility?
   a. Cooling water can help create a supersaturated solution.
   b. If a solid has a solubility of 2.5g/25mL, 7g of the solid will dissolve in 50mL of room temperature water.
   c. You can definitively identify an unknown solid based just on its solubility.
   d. If a solid does not dissolve immediately, it is insoluble.
   e. None of the above are true.

4. When added to water, which of the following will form an acidic solution?
   a. MgI_2
   b. KF
   c. NH_4Cl
   d. $NaNO_3$
   e. None of the above solutions will be acidic.

5. Read the temperature with the correct number of significant figures[10].

   a. 87°C
   b. 87.5°C
   c. 87.50°C
   d. 88.0°C
   e. 87.200°C



6. Which of the following must be the same before and after a chemical reaction?
   a. The sum of the masses of all substances involved.
   b. The number of molecules of all substances involved.
   c. The number of atoms of each type involved.
   d. Both (a) and (c) must be the same.
   e. Each of the answers (a), (b), and (c) must be the same.

7. True or False? When a match burns, some matter is destroyed.
   a. True
   b. False

8. What is the reason for your answer to question 8?
   a. This chemical reaction destroys matter.
   b. Matter is consumed by the flame.
   c. The mass of ash is less than the match it came from.
   d. The atoms are not destroyed, they are only rearranged.
   e. The match weighs less after burning.

9. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:
   a. less than the nail it came from.
   b. the same as the nail it came from.
   c. more than the nail it came from.
   d. It is impossible to predict.

10. What is the reason for your answer to question 10?
   a. Rusting makes the nail lighter.
   b. Rust contains iron and oxygen.
   c. The nail flakes away.
   d. The iron from the nail is destroyed.
   e. The flaky rust weighs less than iron

---

[10] Picture from chem.wisc.edu

11. One gram of each of the following compounds is mixed with 100mL of water. Which will form a solution that will conduct electricity?
    a. C_2H_5OH
    b. $MgCl_2$
    c. $Na_2C_2O_4$
    d. SO_2
    e. None of the above

12. What are the most likely products from the reaction of aqueous sulfuric acid and aqueous sodium hydroxide?
    a. Na_2SO_4(aq), H_2(g) and O_2(g)
    b. Na_2SO_4(aq) and H_2O_2(l)
    c. Na_2SO_4(aq) and H_2O(l)
    d. Na_2SO_4(aq) and H_2OH(aq)
    e. There is no reaction

13. Predict the product(s) of the following displacement reaction:
    $TiCl_4 + 2Mg$
    a. $Ti + 2MgCl_2$
    b. $TiCl_4Mg$
    c. $Ti + 2Cl_2 + 2Mg$
    d. $TiMg + 2MgCl_2$

14. You have 500.0mL of 0.100M aqueous $MgBr_2$. Which of the following statements are true?

Choose at least one answer.
   a. There are 500.0mL of solvent.
   b. For every liter of solution, there is 0.100 mole of $MgBr_2$.
   c. Water is the solute.
   d. If you add water to the solution, the molarity of $MgBr_2$ will decrease.

Inquiry Short Answer:

1. How would you define *scientific inquiry*?
2. How would you define *inquiry-based teaching*?
3. Describe what the TA and students are doing in a typical lab that emphasizes *inquiry.*
4. How would you define *guided inquiry*?
5. Describe what the TA and students are doing in a typical lab that emphasizes *guided inquiry.*

Confidence about Teaching:

1. How confident am I in my ability to (not at all confident, not very confident, somewhat confident, confident, very confident):
    a. Promote student participation in my lab?
    b. Make students aware that I have a personal investment in them and in their learning?
    c. Create a positive laboratory climate for learning?
    d. Think of my students as active learners, which is to say knowledge builders rather than information receivers?
    e. Encourage my students to ask questions during lab?
    f. Actively engage my students in the learning activities that are included in the syllabus?
    g. Promote a positive attitude toward learning in my students?
    h. Provide support/encouragement to students who are having difficulty learning?
    i. Encourage the students to interact with each other?
    j. Show my students respect through my actions?
    k. Let students take initiative for their own learning?
    l. Evaluate student's conceptual understanding of chemistry?
    m. Discuss in-depth chemistry content with students?

Beliefs about Teaching:

1. What do you expect your role to be as a TA in General Chemistry labs?
2. What do you believe is the best way students learn?
3. How would you describe an ideal chemistry lab? What are the students doing? What is the TA doing?
4. My implementing guided inquiry in the general chemistry labs will (extremely likely, somewhat likely, neutral, somewhat unlikely, extremely unlikely)
    a. help students learn to think independently
    b. cause frustration in students
    c. foster positive scientific attitudes and habits of mind
    d. make science relevant to the students' everyday
5. Please provide your opinion on the following statements (strongly disagree, disagree, no opinion, agree, strongly agree)
    a. Students learn science best grouped with students of similar abilities
    b. Inadequacies in students' science background can be overcome by effective teaching
    c. It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics
    d. Students should be provided with the purpose for a science lecture/lab as it begins
    e. At the beginning of lab, students should be provided with definitions for new scientific vocabulary that will be used
    f. Most science courses should provide opportunities for students to share their thinking and reasoning

  g. Laboratory courses should be used primarily to reinforce a science idea that the students have already learned in lecture
6. Thinking about your role as a teaching assistant for the general chemistry labs. How much emphasis do you think each of the following student objectives should receive? (none, minimal emphasis, moderate emphasis, heavy emphasis)[4]
  a. Memorizing chemistry vocabulary and/or facts
  b. Understanding chemistry concepts
  c. Learning science process skills (for example: observing, measuring)
  d. Learning how to communicate chemistry ideas effectively
  e. Learn how to evaluate arguments based on scientific evidence
  f. Learning about the nature of science (for example: scientific knowledge may change as new evidence is gathered, scientists work collaboratively)
  g. Learning about real-life application of chemistry
  h. Increasing students' interest in chemistry
  i. Preparing students for further study in chemistry

Background Experiences

1. What year are you in your program? (i.e., 3rd year undergraduate, 1st year graduate)
2. If you are a graduate student, what prior degree(s) do you have? Please indicate the type of degree and school(s) you received each degree.
3. Have you had any prior research experience? Yes/No
  a. Please indicate the general type of research (i.e., biochemistry, organic synthesis)
  b. Where was the research conducted? (i.e., during undergraduate in a faculty research lab, at a pharmaceutical company)
  c. How long were you involved in the research?
4. Have you had any prior teaching experience? Yes/No
  a. What did you teach? (i.e., undergraduate organic chemistry, high school physics)
  b. When did you teach?
  c. What were your responsibilities?
5. What experience, if any, have you had with inquiry teaching?
  a. As a student?
  b. As an instructor?
6. What made you decide to major in chemistry (undergraduate TAs) or get a Ph.D. in chemistry (graduate TAs)?
7. At this point, what do you intend to do when you graduate?

Demographics

1. How old are you?
2. What is your ethnicity?
3. Are you an international student? Y/N
4. Male/Female

Appendix D
TA Interview Protocol

This interview is to follow up on your experiences during the TA training and your answers to survey questions. This interview will be recorded and the tape will be destroyed after the data is transcribed. No identifying information will be used in the data analysis and the data will only be analyzed for the purposes of my course project.

1. First, I'd like to follow up on your background experiences
    a. When did your initial interest in science begin?
    b. Tell me more about your research experience
    c. Tell me more about your teaching experience
    d. What was your General Chemistry lab experience like?
2. I would like to ask you more about being a TA
    a. How do you describe your role as a TA?
    b. How do you believe you (will) maximize student learning in your laboratory?
    c. How will/do you know when your students understand?
    d. How do you believe your students learn science best?
    e. How do you know when learning is occurring in your lab?
3. I would like to ask you more about being in lab
    a. What, if at all, do you do to prepare for TAing?
    b. Describe to me how you feel about the content associated with the lab? (Probe: How confident are you with your content knowledge?)
    c. Describe how you feel about interacting with students in lab? (Probe: What do you do when students are planning? Experimenting? Presenting?)
    d. What are you most confident about in lab?
    e. What are you least confident about in lab?
4. You've been very helpful. Are there other thoughts are feelings you'd like to share with me to help me understand what the experience of being a TA has been like for you?

Appendix E

DESIGNING A CALCIUM SUPPLEMENT[11]

Many older people find that they have become susceptible to osteoporosis. In order to guard against this insidious ailment, doctors often recommend that people take a calcium supplement. There are a number of brands already on the market, including antacids such as Tums, and liquid supplements such as Mylanta. However, many people find these supplements "chalky," making them difficult or unpleasant to swallow.

Your task is to design and test a calcium supplement that could be taken as a clear liquid.

Criteria for Completing the Project:

Under no circumstances should you ever ingest any materials in the chemistry laboratory. Your criteria for making an acceptable solution should be:

- It is clear.
- It has a pH between 4 and 10.
- It contains minimally toxic materials (as indicated in the MSDS for this material).
- It has a known concentration verified experimentally so that people will know how much to drink to consume the required dose.

By the end of the project you should be able to:

- Know the solubility of various calcium salts
- Explain how to affect the solubility of an insoluble salt
- Understand the relationship between concentration, moles and volume.
- Calculate the concentration of calcium in solution from: 1) the mass of a salt and volume of solvent; 2) the recommended daily allowance of calcium; and 3) titration data
- Understand the purpose of a titration
- Calculate a % error and evaluate your experiment based upon a % error

Safety Notes/Waste Handling:

- Be sure to consult the MSDS for any compound you work with.
- Dispose of wastes in the labeled containers. Do not pour any wastes down the drain
- Use great care when transferring solutions of strong acids and bases.

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[11] Modified from Cooper, M.M (2012). Designing a Calcium Supplement. In *Cooperative Chemistry Laboratory Manual.* Clemson University. New York: McGraw Hill.

Equipment & techniques you may find useful:

- Use of Beral pipets
- Solubility and how to increase solubility
- Use of a buret and titrating

The cheapest source of calcium is calcium carbonate, and this will be your starting point because it will not be economically feasible to use any other sources of Ca^{2+} in a large-scale production.

Available Chemicals:

$CaCO_3$(s)	EDTA(s)	EBT indicator

Carboys out all semester – ***varying concentrations***

HCl (aq), $HC_2H_3O_2$ (aq). HNO_3 (aq), NaOH (aq), KOH (aq), H_2SO_4 (aq)

Lab techniques

Click on the link for one of the lab techniques you may find useful for your experiment. Follow the directions to practice this lab technique and answer the three questions in your lab notebook to be turned in with your plan. There are many different techniques that will be used in projects this semester, and you only need to practice one for each project. REMEMBER: Your team must choose an appropriate technique and you cannot repeat techniques during the semester. Your TA must sign your lab notebook to confirm you practiced your lab technique.

Possible lab techniques: Lighting a Bunsen burner, Cleaning & conditioning a pipet, using a conductivity probe, Diluting a solution, Evaporation, Filtration -vacuum, Performing a Flame test, Making an Ice Bath, Using a Mohr pipet, Using pH paper, Using a pressure sensor, Using a spectrophotometer, Creating a Stock solution, Measuring temperature, Completing a titration using indicator, Completing a titration using a pH meter, Correctly measuring volume, Using a Volumetric pipet, Weighing out solid material

Part I Planning Questions:

- How can you take calcium carbonate, which is insoluble, and chemically alter the compound so the calcium ions become soluble in water?
- How does altering the pH affect the solubility of calcium carbonate?
- What is the solubility of your calcium salt and recommended daily requirement (RDA) for Ca^{2+}? How will you use these values to make your calcium supplement solution?
- How will you insure the pH of your calcium supplement is within the acceptable range? What will you do if it is not within the acceptable range?

Part I Summary Questions:

- What chemical reactions did you perform to make the calcium carbonate soluble? Write an equation to show what happened.

- Give a brief synopsis of the techniques you used to make the calcium carbonate soluble.
- What is the $[Ca^{2+}]_{calc}$ and pH of your solution?
- How much of your solution would someone have to drink to consume the recommended daily requirement (RDA) for Ca^{2+}?

Part II Planning Questions:

- How will you experimentally determine the concentration of calcium in your supplement?
- How does the pH of your solution influence your experiment?

Part II Summary Questions:

- What is your $[Ca^{2+}]_{exp}$?
- How does $[Ca^{2+}]_{calc}$ compare to $[Ca^{2+}]_{exp}$?

LAB WRITE-UP:

For this project, your **group** will turn in the Experimental and Results section due the day of your presentation. You will **individually** complete the Discussion and Conclusion, due the week after your presentation. Use the write-up questions below to help guide your writing (**do not** write the answers to the questions as but integrate them into the appropriate sections – make sure to include all components of the sections according to the rubric). Always use proper grammar, format and include a list of references in ACS format!

Write-up questions:

1. How did you get calcium carbonate to dissolve? What is/are the underlying chemical process(es) that facilitate/hinder dissolution?
2. Was your pH within acceptable range? Why or why not? If not, how did you get the pH within the range? What is happening at the molecular level when the pH is changing?
3. What is the purpose of a titration? How did you use a titration to experimentally determine the concentration of calcium? If you did not use a titration, what process did you use and why did you choose to use this method?
4. What chemical reaction occurs during the titration that allows you to determine the concentration of calcium?
5. Evaluate the concentration of your solution. Were you successful in making your calcium supplement with the correct RDA? How do you know?
6. What experimental processes could be improved to make a calcium supplement with a more accurate concentration?
7. Why is it important to create soluble calcium supplements? Why is it important to experimentally determine the concentration of calcium in your supplement

Appendix F

Calcium Day 2 Experiment Chemical Concepts

To better understand the observation results, an understanding of the general methods students used to experimentally determine the calcium ion concentration is warranted. During the second day of lab, students all decided to use a titration as the method for determining the experimental concentration of their calcium supplement[12]. The purpose of a titration is to use a solution of known concentration, the *titrant*, to determine the unknown concentration of another solution, called the *analyte*. The observed color change of a third compound, called an *indicator*, indicates when the moles of the titrant and analyte are equivalent. From the known volume and concentration of titrant and the known volume of analyte, the concentration of the analyte can be calculated.

In this titration, called a *complexometric titration*, Eriochrome Black T (EBT) was the indicator, the calcium supplement solution was the analyte, and Ethylenediaminetetraacetic acid (EDTA) was the titrant. The EBT-calcium complex in solution starts pink at a basic pH, and when EDTA, an acid, is added to the solution it loses hydrogens and can bind positive calcium ions. The calcium will then be attracted to EDTA, uncomplex with EBT and bind with EDTA. Once all of the calcium complexes with EDTA, a color change will be observed as free EBT produces a blue color. This color change is called the *endpoint* and represents equivalent moles of titrant and analyte. The challenge with this titration is that EBT must be kept at a basic pH to produce a color change related to the complexation with calcium. Since EDTA is an acidic compound, this can be challenging without the use of a buffer, which the students did not have available. Students had a variety of strong bases available to alter the pH and pH paper to monitor the pH.

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[12] There were few methods students could use within the context of the lab that would help them experimentally determine the concentration of calcium ions. While students overall method of titration was, in essence, predetermined, students had to develop a procedure of how to execute this titration. Student's had to determine solution concentrations, equipment, and pH range for the titration and had to analyze the gathered data to draw conclusions about their calcium supplement.

Appendix G

Student Survey

Please answer the following questions to the best of your ability. For content-based questions you may use a calculator and periodic table if needed. Your responses will not be graded but will be for research purposes if you do not waive consent. If you do not feel comfortable answering a question, please leave the question blank.

Content Multiple Choice:

1. A sealed flask at room temperature contains helium and oxygen gases. If the total pressure is measured as 1.12atm, and the pressure of helium in the container is .78atm, what is the pressure of oxygen in the container?
   a. 1.90 atm
   b. 1.05 atm
   c. 0.73 atm
   d. 0.34 atm
   e. none of the above

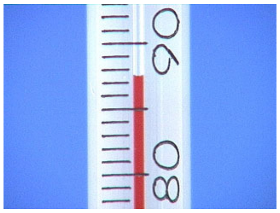
2. What is the concentration of nitrate ions in a 0.050 M $Ca(NO_3)_2$ solution?
   a. 0.025 M
   b. 0.150 M
   c. 0.100 M
   d. 0.050 M
   e. Cannot be determined from the information given

3. Which statement below is TRUE regarding solubility?
   a. Cooling water increases the amount of solute you can dissolve in solution.
   b. If a solid has a solubility of 2.5g/25mL, 7g of the solid will dissolve in 50mL of room temperature water.
   c. You can definitively identify an unknown solid based just on its solubility.
   d. If a solid does not dissolve immediately, it is insoluble.
   e. None of the above are true.

4. When added to water, which of the following will form an acidic solution?
   a. MgI_2
   b. KCl
   c. NH_4Cl
   d. $NaNO_3$
   e. None of the above solutions will be acidic.

5. Which temperature is written to the correct number of significant figures based on the picture of the thermometer [13].

   a. 87°C
   b. 87.5°C
   c. 87.50°C
   d. 88.0°C
   e. 87.200°C



6. You experimentally determine the volume delivered by a 5.00 mL pipet to be 5.02 mL. What is the % error of the instrument?
   a. 1.0%
   b. 0.40%
   c. 0.0040%
   d. 0.010%

7. Which of the following is a chemical property?
   c. rusting
   d. density
   e. malleability
   f. solubility

8. What is one way to increase the solubility of calcium carbonate?
   a. add a soluble salt
   b. add base
   c. add acid
   d. cool the solution
   e. calcium carbonate is soluble

9. Which of the following statements is false?
   a. The theoretical yield of a product is calculated based on the moles of starting reactants present
   b. % yield = (theoretical-experimental)/theoretical x 100
   c. A % yield greater than 100% suggests impurities in the product
   d. The experimental yield is determined from the actual mass of the product created

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[13] Picture from chem.wisc.edu

10. Which of the following statements is **true**?
    a. The vapor pressure of a volatile liquid increases with increasing temperature
    b. The vapor pressure of a volatile liquid increases with increasing molecular weight
    c. The vapor pressure of volatile liquids is independent of molecular weight
    d. The vapor pressure of water is higher than the vapor pressure of a volatile liquid

11. You mix one gram of each compound with 50mL of water. Which solution will be a good conductor of electricity?
    f. $C_6H_{12}O_6$
    g. $Ca(OH)_2$
    h. KCl
    i. H_2S
    j. All of the above

12. Which of the following compounds is **<u>insoluble</u>** in water?
    a. $CaNO_3$
    b. NH_4CO_3
    c. FeCl2
    d. BaSO4
    e. None of these compounds is insoluble in water.

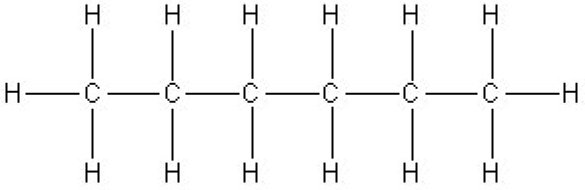
13. Predict the product(s) of the following displacement reaction:
    $3FeCl_2(aq) + 2Al(s) \rightarrow$
    e. $3Fe + 2AlCl_2$
    f. $Fe_3Cl_6Al_2$
    g. $3Fe + 3Cl_2 + 2Al$
    h. $3Fe + 2AlCl_3$

14. You have 250.0mL of 1.00M aqueous NaCl. Which of the following statements is **<u>false</u>**?
    e. There are 250.0mL of solvent
    f. For every liter of solution, there are 2.00 moles of NaCl.
    g. Water is the solute.
    h. If you add water to the solution, the molarity of NaCl will decrease.

15. Which of the following statements is **true**?
    a. A liquid with a low vapor pressure at room temperature will probably have a low surface tension and a high boiling point.
    b. A liquid with a low vapor pressure at room temperature will probably have a high surface tension and a high boiling point.
    c. A liquid with a high vapor pressure at room temperature will probably have high intermolecular forces and a low boiling point.

d. A liquid with a low vapor pressure at room temperature will probably have high intermolecular forces and a low boiling point.

16. What type of intermolecular forces must be overcome when liquid hexane[14] vaporizes?



n-hexane
C_6H_{14}

a. London forces
b. dipole-dipole forces
c. hydrogen bonds
d. covalent bonds

17. You have an unknown solid metal object. Use the following table of properties to identify the metal found in the unknown object.

Metals	Mass (g)	Volume (cm^3)	Reaction with acid	Color
#1	20.12g	4.0cm^3	some bubbling	dark silver
#2	35.99g	6.2cm^3	no bubbling	shiny orange
#3	49.99g	5.2cm^3	vigorous immediate bubbling	light silver
Unknown	50.25g	10.0cm^3	minimal bubbling	light silver

a. Metal #1
b. Metal #2
c. Metal #3
d. none of the above

18. What is the purpose of a titration?
a. To identify an unknown compound
b. To measure the rate of a reaction
c. To verify the pH of a solution
d. To determine the concentration of a solution

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[14] Image from http://science.pc.athabascau.ca/reagentstud.nsf/

19. What is the name of H_2SO_4?
    a. sulfurous acid
    b. sulfuric acid
    c. hyposulfuric acid
    d. hydrosulfurous acid
    e. dihydrogen sulfur tetraoxide

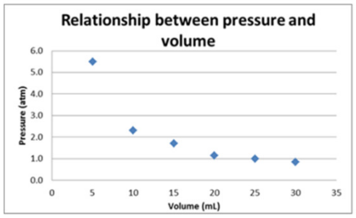
20. Calculate the volume of an unknown liquid whose mass is 5.10g at 19.4°C? (density at 19.4°C = 1.200g/cm^3)
    f. 4.250 mL
    g. 4.25 mL
    h. 6.12 mL
    i. 6.120 mL
    j. Not enough information

21. What is the molarity of a solution containing 5.110g of calcium chloride dissolved in enough water to make 100.0 mL of solution?
    a. .6766 M
    b. .4604 M
    c. .2500 M
    d. 46.04 M
    e. 5.110 M

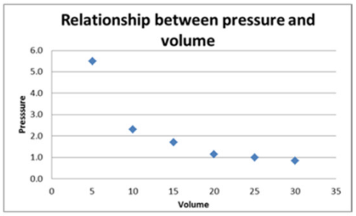
22. Predict the likely products from the reaction of aqueous carbonic acid and aqueous calcium chloride:
    f. $CaCO_3$(aq) and H_2Cl(l)
    g. $CaCO_3$(aq) and HCl(aq)
    h. $CaCO_3$(s), H_2(g), and Cl_2(g)
    i. $CaCO_3$(s) and HCl (aq)
    j. There is no reaction

23. You want to illustrate the relationship between volume and pressure of a gas. Which of the following representations best shows the relationship?

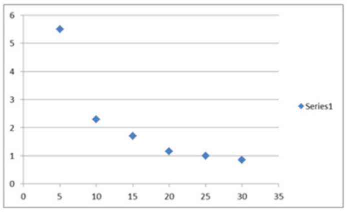
Graph 1



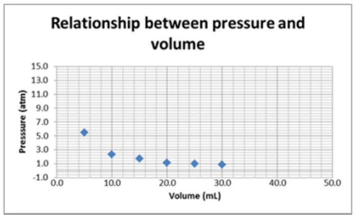
Graph 2



Graph 3

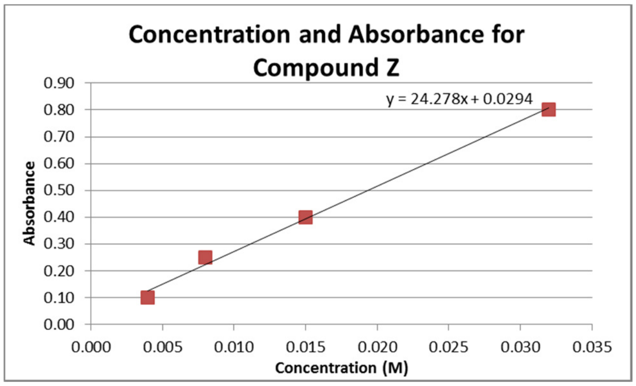


Graph 4



24. Which of the following is the best tool to measure 15.0 mL of liquid?
a. 25mL volumetric pipet
b. 50 mL Beaker
c. 100 mL Erlenmeyer flask
d. 25 mL Graduated cylinder

25. What would you predict the absorbance to be for an unknown compound whose concentration is 0.025M?



a. 0.58
b. 0.60
c. 0.64
d. 0.70

Background/Demographics

1. What year are you in college?
    a. 1st
    b. 2nd
    c. 3rd
    d. 4th
2. What is your intended major?
3. What chemistry experience did you have in high school? Check all that apply
    a. none
    b. chemistry
    c. honors chemistry
    d. AP chemistry
4. At this point, what do you intend to do when you graduate?
5. How old are you?
6. What is your ethnicity?
    a. Black, Afro-Caribbean, or African American
    b. East Asian or Asian American
    c. Latino or Hispanic American
    d. Middle Easter or Arab American
    e. Non-Hispanic, White or Euro-America
    f. South Asian or Indian American
    g. Other
7. What is your primary spoken language?
8. Are you an international student? Y/N
9. Male/Female

Pre-survey

What do you expect the role of your TA to be in lab?

Post-survey

1. How has your TA interacted with you during lab?
2. What has your TA's role been in lab this semester?
3. How, if at all, has your TAs role changed over the course of the semester?
4. How does your TA's actual role in lab compare to what you expected their role to be in lab?
5. What was one thing you learned this semester?
6. What is one suggestion you hsve for improving the course?

Appendix H
Beliefs Rubric

	What can students learn in guided inquiry labs?	How would you describe your role?	How do you maximize student learning?
Deficit	**Focus on the limitations of inquiry. "Inquiry reduces amount of content/concepts learn." "Students couldn't achieve objectives of lab such as data analysis." "Student frustration limits learning." Not all students learn the same thing.**	**Focus on not doing anything. "Babysitter." "Caretaker." "Dealing with logistics."**	**Making learning easy for students by telling them the answers**
Traditional	**Focus on memorization and content knowledge. "Students memorize"**	Focus on information and structure. "Deliverer of information," **"answering questions," "Telling students what to do"**	Teacher provides information in a structured environment. "By using ppt presentations." "I use a textbook, a study guide, and we have it on the web."
Instructive	**Focus on laboratory skills, math skills or connecting concepts as learning outcomes.**	Focus on providing experiences. "I maintain student focus to minimize management issues." **Helping students with lab techniques**	Teacher monitors student actions or behaviors during instruction. "By looking at the student's responses." "I watch my students closely as they complete a lab."
Transitional	**Focus on learning critical thinking or problem solving skills.**	Focus on teacher/student relationship or student understanding. "I need to develop a good rapport with my students." "You have got to make the students feel comfortable or they will have a difficult time learning." "To guide the students in developing conceptual understanding and critical thinking skills." **Facilitate discussions**	Teacher creates a classroom environment that involves the student. "My encouraging them to do their own thinking" (Cognitive). "My building a positive, supportive environment" (Affective). **Engaging students in more in-depth discussions.**

	What can students learn in guided inquiry labs?	How would you describe your role?	How do you maximize student learning?
Responsive	**Focus on using NOS, applications of chemistry, excitement as vehicle for engaging students in learning skills and concepts.**	Focus on collaboration between teacher and student. "To set up my classroom so that my students can take charge of their own learning." **"Working with rather than over students."**	Teacher designs the classroom environment to enable students to interact with each other and their knowledge. "By using small group activities in which students hypothesize, predict, create, share and question." "By giving students the opportunities to defend their ideas in front of their peers."
Reform-based (needs to have enough detail to really know they mean this)	**Focus on NOS, applications of chemistry, or inquiry as learning outcomes instead of methods for engaging students. Students learn divergent thinking**	Focus on mediating student prior knowledge and the knowledge of the discipline. "I am a tour guide who helps students make sense of their surroundings in a manner that is consistent with what is known."	Teacher depends upon student responses to design an environment that allows for individualized learning. "Knowing that not all students learn the same, I have to think of different ways to organize the lesson." "By allowing students to choose their own vehicles to learn by." **"Allowing students to approach a problem in a different way, even if it's not going to work, and use it is a learning opportunity."**

	Know when students understand?	Evidence of student learning?	How do your students learn science best?
Deficit	**NA**	**NA**	**Struggling and frustration hinder student learning. By doing the minimum amount of work to pass.**
Traditional	When they receive information. "We covered it in class." "We covered it in different ways."	Determined by action of students during instruction. Emphasis is on order and attention as related to the student. "It is still and quiet at the end of the less." "They are paying close attention to lecture."	From the teacher. "By paying attention." "By taking good notes." **"Being told what to do."**

	Know when students understand?	Evidence of student learning?	How do your students learn science best?
Transitional	When they give an explanation or response that is related to the presented information. "When they talk about the presented knowledge in new ways" (Knowledge). "Their faces light up" "They get excited" (affective).	Determined through subjective conclusions about the student. "The students are actively engaged rather than passive." "The students write a reflection about their learning" (Cognitive). "I can tell by the look in their eyes." "It gets noisy" (Affective).	By using procedures/guidelines. "By doing hands-on activities." **"Applying lecture concepts to lab." "Applying/completing."**
Responsive	When they can utilize presented knowledge. "When they can clearly defend their ideas using evidence and examples they experienced." "When they can discuss new phenomena that they encounter in class."	Students interact with their peers or the teacher about the topic. Responses are limited or preliminary. "When students interact to solve problems." "When students are helping each other." "Students defend their ideas through the use of evidence and examples."	By encountering and interpreting phenomena. "They are challenged to create their own understanding to explain their generated data." "When they interact with one another as they try to explain their results." "**"Learning concepts occurs within lab as students struggle with the information." "Building upon prior knowledge to create new knowledge."**
Reform-based (needs to have enough detail to really know they mean this)	When they can apply knowledge in a novel setting, or construct something novel that is related to the knowledge. "They can come up with questions or comments that represent an understanding of the topic. Often these questions use the knowledge in a new situation that they have not experienced in class." "One of my students used trigonometry to solve physics problems." "When students can question/dialogue in a manner that expands their understanding. They understand how a chemical reaction can be altered by the modification of an element."	Students initiate significant interactions with one another and/or the instructor about the topic. "Students can formulate thoughtful questions about the content." "Students seek other student's opinions about the content and what they know about an idea." "When students are challenging one another" **"Students come up with alternate ideas based on a synthesis of ideas."**	By eliciting, encountering, and constructing their ideas about phenomena. "When they have ownership over what they learn and how they choose to go about learning it." "They all learn differently, but they need rich experiences which allows each student to explore their notion of the experience and make sense of it in a new way." **"Students struggle with material in different ways to make sense of it." "Constructing."**

Bolded responses indicate modifications made to original rubric by Luft & Roehrig (2007).