University of Northern Colorado
Scholarship & Creative Works @ Digital UNC

Dissertations | Student Research

10-7-2015

A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions

Kitty Lane Roach

Follow this and additional works at: http://digscholarship.unco.edu/dissertations

Recommended Citation
Roach, Kitty Lane, "A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions" (2015). *Dissertations.* Paper 312.

This Text is brought to you for free and open access by the Student Research at Scholarship & Creative Works @ Digital UNC. It has been accepted for inclusion in Dissertations by an authorized administrator of Scholarship & Creative Works @ Digital UNC. For more information, please contact Jane.Monson@unco.edu.

© 2015

KITTY LANE ROACH

ALL RIGHTS RESERVED

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

A STUDY OF NOVICE INSTRUCTORS' QUESTIONING TECHNIQUES AND CLASSROOM DISCOURSE SURROUNDING THOSE QUESTIONS

A Dissertation Submitted in Partial Fulfillment
Of the Requirements for the Degree of
Doctor of Philosophy

Kitty Lane Roach

College of Natural and Health Sciences
School of Mathematics
Educational Mathematics

August 2015

This Dissertation by: Kitty Lane Roach

Entitled: *A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions*

has been approved as meeting the requirement for the Degree of Doctor of Philosophy in College of Natural and Health Sciences in School of Mathematics, Program of Educational Mathematics

Accepted by the Doctoral Committee

____

Robert Powers, Ed. D., Co-Research Advisor

____

Shandy Hauk, Ph.D., Co-Research Advisor

____

Jodie Novak, Ph.D., Committee Member

____

Anton Dzhamay, Ph.D., Committee Member

____

Richard Jurin, Ph.D., Faculty Representative

Date of Dissertation Defense ________________________________

Accepted by the Graduate School

____

Linda L. Black, Ed.D.
Associate Provost and Dean
Graduate School and International Admissions

ABSTRACT

Roach, Kitty Lane. *A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions*. Published Doctor of Philosophy dissertation, University of Northern Colorado, 2015.

The goals of this dissertation were to examine how novice calculus teachers used questions in their classrooms, how those questions and their use might change after video case-based course coordination, and what evidence of influence on student learning might be seen in undergraduate student achievement. This research focused on one way to elicit student ideas--by asking questions--and how professional development might facilitate asking questions as a way to learn about student thinking in calculus. This dissertation defined question depth (in terms of cognitive demand), question category (comprehension check, content check, elicit thinking, probe thinking), and discourse neighborhood as aspects of questioning in classroom "math talk." The mixed methods included instructor interviews and teaching logs, observations of course coordination meetings, and observation and video-capture for six hours of calculus class meetings for each of five novice instructors. Deep analysis of four class meetings for each instructor informed the revision of a framework describing the relationships among question depth, question category, and the instructors' professional development. The teaching-focused development activities for these instructors were during regular course coordination meetings and included the use of four video case activities about college classroom and office hour instruction.

Instructors asked an average of about 50 to 125 questions per class with 62% being low cognitive demand checks for comprehension, “Did you get that?” and 32% having slightly deeper demand for a product “What did you get?” or steps in a process “How did you get that?” The remaining 6% of questions had moderate cognitive demand, eliciting details about decision-making “How did you decide the pieces here for using the chain rule?” No novice instructor in this study asked a question that probed deeply for sense-making or complex justification (e.g., “What in the mathematics here indicates that the chain rule is appropriate?”). On the large scale, all tended to follow the teacher initiated-respond-follow-up (IRF) pattern, focused on evaluating and fixing student responses. These results reflect and extend to the college level the K-12 research literature, which has demonstrated that novice teachers begin with evaluative IRF practices. On the smaller scale, instructors had their own ways of enacting some shared discourse patterns, such as questions like “Do you understand?” and “What is the next step?” The main results of the qualitative work were the detailed profiles of novice instructors and their questioning techniques, documentation that neither final exam nor course grades were sensitive to the small changes in instruction that novices implemented when participating in video case-based professional development, and examination of novice instructor’s experiences of that professional development. The model-building result is a revised framework for novice instructor classroom communication that offers language for noticing and talking about question depths and question categories in examination of teaching practice.

Keywords: questions, novice, college mathematics instructors, professional development

ACKNOWLEDGEMENTS

There are so many individuals whose generosity in time and council has brought me to this point of completion of my dissertation and PhD program. Although I could never thank everyone here, I want to acknowledge a few important people.

To my family; my husband, Mark, my two children, Jacob and Kailyn, my mother, Louise, and my brother John, thank you for supporting me, believing in me and understanding the time it has taken to complete this degree. I love you all very much and could never have finished without your love and support.

To those incredible people I am proud to identify as friends, thank you for your support throughout the last few years, especially Dr. Nissa Yestness, Dr. Lee Roberson, and Kristin Noblet. Your editing assistance, experienced council, coding expertise, and persistent encouragement (especially the random "I believe in you" texts), helped me to focus on task and remain motivated. Friendship has been my lifeline in those times when exhaustion and frustration made the whole process seem insurmountable. I appreciate you all.

I am grateful to my committee, particularly my advisors, Dr. Shandy Hauk and Dr. Robert Powers. You have been a valuable resource for me and an incredible inspiration. I appreciate the time, energy, and support you have given me. Thank you for not giving up on me, believing in me, and pushing me to be better than I thought I could be.

And posthumously I express my gratitude to my father, Dr. Doyle Bostic whose life-long dedication to science, mathematics, youth, and education has inspired me to continue his legacy.

TABLE OF CONTENTS

CHAPTER

II. continued

CHAPTER
III. continued

CHAPTER

IV. continued

LIST OF TABLES

Table

LIST OF FIGURES

Table

CHAPTER I

INTRODUCTION

The Journey Begins

We all have moments in life that shape who we are. For me one of those moments happened during my first year as a full-time college mathematics instructor.

Asking One Question Can Change Everything

After I completed my Master's degree in pure mathematics and worked two years as a teaching assistant, I went to my first full-time, university teaching position. At this university, I was fortunate to have developed a close relationship with one of my former professors. I often sought advice from him. As I was preparing for teaching my calculus class, my former professor dropped by and was curious what topic I was teaching on that day. I explained that we would be reviewing local maximum and minimum values of functions. My professor laughed and said "Make sure you ask them *why* setting the first derivative to zero will give the possible maximum or minimum values."

I replied, "Of course they know that, we already had a quiz and they all did well on it."

He laughed again and said, "Just ask them."

I knew my students understood the concept. After all, we had discussed this in class, they had done homework, and they scored well on a quiz about the topic. I decided to prove to my former professor what I great teacher I was and ask the question. The next

day in class, after I handed back quizzes, I asked my students, “Why do you set the first derivative equal to zero to find the local maximum or minimum values? In other words, why does that work?”

As I stood in anticipation, waiting for my students to confirm the greatness of my teaching and their understanding of the concept, one of my stronger students began to explain:

> We set the first derivative equal to zero since we know that the function will have a maximum or minimum value when it is equal to zero. So if we set the derivative equal to zero, that will tell us where the function is equal to zero and that gives us our maximum or minimum value.

Wait, what did he say? I could not believe what I was hearing. Not only was he wrong, I couldn’t even understand where such an answer would come from. After all, we had talked about the first derivative and how it related to slopes of tangent lines, not to function values. I knew that he must be alone in his thoughts. I looked around the room and saw several other students nodding in agreement. I was shocked.

> Before I had a chance to respond another student said, “No, that’s not it.”
> I thought, “Oh good, now we’ll hear the correct answer.”

He continued, “It’s because when the derivative is zero the graph can go no lower or no higher when we reach our maximum and minimum values, so that’s why the derivative is zero, because the graph can’t be higher or lower than that.”

“Oh, no,” I thought, “it’s getting worse.” and to my astonishment I looked around the room to see students nodding in agreement with this answer as well.

I quickly regained my composure and we took the next few minutes discussing why we actually set the derivative to zero. At that point several students made comments about the first derivative test and that now it made sense that positive numbers related to

positive slopes of tangent lines and to the idea that the function values would be increasing (reading from left to right). After class, several students thanked me for going over that and said it really cleared up things for them.

I left the room that day completely confused. I had taught that! They had done homework on the topic. They had taken a quiz and done well. More importantly, I HAD TAUGHT THAT! What happened? Why hadn't they learned? This experience made me realize that something was wrong. There was obviously a disconnect between my perceptions of the students' understanding and reality. I knew that I needed to change how I was doing things and reassess my teaching. I realized that if I had not asked that simple question, I might never have known what my students were thinking.

That day I began to change as a teacher. It didn't happen overnight, but I began to change. I realized that by asking questions I could find out what my students were thinking. I could help guide them in understanding and asking the right question could make them think. And so, my journey began.

My Personal Experience in Undergraduate Mathematics

Growing up, I had often heard about mathematics lectures. When I went to graduate school to get my master's degree, I found out that my idea of a "mathematics lecture" and what was commonly done during a mathematics lecture were completely different.

Fortunately for me, I had an unusual undergraduate mathematics experience. I took classes primarily from my father, who was a mathematics professor at the school I attended. In fact, I only had four different mathematics professors as an undergraduate, my father, two of his former students, and one other professor. My dad helped in hiring

every mathematics faculty professor that taught at the school. All my mathematics professors believed that pure lecture was a highly ineffective way to teach.

A typical mathematics class for me as an undergraduate consisted of 10 to 15 minutes at the beginning of class in which the professor “lectured” at the board. During this “lecture” the professor would ask many questions and expected answers as well as class discussion. We would then break into groups and spend the majority of the class working problems while the professor roamed around the room to answer questions and provide guidance. The class generally put the seats back in rows for the last five minutes while the professor gave a summary of the topics covered for that day. For me, the beginning of the class, which most people would probably call a class discussion, was a mathematics lecture. I did not realize that anyone would teach mathematics in any other way, until I went to graduate school.

My first experience with an hour-long, professor-talks-and-students-do-not mathematics lecture occurred in graduate school. The graduate course professors faced the board and wrote, turned and stood at the board facing the room, talking about mathematics and sometimes about how do to proofs. It was not always clear that the speaking was directed to the people in the room. Perhaps, if the students were not there, the lecture would have happened in the same way. Usually, when a student raised a hand it was ignored, and when we voiced questions we were either ignored or told to come by the professor’s office later. This was a completely shocking experience for me. I was still pretty certain “teaching” like this was unique to *graduate* mathematics classes. I have since learned that similar lecturing is considered “traditional” instruction for high school and college.

The Research Problem

The U.S. faces profound challenges in the global and technological economies. Our ability to meet these challenges relies in large part on the instruction in mathematics provided in the first two years of college (President's Council of Advisors on Science and Technology [PCAST], 2012). Research in education and faculty development acknowledge the complexity of teaching (and of learning to teach) as well as the influences of disciplinary culture and context on practice. Advances in research have enabled the education community to target preparation and development to help K-12 teachers use practices, such as those in my undergraduate experiences, that are known to improve student learning. However, the same is not yet true at the college level. In college mathematics, from gateway classes for future teachers to advanced courses for future engineers, instructors learn about teaching almost entirely by trial and error (Kung & Speer, 2009). The unfortunate result is reflected in high failure rates (e.g., 60%), particularly in calculus and its prerequisite courses (Hastings, Gordon, Gordon, & Narayan, 2006; Herriott & Dunbar, 2009).

For most prerequisite mathematics courses a student must have a C or better to continue to the next course. Therefore, a course grade of D, F, or W (withdraw) is considered a "fail" (i.e., an unsuccessful completion of the course) and a course grade of A, B or C is considered a "pass" (i.e., a successful completion of the course). Bressoud, Carlson, Mesa, and Rasmussen (2013) report that among students who enroll in college Calculus ready for the course (i.e., meeting pre-requisites and placement requirements), at least 28% fail it. If we consider the fail rate reported by Bressoud and colleagues, approximately 85,000 students will fail Calculus I each fall semester. In response to

course surveys, students reported that the teaching of Calculus I was “ineffective and uninspiring, the course was ‘over-stuffed’ with content and delivered at too fast a pace, assessments were poorly aligned with what was taught and the instructor lacked connection to students and the course” (Bressoud et al., 2013, p. 10). The national problem driving the research presented here is the ill-spent time, effort, and money of students and university resources when so many students arrive at college ready for Calculus and fail the class. Something is happening in Calculus classrooms. For more than a quarter of the students, there seems to be a disconnect between the instructional practices and the students.

What Can be Done to Address the Problem?

Most university calculus instructors learn to teach as graduate students (Seymour, Melton, Wiese, & Pedersen-Gallegos, 2005). Many mathematics and science graduate students welcome guidance in learning to teach, though few actually receive it (Austin, 2002; Seymour et al., 2005). At masters- and doctoral-granting institutions, graduate student Teaching Assistants (TAs) play central roles in the academic lives of undergraduates. Yet, TA contact with undergraduates is difficult to quantify. Lutzer, Rodi, Kirkman, and Maxwell (2007) report enrollment figures that indicate that 21% of mathematics, and 17% of statistics undergraduate enrollees at doctoral granting institutions are taught *only* by TAs. Yet, these figures do not answer the question of how many students take at least one course during their college careers with a TA. One estimate is that about 37% of undergraduates have a TA as a mathematics instructor at some time (Speer, Murphy, & Gutmann, 2009). This is noteworthy, given that most

undergraduates will encounter the TA early in their college careers, often in courses that serve as prerequisites to majors or programs.

Graduate student TAs work in all of these various university department environments. For many TAs, college classroom knowledge comes from their experience as students of “traditional” lecture-based instruction (National Center for Education Statistics, 2000; Sofronas & DeFranco, 2008). Early experiences as an instructor, particularly what TAs learn about how their students think, will influence their later work as teachers (Kung, 2010). The roles these future faculty members will be expected to take on when they enter the professoriate include facilitating learning by engaging students deeply in sense-making (Holton, 2001). Being responsive to students, particularly engaging students where they are in their understanding, requires recognizing information about student thinking from multiple sources, including the things students say and write. As soon as an instructor starts asking questions--particularly deep questions about ideas--conversation and interaction are opened. Novice instructors report how rewarding it is to experiment with opening up conversation in the classroom and how valuable it is to have the opportunity to discuss these efforts (successful and otherwise) with instructional colleagues (Hauk, Mendoza-Spencer, & Toney, 2009; Roach, Roberson, Tsay, & Hauk, 2010). In fact, the existence of the video case materials used in the dissertation intervention being studied is evidence itself. All of the college teachers in the cases, mostly graduate students, agreed to be recorded for sharing with others (Hauk, Speer, Kung, Tsay, & Hsu, 2011).

Research has found that when teachers have a better understanding of student thinking, it improves teaching (Ball, 1997; Carpenter & Fennema, 1992; Fennema et al.,

1996). Students perform better on exams when they have teachers who incorporate student thinking into their daily practices (Carpenter & Fennema, 1992; Fennema et al., 1996; Peterson, Fennema, & Carpenter, 1989). By learning how to ask students questions, an instructor can open up a dialog with students and learn about the student thinking in the room. The collegiate mathematics education literature points to a need for insight into how TAs learn about student thinking (Speer & King, 2009). The research needed includes exploration of how novice instructors learn from their own practice and through professional development (Speer & Hald, 2008). Included in the field's identification of needed work is a call for research on the instructional practices that support learning to learn from the teaching process itself, such as the in-class use of questions (Deshler, Hauk, & Speer, 2015).

This dissertation study answers that call. I investigated how course coordination that includes video case based activities might facilitate reflection on and asking of questions in the classroom.

Research Questions

RQ1 What is the nature of novice calculus instructors' discourse patterns surrounding questions they ask?

RQ2 What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?

RQ3 How does video case based professional development shape perceptions and intentions about the role of questions in teaching held by TAs?

RQ4 Does professional development that includes video case materials hold promise as a way to improve the learning of college calculus students?

In this dissertation, "within a semester" refers to the second half of the semester, specifically weeks 8 through 15.

CHAPTER II

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Introduction

This dissertation study was concerned with formulating and then testing a theoretical framework for identifying instructor knowledge in the area of classroom questioning practices. Hence it is *basic* research (as opposed to applied, evaluation, or action types of research; Patton, 2002, p. 215). The initial framework model, presented at the end of this chapter, is one colleagues and I have developed inductively from existing theories about learning to teach and pilot study research in college mathematics classrooms.

The review of the literature in this chapter serves three purposes. First, it provides a big picture view of the research space, identifying pertinent areas of research to date on college instructors learning to teach. Second, it gives background on the research related to these pertinent areas, including research from the K-12 and post-secondary education literature. Third, it introduces the framework that was the inductive hypothesis or "basis step" for the dissertation work. At the end of the chapter, as a transition to the methods discussed in Chapter III, I offer an illustration of the framework in use.

The Research Space

The foundations for basic research are the results to date in related research. However, the research to date on how U.S. college instructors learn to teach is sparse, as

is reflected in research reports and national calls for research on the development of knowledge for teaching college mathematics (Dorff, 2013; Friedberg, 2005; President's Council of Advisors on Science and Technology [PCAST], 2012; Reys, 2013; Speer, Smith, & Horvath, 2010). Among the research that has been done, about half is on knowledge for college mathematics teaching in calculus service courses (e.g., for non-mathematics majors)--this is part of the reason for the calculus focus of the dissertation project.

A richer research base exists for the related experiences of high school, middle school, and elementary school teachers of mathematics and this literature review draws on that research, cautiously. K-12 teachers and college instructors come to the work of teaching with different sets of expertise in content and pedagogy (Kung & Speer, 2009). Moreover, a unique aspect of college mathematics instructor experience for *novices* is that most begin their learning about teaching as graduate students, in the context of daily pursuit of an intellectual goal (e.g., a degree) that is removed from the daily work of teaching (Hauk et al., 2009; Herzig, 2004). Thus the research space is concerned with the development of post-secondary mathematics instructors, particularly novices (TAs) around teaching in calculus, particularly in service course calculus (e.g., for biology majors).

One method for unpacking the teaching of mathematics is to consider the contexts of the intended, enacted, and achieved curricula (Beyer & Liston, 1996). The *intended curriculum* is the plan to reach specific goal knowledge states and relational understandings over time. This is distinct from the instructional materials--the tools and resources that comprise a series of tasks an instructor might use. The *enacted* curriculum

is the actual pathway followed by an instructor, using the materials, in an effort to realize the plan (the intended curriculum). The *achieved* curriculum is the plan as it is experienced by students. This dissertation project presents a multi-pronged approach to examining a perturbation to the enacted curriculum and researching the achieved curriculum in the larger universe of discourse of graduate school (see Figure 1). To investigate the enacted curriculum among novice college calculus instructors who are graduate student TAs requires attention to four areas from Beyer and Liston (1996): environment, intended curriculum, enacted curriculum, and achieved curriculum. Environment answers questions like: What does the research on teaching and learning to teach in a mathematics department where one is a *graduate student TA* tell us? What does the research on *professional development*, on learning about teaching, contribute to the investigation? Intended curriculum addressed the questions: What does the community say in policy (e.g., MAA) and syllabi (e.g., locally at the university where the research is conducted) about calculus target learning and the pathway envisioned for learning it? Enacted curriculum answers the question: What does research on enacted practice, particularly on using questions for learning from teaching, offer? Achieved curriculum is about the question: What do we know about how people learn calculus, particularly the nature of *student thinking* in learning calculus?

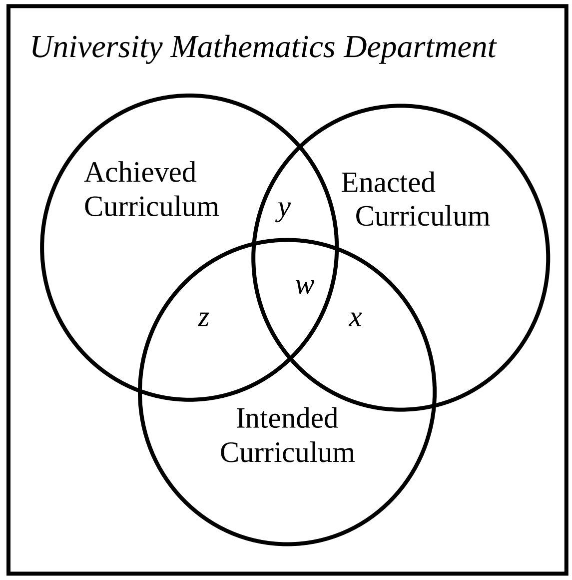

Figure 1. Diagram of the research space.

In the diagram shown in Figure 1 each of the overlaps represents an area open for research. An example of the overlap in Figure 1 labeled *w*, the intersection of Achieved, Enacted, and Intnded Curriculum, would be a situation in which the syllabus says the student will learn concept A (intended curriculum); in the classroom the teacher models concept A through lecture or problem-solving or classroom activity (enacted curriculum); and the student understands concept A--for example, demonstrates mastery of it on a test (achieved curriculum).

In the area of Figure 1 labeled *x*, an example is that the syllabus says the student will learn concept A (intended curriculum); the teacher models concept A through lecture or classroom activity (enacted curriculum); but the student does not understand concept A - for example, does not demonstrate mastery of it on a test (achieved curriculum). In Figure 1 area *y*, the situation might be that the syllabus does not include concept A

(intended curriculum); yet, the teacher uses concept A in lecture or classroom activity (enacted curriculum); and the student understands concept A - for example, demonstrates mastery of it on a quiz (achieved curriculum). In Figure 1 area *z*, the syllabus includes concept A (intended curriculum), the teacher did not model concept A during classroom activities; yet, the student does appear to understand concept A - for example demonstrated mastery of it on a test. A related idea is the overlap among areas of the literature in the research space, in Figure 2.

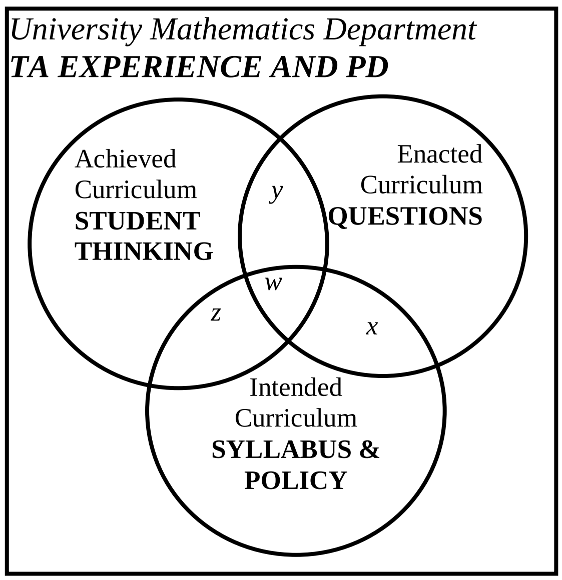

Figure 2. Literature in the research space.

Literature related to the overlaps in Figure 2 is not evenly distributed. Some areas are more sparsely populated than others. For example, existing literature in the three-way overlap in Figure 2, area *w*, tend to be efficacy or impact studies (very rare). Such work tells the story of success: a program or intervention is planned (intended), put to use (enacted), and results in the desired student outcomes (achieved). While some studies and

meta-analyses exist in the K-12 literature (e.g., Blank & de las Alas, 2009), to date the only collegiate mathematics research in that area is in the work currently under way by Bressoud and colleagues (2013). Some reports in the literature are represented by area *x* in Figure 2. Commonly relying on self-report (e.g., the Higher Education Research Institute studies), researchers report on how instructors encouraged student participation by means of questions (Questions) and give evidence of how instructor use of questions may have played out in the classroom, sometimes evidenced what is reported on by students in course evaluations (Syllabus & Policy); but such research does not systematically gather information on the nature of changes in student mathematics thinking or achievement related to the presence/absence of questions (Student Thinking). Research represented in area *z*, might report on students achieving the goal of participating and sharing their thinking without the instructor prompting, perhaps because the curriculum itself is full of complex questions and the policies for instructor development focus on the curriculum driving instruction (for example, the Good Questions project; Miller, Santana-Vega & Terrell, 2006). Represented in area *y*, would be research like that often reported on Moore method or discovery learning, where students are questioning each other, data are collected about student thinking, but the research does not include attention to the role of syllabus or instructor preparation for such teaching. As noted above, the area represented in Figure 2 by *w* is the area in which research examines questions asked by the instructor, documents ways students respond with how they are thinking about the topics, and attends to policy behind the classroom interaction such as methods and concepts included in the syllabus or in TA preparation/policy--this dissertation contributes to the very sparse literature in this area in

two ways. First, it is not an undergraduate student-focused quantitatively-driven story--thus it augments Bressoud and colleagues' efforts. Second, the work reported here provides detailed information about a particular type of instructor-of-record (TA) and a particular type of policy (video case-based professional development) in the context of a large public university.

In the sections that follow, the literature for each of the aspects of curriculum is discussed in turn. To ground the theoretical framework for the proposed work, I start with a discussion of the enacted curriculum and the role of questions. This is followed by an examination, using the lens of mathematical discourse, of current research and development literature in the guiding curricular ideas for calculus, the particulars of student thinking, and learning to teach as a novice TA in a mathematics department. To set context, a section is included on teacher professional development and the larger picture of the nature of graduate student experience.

Enacting the Curriculum: Questions and Question Strategies

Questions about Questions

When is it a good thing to ask a question? What knowledge does a teacher bring to bear in making the decision to ask a question? . . . in deciding *what* to ask (and what to avoid)? What additional understandings might be used as an instructor listens to student response and makes subsequent decisions, in real-time interactions or in planning, for continuing a thread of intellectual activity? How do people who are novices at college teaching learn about effective mathematical discourse and how to orchestrate it to support student learning (e.g., question and answer strategies)? A query like "What questions do you have?" can be a much more fruitful opening to an exchange of ideas in the classroom

than “Does anyone have any questions?” or the terser, “Questions?” Asking questions that have a "yes" or "no" answer are unlikely to be taken as an invitation to a conversation (Weber, 1993, Section 2.4.4). On the other hand, "What questions do you have?" assumes that the students have questions and issues the invitation to talk about them. When and how might new college instructors learn about that? This is discussed later in this chapter, in the section titled "Mathematical Discourse."

By using the variation in the types and depths of questions, and questions at the appropriate time, teachers can engage students more effectively with mathematics and create greater opportunities to learn. This has been evidenced in the work in the K-12 literature on cognitively guided instruction (CGI) and in several other research studies (Hufferd-Ackles, Fuson, & Sherin 2004; Sorto, Mccabe, Warshauer, & Warshauer, 2009; van Zee & Minstrell, 1997).

Though research is thin around questions people ask in teaching calculus in college (the specific focus of this study), Miller et al. (2006) explored the idea of *written* “good questions” in a calculus classroom. These were in tasks and activities used by novice instructors to examine student performance. While largely anecdotal, their initial work came from many years of classroom experience and mentoring of TAs. Miller and colleagues state that good questions in tasks will spark classroom discussion and allow the instructor to assess the understanding of the students. These questions may not have one correct answer, but can be used to illustrate the larger concepts of calculus.

Other research on the role of questions comes out of the cognitive and learning sciences (largely clinical rather than classroom-based). This work has focused on the

theoretical underpinnings of the connections between questions and explanations, including self-explanations.

Building Explanations by Asking and Answering Deep Questions

Cognitive theories for building complex understanding of a topic place great importance on explanation because it leads to fluency and a reduction in the amount of processing resources needed to retrieve knowledge and execute a cognitive skill (Anderson, 1983; Schneider, Dumais, & Shiffrin, 1984; Schneider & Shiffrin, 1977). Effective co-development of conceptual *and* procedural knowledge may be improved by prompting students to explain responses to self and to others (Gray & Tall, 1994; 2001 In deep explanations, students are *reasoning* (Ball & Bass, 2003). They make and test conjectures about causes and consequences, seek evidence, and generate justifications. The types of deep questions that prompt such explanations include comparisons, and queries rooted in what-if, why, how, and counter-exemplar (why-not) probes. Positive effects of deep questions have been reported in a variety of K-16 courses (Beck, McKeown, Hamilton, & Kucan, 1997; Craig, Sullins, Witherspoon, & Gholson, 2006; Driscoll, Craig, Gholson, Ventura, & Graesser, 2003; Gholson & Craig, 2006; Wisher & Graesser, 2007). Deep questions may be more effective *and* more efficient for learning and transfer because they allow, for example, students to spend limited cognitive resources on understanding the ideas underlying a solution rather than on generating a solution (Rosenshine, Meister, & Chapman, 1996). In the realm of why-not questions, asking students to explain why incorrect answers are incorrect is common in Japanese K-12 instruction, where mathematics achievement is outstanding by world standards (Stigler & Stevenson, 1992). Further, a number of empirical laboratory studies confirm

that asking students, including undergraduate learners, to explain incorrect as well as correct solutions leads to greater learning (Grosse &Renkl, 2007; Rittle-Johnson, 2006; Siegler & Chen, 2008).

Effective mathematics instruction depends on the presence of deep questions to prompt student explanations and is tied to cognitive models of student knowledge and understanding (Pellegrino, Chudowsky, & Glaser, 2001; Wilson & Bertenthal, 2005). Virtually every curriculum, and especially those developed to align with or extend the National Council of Teachers of Mathematics (NCTM; 2000) *Principles and Standards for School Mathematics* and Common Core Standards Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), includes a wide range of question types in text and assessment materials. Thus, the design of professional development for novice mathematics instructors, and of research on its implementation, attends to what questions are asked, when, and how the resulting explanations are responded to (by self, teacher, fellow learners, others).

Related to this work in cognitive science, is K-12 in-the-classroom research that has examined real enactment. Of particular interest for this project is the work that has examined mathematically rich classroom conversation.

Levels of “Math Talk”

Hufferd-Ackles et al. (2004) reported on a case study of a particular novice third grade teacher (from a larger study) and the evolution of classroom discourse over a year as the teacher implemented a new reform-based curriculum for the first time. The authors’ defined “math talk” as discourse that supports the learning of mathematics of *all* in the classroom. Their framework for identifying trajectories in the discourse, for both

teacher and student, had four categories: questioning, explaining thinking, source of mathematical ideas, and responsibility for learning. For my work, I focus on the *questioning* category along with the coding scheme they identified for levels of interaction.

Within questioning, Hufferd-Ackles and colleagues discussed four “levels” or types of interaction. Level 0 was considered to be a traditional classroom in which the teacher directs the classroom and only brief answers or responses are required from the students. The teacher is the only one who asks questions and the questions are mostly to make sure the students are awake and paying attention. These questions often only require a yes or no response. Level 1 math talk means the teacher is beginning to focus on students’ mathematical thinking and less on correct answers, however, the teacher is still the center of attention. The teacher is the only one who asks questions, however there are more follow up questions about procedures and answers. Level 2 interactions are where the teacher is starting to help the students build new roles and the students may even be “co-teaching.” The teacher is modeling mathematics talk. The teacher asks probing questions and facilitates the students talking to each other by asking the students to explain to each other their reasoning. Students are encouraged to ask questions about each other’s work. Level 3 is the last level, in which the teacher is co-teacher and co-learner. The teacher observes and monitors everything that is going on. The students are expected to ask each other about their work and explain their thinking to one another. The teacher is there to guide the discourse. Many of the questions are “Why?” questions and require justification. The authors reported that in the case study classroom the community of learners moved from mostly level 0 to mostly level 3 discourse over the course of the

year. When the teacher introduced a new topic, she would fold back to a level 0 or 1 and then rapidly push the classroom interactions to higher levels by eliciting more complex explanations from students with “how” and “why” questions (Hufferd-Ackles et al., 2004).

While the “math-talk” levels identify complexity of interactions, they say nothing about the cognitive demand of the tasks around which the interactions are taking place. Stein and Smith (1998) developed a Mathematical Task Analysis Guide to offer a framework to help identify and discuss the cognitive demand of a given mathematical activity. In their work about implementing NCTM standards-based curriculum in the context of middle school mathematics, Stein, Smith, Henningsen, and Silver (2000) investigated the kinds of mathematical activities used in classrooms and found that often the activities that required a higher cognitive demand were more difficult to implement well and that teachers tended to funnel the information, over-scaffolding and transforming complex activities into tasks with a much lower cognitive demand. Their analysis categorized four types of cognitive demand, with high demand tasks requiring procedures-with-connections and “doing math” as opposed to low demand tasks calling for memorization/recall or procedures-without-connections (see Question Categories section below for more detail on this framework).

The focal teacher in Hufferd-Ackles and colleagues’ work, at the beginning of the year, would have been considered a traditional classroom teacher. Eventually, by listening to students’ answers to her deeper questions, the teacher discovered more about the students’ thinking and avoided funneling tasks to lower levels of cognitive demand. At the start of the year the questions she asked focused on the answer to a mathematics

problem. At one point early in the school year the curriculum suggested that she ask "How?" or "Why?" something might happen. She did. This triggered conversations by the students and challenged both the students and the teacher to think more deeply about the mathematics. As the year progressed, the classroom transitioned from all level 0 to include even level 3 math talk. This occurred as the teacher asked more cognitively demanding "deeper" questions, supporting the class to link mathematical procedures with the reasoning and justification about the mathematics.

Van Zee and Minstrell (1997) conducted a study to examine the use of questions posed early in the year of a high school science classroom. Minstrell, the instructor, used a type of question he referred to as a *reflective toss*. His goal was to maintain the cognitive demand on students during tasks. Minstrell described this process by "catching" what the students said and then "throwing" the responsibility for thinking back to the students in the class. These reflective toss sequences usually began with a short student statement, followed by a teacher question, which was then followed by a student elaboration. Minstrell did not judge student responses but asked for further explanation and often called on other students for assessing whether a method was correct or not, working to "promote *true dialogues* (Lemke, 1990), which rarely occur during traditional teacher questioning (Dillon, 1988)" (van Zee & Minstrell, 1997, p. 230).

Roach et al. (2010) also found that when teachers responded to students with a cognitive demand-preserving question (e.g., supporting procedures-with-connections and "doing math" types of activity), and then waited for the students to respond, the result was often a rich student discussion about the problem posed. However, when the instructor posed a question that lowered cognitive demand, the result was students

turning to level 0 or 1 math talk. The discussion rarely, if ever, continued after the teacher evaluated a student statement for correctness. The authors also found that the context of the question was important. The words in a question come with context, including how they may have been used in the immediately preceding classroom conversation. That is, the conversational neighborhood mattered.

Discourse Neighborhood

The idea of *discourse neighborhood* was developed by Sorto et al. (2009) when they observed and transcribed class sessions and found that often when looking, even locally, at a question sequence, it appeared that the teacher would “misspeak” or not pay attention to things the students said. However, when the researchers reviewed what had happened earlier in the class period it, was clear that the teacher did not misspeak or ignore the students. Often the teacher was trying to challenge the student or guide the student in making a connection to a previously discussed problem or mathematical concept. Sorto et al. compared the nature of interpretation of teacher questions and student responses in isolation and in the larger context of “discourse neighborhoods.” The authors explained that without an awareness of the context and setting of an instructor’s question, it may be difficult to comprehend the appropriateness or depth of the question. That is, sometimes a teacher may ask a “good question” but it may be contextually inappropriate or inaccessible to students. Intended curricula often have associated instructional material that includes a list of questions for teachers to ask. When taken out of context the questions can be ineffective. The authors stressed the importance to “let the big ideas drive the questions and not the other way around” (p. 58).

Even without changing the wording of a question, what an instructor does after asking a question impacts students' opportunities to engage with the query. For example, after posing a question to a small group of students, a teacher may wait for an answer or walk away allowing students to decide on an answer amongst themselves. Both situations of question posing have distinct aspects of question context. In research on context, Rowe (1986) found that waiting longer (at least three seconds) after asking questions increased the likelihood that students would respond. Furthermore, increasing wait time as little as three seconds aided the teacher in responding to student thinking (Rowe, 1986).

Along similar lines, Ingram and Elliott (2014) examined wait time and turn taking in classroom interactions. The researchers have asserted that the usefulness of wait time is context dependent (i.e., depends on the discourse neighborhood). The social and socio-disciplinary norms in the room are at work in how rules for turn-taking and associated valuing of student engagement get established in a classroom. A five second wait time early in a semester may be perceived and responded to quite differently (by college students and instructors) than the same question and wait at mid-semester. Classroom interactions are more constrained than conversational interactions. This means that without explicit attention to establishing conversational or discourse norms that are different from the common teacher asks--student(s) respond--teacher evaluates, there are fewer opportunities to speak and students will often wait until a response is directly solicited.

In each of the above examples, questions take a large role in the teaching process. It is important to look at the context, the discourse neighborhood, of the question and when possible the cognitive demand-related purpose of the question.

What is a Question?

For this study I used the definition offered by van Zee and Minstrell (1997) to describe what was considered a question. In that work, based on a questioning taxonomy suggested by Saha (1984), questions are utterances with a rising intonation, begun with interrogative words (e.g., what, where, when, why, who and how), or that start with a verb, or other utterances that contained embedded questions.

Question Categories

The research discussed thus far has addressed questions in different ways. Mehan (1979) offered a framework that focuses on the *type* of question based on the type of answer that could result (more details on this research in the section, Mathematical Discourse). Hufferd-Ackles et al. (2004) approached questions as a way of looking at the math talk happening in the classroom. As discussed above, researchers have asserted the value of deep questions--asked by self and others. Yet, the bulk of that work has conflated the kind of math talk and question type with whether questions occurring are "deep" or not. None of that work has attended to depth *and* context as dual characteristics of a question-based interchange. For example, in level 0 math talk, the responsibility for sense-making is with the teacher. So a teacher asking "Why do we want the slopes of the tangent lines here?" can serve to elicit student thinking *if* the teacher steps back and waits for students to respond, or asks students to write individual responses down. The same query can also serve as a cue for students to poise pencils over paper to write down the answer that will, inevitably, come from the teacher. That is, in the discourse practices of the classroom, in particular the neighborhood around the question, though the question has the potential (and may have the intent by the instructor) to elicit student thinking, the

enactment of the question may not be an opportunity for deep engagement of ideas by students.

In my earlier work, colleagues and I offered a framework for question categories (Roach et al., 2010). Question categories are a classification of the pedagogical purposes of questions. The four categories illustrated in Table 1 emerged from observations of novice and experienced instructors. By reviewing video of classroom interactions our qualitative work identified four central themes in instructional use of questions: the instructor was, (a) attempting to assess a student’s understanding (Comprehension Check), (b) directing the focus to particular mathematical ideas (content check), (c) making explicit what a student was thinking (elicit student thinking), or (d) gaining insight into the reasoning behind a student’s thought or thought process (probe student thinking). While question categories are similar to the Mehan types, they build on Mehan’s (1979) work by further classifying not only the type of response one may expect from the student but also the perceived intent of the instructor. In particular, the question categories used in this research have been developed from observations of actual college mathematics classrooms. Using actual college classrooms means the categories reflect common college mathematics paradigms. In particular, the Comprehension Check category is an example of a question that crosses Mehan’s types. Notice that in Table 1, the two examples illustrate both choice and product versions of Mehan’s question types.

Table 1

Question Category Definitions

Category	Definition
Comprehension Check	To assess one or more students' declarative understanding of a topic, procedure or task (e.g., What should we do next?, Does that make sense?)
Content Check	Used to push the mathematical focus or direction of the students' attention (e.g., Should we try the chain rule?)
Elicit Student Thinking	To draw out what the students were thinking, including prompts for students to communicate their *what* they thought to other students or teacher (e.g., What do you first notice about this graph?)
Probe Student Thinking	Investigate reasoning behind or explanation for a given response or procedural work, including prompts to communicate *why* a person or group thought what they did (e.g., That's correct, but why?)

Hufferd-Ackles et al. (2004) focused on classroom discourse over long expanses of time (a school year) and identified questions as one aspect contributing to classroom discourse. The identification and use of question categories adds a finer grained approach to examining classroom discourse, particularly the details around question purpose, depth (more on this below) and neighborhood (more on this below).

While the question categories are a useful tool for identifying and discussing questions, there is a qualitative difference between "Does that make sense?" and "What is the next step?" Both fall into the Comprehension Check category, but they make different cognitive demands on students. That is, not all "deep" questions are of the same depth.

Defining Question Depth

Paying attention to the immediate context of a question, as was possible when reviewing video, allowed for noticing the kind of cognitive demand explicit (or implicit) in the question. This meant a question could be categorized by the codes from previous research--Comprehension Check, Content Check, Probe Student Thinking, and Elicit Student Thinking--*and* a cognitive-demand-identification could be made in context. This contextualized rating I called *question depth* (see Figure 3). This scale is based on the research-based Task Analysis Guide for mathematical tasks, with four levels of cognitive demand, by Stein et al. (2000).

Mathematical Discourse

At the intersection of deep questions that elicit rich explanation and the in-the-classroom enacted curriculum, lies the theory of classroom discourse. Here the term “discourse” (little d) means connected stretches of language that make sense to those involved in producing (e.g., speaking) and taking it in (e.g., hearing; Gee, 1996, p. 127).

In a college mathematics classroom, discourse comes from spoken, written, and, at times, gestural language. This can be distinguished from contextualized discourse, called Discourse (with a capital D), that involves rules, values, artifacts for “identifying oneself as a member of a socially meaningful group or to signal (that one is playing) a socially meaningful role” (Gee, 1996, p. 131). The “big D” Discourse of academic mathematics values explanation, justification, and validation (Arcavi, Kessel, Meira, & Smith, 1998; DeFranco, 1996; Schoenfeld, 1998; Weber, 1993).

Lower Cognitive Demand	Higher Cognitive Demand
Depth 0 The question involved a memorization task or recall of information. This type of question could also be to "check in" with the students to see if they are paying attention or for confirmation that they are understanding the material.	**Depth 2** Like 1, the question involved performing, explaining for giving a procedure, but was also *connected* to a concept or reason behind the procedure. This type of question was used to develop a deeper understanding of the mathematical concepts involved to complete a problem or to make a connection among the concepts. They purpose was to engage the students on a deeper cognitive level than the previous two question depths.
Depth 1 The question involved performing, explaining or giving a procedure with no connection to a concept or meaning behind the procedure. This type of question focused on what needed to be done and/or how.	**Depth 3** The question called for "doing mathematics." This type of question pushed students to a higher cognitive level and called for access and/or synthesis of knowledge and experience to make generalizations or conclusions about mathematical concepts. This type of question could also be used to self-regulate one's cognitive processes.

Figure 3. Question depth descriptors.

Instructors ask questions to evaluate what students know and to elicit what students think. One model of classroom discourse common in the U.S. is the interaction pattern where teacher *initiates*--student *responds*--and teacher *follows-up* or *IRF* structure (Mehan, 1979; Wells, 1993). In college classrooms, this is most often initiated by instructors, but not exclusively so (Nickerson & Bowers, 2008). In his ethnographic work, Mehan identified four types of teacher questions (see Figure 4).

Evaluate what students know	Elicit what students think
Choices--response constrained to agreeing or not with a statement (e.g., Did you get 21?) ***Products***--response is a fact (e.g., What did you get?)	***Processes***--response is an interpretation or opinion (e.g., Why does 21 make sense here?) ***Metaprocesses***--response involves reflection on connecting question, context, and response (e.g., What does the 21 represent? How do you know?)

Figure 4. Initiate-Respond-Follow-up (IRF) question types and anticipated response type.

If *choice* and *product* questions dominate a teacher's contributions to discourse, then multiple disconnected *IRF* interactions result in teacher-regulated level 0 and level 1 math talk that does not include deep participation by students. This can be true even in inquiry-based instruction (Nassaji & Wells, 2000; Wertsch, 1998). Research suggests that U.S. mathematics instructional practice is most often of the type characterized on the left in Figure 3 (Stigler & Hiebert, 2004; Wood, 1994).

The use of *process* and *metaprocess* questions as *follow-up (F)*, expands discourse into the "reflective toss" realm of comparing and contrasting different ways of thinking (with justification but without judgment), monitoring of the discussion itself and of the evolution of one's own thinking (van Zee & Minstrell, 1997). Such IRF cycles can be present in level 1 math talk but are more common in level 2 math talk. Level 3 math talk is evidenced when students regularly are initiators and interact with each other and with the teacher asking all four types of questions. In this way, orientation towards mathematical culture and discourse can evolve from "the answer is 21" to exploration of concepts. As noted above, one example of swapping a choice prompt for a process prompt is replacing "Do you have any questions?" with "What questions do you have?"

Ryve (2011) analyzed mathematics education articles that focused on discourse and found that only 19% of the articles gave a detailed definition of how they were using the word discourse. In this dissertation work, I use the definition of discourse (little d) offered by Gee (1996). The discourse I refer to will be that of lower case d, discourse.

The Achieved Curriculum: Student Thinking in Calculus

Research and development in the reform of calculus have supported an enacted curricular focus on building critical thinking and communication skills while working to understand deeply a small set of important concepts: covariation, limit, and their core relationship in the fundamental theorem of calculus. Understanding and using covariation and limits flexibly is foundational to success in algebra and calculus (Carlson, Jacobs, Coe, Larsen, & Hsu, 2002; Saldanha & Thompson, 1998). In calculus curricula, covariation largely occurs in the form of either proportional or functional relationships (e.g., Killpatrick, Martin, & Schifter, 2003). Lester & National Council of Teachers of Mathematics, 2007). These ideas remain central in new initiatives revamping college curricula (Cullinane & Treisman, 2010).

Tall and Vinner (1981) examined calculus students' formal and informal views of function and limits and their related concept images and concept definitions. Since that time, there has been a growing body of research concerning how students learn and make sense of calculus concepts. However, there is a shortage of research on how teachers may use this information to improve the teaching of calculus (Nickerson & Bowers, 2008).

Procept

Gray and Tall (1994) came up with the terms *procept* and *proceptual* thinking. A procept is a way of conceiving of a mathematical statement, and includes "a *process*

which produces a mathematical *object*, and a *symbol* which is used to represent either process or object" (p. 6). Proceptual thinking is a combination of both conceptual and procedural thinking. Gray and Tall found that students who displayed more proceptual thinking than procedural thinking tended to be more successful than those who only thought procedurally. Procedural thinking is a focus on process or algorithm, the input and output. Proceptual thinking is characterized by the ability to think of symbols as objects that can be decomposed and recomposed. While Gray and Tall's and original work was with arithmetic, the idea has been used in more complex mathematical situations. Farmaki and Paschos (2007) reported a case study of a student, Peter, as he attempted to make sense of a calculus problem. The researchers found that Peter used many representations of the problem to help him work through the problem. He used a geometric representation that evolved, through intuition and visualization, into a mathematical model that helped him reason mathematically. He moved between the mathematical model and his graphical representation, often referring to mathematical theorems, to aid him in developing a proceptual understanding of rate of change. The idea of procept has also been extended to calculus learning and the concept of a function.

Function

Carlson (1998) investigated student understanding of functions. In this investigation Carlson looked at three groups of students; college algebra students, undergraduates in calculus, and graduate student. Those with a richer understanding of functions seemed to show an ability to think about functions as processes that can have different input values. The students who demonstrated a sparser understanding of functions had difficulty thinking of the function as anything more than a procedure and

seemed to have a pointwise view of functions. That is, using Gray and Tall's (1994) procept idea, the more advanced students had a proceptual way of thinking about functions. They could move fluidly between the function notation and graphical representations and thought of functions a both process and object.

Tall and Vinner (1981) is a pivotal point in research on cognition and student thinking in calculus. It has been a foundational study for research in the last 30 years. The bulk of work informed by Tall and Vinner's attention to student meaning making in calculus illustrates how the research in mathematics education has been evolving around student thinking. Similar to the K-12 research, we can use this body of research to inform professional development at the collegiate level.

Professional Development

How Teachers Learn about and Use Student Thinking

K-12 research base. The CGI research in K-12 mathematics demonstrates that if professional development includes a focus on student thinking and understanding of mathematics, then instruction changes and student scores increase. The goal of CGI is to provide teachers with an understanding of student conceptions so that the teacher can better guide student learning. Carpenter, Fennema, and Franke (1996) conducted a study in which teachers focused on children's conceptions of whole number operations. The authors found that by using CGI in professional development, teachers' beliefs that they were a "dispenser of knowledge" began to change and evolve into a more student focused classroom in which student knowledge became worth listening to and served as a starting point on which to build knowledge.

Carpenter, Fennema, Peterson, Chiang, and Loaf (1989) found positive effects on student achievement when teachers participated in professional development that focused on students' knowledge of number facts. These students' scores on number facts exceeded students in a control group. Saxe, Gearhardt, and Nasir (2001) also found positive effects on student achievement when teachers participated in professional development that included attention to teachers' understandings of student thinking. In this study, three groups were examined, one group had professional development that included examining student thinking as well as mathematical content, a second group had professional development that focused primarily on content without studying student thinking, and a control group that did not participate in the professional development. These are promising studies that show that when professional development includes examining student thinking, teachers become more aware of how students think and student scores increase.

Collegiate mathematics. According to Kung (2010), TAs primarily learn about student thinking by listening to student conversations, seeing student written work, and watching students work problems. During interviews, all the participants in his study stated that they learn from seeing students work problems and hearing their conversations and that they learned about student misconceptions by watching and listening to students work problems. TAs also reported that part of their learning about student thinking came when writing problems for quizzes and tests. Writing the problems caused TAs to think about the difficulties students might have and to reflect on what students might do with the problems. TAs also said they learned about student thinking by grading student work. While grading, TAs would try to figure out a student's thought process from the shadows

of it apparent in the student's written work. Though not as common, three of Kung's eight case study participants mentioned self-reflection as a way to try to understand student thinking, but noted that this did not always work. Some TAs mentioned other ways to learn about student thinking for example, during office hours or by reading about student thinking, but these were not mentioned by others.

Speer (2001) in her dissertation observed TAs building knowledge of student thinking by asking students questions during calculus recitations. These recitation classes consisted of students working problems in groups and the TAs would wander from group to group offering help and asking questions. Speer found that the questions the TAs asked aligned with their beliefs about learning. For example, one of the TAs believed that students could have an answer wrong but still understand the material and that if their answer was correct it illustrated an understanding of the problem. This TA would often ask questions, ignore incorrect answers, and wait or rephrase a question until he was given the correct answer. The other TA in the study believed that students could have a correct answer and not necessarily understand the problem. This TA would often ask the students to go back to the beginning of the problem and explain what they had done even when they had a correct answer. He would then ask questions and ask the students to explain why they answered how they did and why the procedure they chose would work in the problem.

Use of Cases for Professional Development

Noting similarities between a case video and personal practice reassures novices they are doing some things well, while cases also provide alternatives--how things might be done differently. Also, when novices take the student perspective while watching a

case (or observing another instructor in real-time), it sensitizes them to the impressions they may be conveying to their own students. Over the last 20 years the use of textual and video case materials for teacher preparation, mentoring, and induction have been well documented (Brophy, 2008; Friedberg et al., 2001; Hatfield & Bitter, 1994; Merseth & Lacey, 1993; Seago, Mumme, & Branca 2004). However, despite the advantages of digital video, there are characteristics of it that differ from the bombarding of the senses when one steps into a college mathematics class. The video case materials for this dissertation project intervention include more activities that focus attention at particular moments worth noticing. During case use the goal is that novice instructors build skills in noticing and mindfully directing attention in a complex classroom situation. Discussion questions like those in the case activities to examine video can move novice instructors from chronological recounting of behaviors and broad conclusions like “the teacher seemed unprepared” to a dynamic analysis that captures pedagogically important aspects, what the main ideas were, what students seemed to be thinking, and how an instructor might elicit more about that student thinking (Coles, 2013; Sherin, 2007).

The importance of directing attention when using video with novices has been researched in a variety of settings. Borko, Jacobs, Eiteljorg, and Pittman, (2008) conducted a study in which teachers were shown video clips of their colleagues teaching. Prior to viewing the video clips, the teachers were told to focus on something in the clip such as how the teacher asked questions, or to focus on how the student explained the problem. The study took place over the course of three years, and by the end of the three years the teachers expressed in interviews the benefits they felt they had received by participating in the study. Benefits included a stronger sense of community and a better

understanding of student thinking. The topics in the video clips that were viewed pertained to all the teachers since they all taught the same lesson. This allowed the teachers to focus on how their peers presented the information and teachers noted that they could take away things that they saw and use or apply them to their classrooms. Teachers also reported that the video clips gave them a chance to reflect upon their teaching and offered a stepping stone to productive discussions about teaching. The authors state that it was important for the facilitators to ask the teachers to focus on a particular aspect of what they viewed. By doing this, the facilitators avoided the teachers criticizing one another's teaching and were able to find ways to discuss what they saw in a positive manner.

Why use video cases? People think and learn through images (Borko, 2004; Gee 1996). One method of learning and receiving vicarious experience is through watching video of teaching (Sherin, 2007). The video vignettes and associated activities used in this dissertation work grew out of what is known about professional development in K-12 and college settings (Hauk et al., 2011).

Effectiveness of Professional Learning

K-12 research. When teachers better understand student thinking, it improves teaching by helping teachers understand that teaching is more than just talking (Ball, 1997; Carpenter & Fennema, 1992; Fennema et al., 1996). Further, students whose teachers find ways to incorporate student thinking into their daily practices, perform better on exams (Carpenter & Fennema, 1992; Fennema et al., 1996; Peterson et al., 1989). It seems reasonable that if K-12 teachers can improve teaching by having a better

understanding of student thinking, university and college teachers could also improve teaching by having a better understanding of student thinking on a collegiate level.

This is further supported by The Council of the Chief State School Officers (CCSSO). The CCSSO "is a nonpartisan, nationwide, nonprofit, organization of public officials who head departments of elementary and secondary education in the states, the District of Columbia, and the Department of Education" (Blank & de las Alas, 2009, p. 2). One of the primary purposes of the CCSSO is to provide leadership in assessing the condition of K-12 education. Blank and de las Alas provided a synthesis of published research that dealt with professional development and student performance. While there is a large body of research in K-12 dealing with professional development, there is little research that translates professional development to student achievement. In studying articles from January, 1986, to August, 2007, the authors identified 416 articles that addressed professional development. Of those articles all but 20 were eliminated because of incomplete or inconsistent methodology or reporting. The 20 that remained were empirical studies that dealt with in-service K-12 mathematics and science professional development in the United States, and reported on student achievement outcomes--not feelings, impressions or opinions (Blank & de las Alas, 2009). The researchers found that there were characteristics of professional development that did result in higher student achievement. First, the professional development should align with the school's learning goals and/or curriculum. Second the professional development should be calibrated to the day to day operations of schools and teachers. And last, the professional development should align with the practices and knowledge required by teachers' particular classroom assignments (Blank & de las Alas, 2009).

In examining relationships between types of professional development activity it became clear the most powerful change came with summer plus follow-up format and engaging participant teachers in learning. Blank and de las Alas (2009) found statistically significant positive correlations between:

- public presentation at a conference and leading a discussion or team (r = 1.000)
- summer institutes and developing assessments and reviewing student work (r = 0.345)
- summer institutes and observing other teachers (r = 0.418)
- study group and receiving classroom mentoring (r = 0.579)
- classroom mentoring and engaging in learning network (r = 0.796) and
- classroom mentoring and developing assessments or reviewing student work (r = 0.883).

These relationships are illustrated in Figure 5. Any closed loop was shown to result in a statistically significant positive correlation as described above. All the PD reported on by Blank and de las Alas included Summer plus Follow-up format.

College level. There is little research at the collegiate level that investigates how professional development around examining student thinking could impact teachers' classroom behaviors and none to date on whether that translates into higher test scores for students (Deshler et al., 2015). So what has been done? The research surrounding professional development at the collegial level has primarily been about how teachers, in particular graduate teaching assistants, think about student thinking.

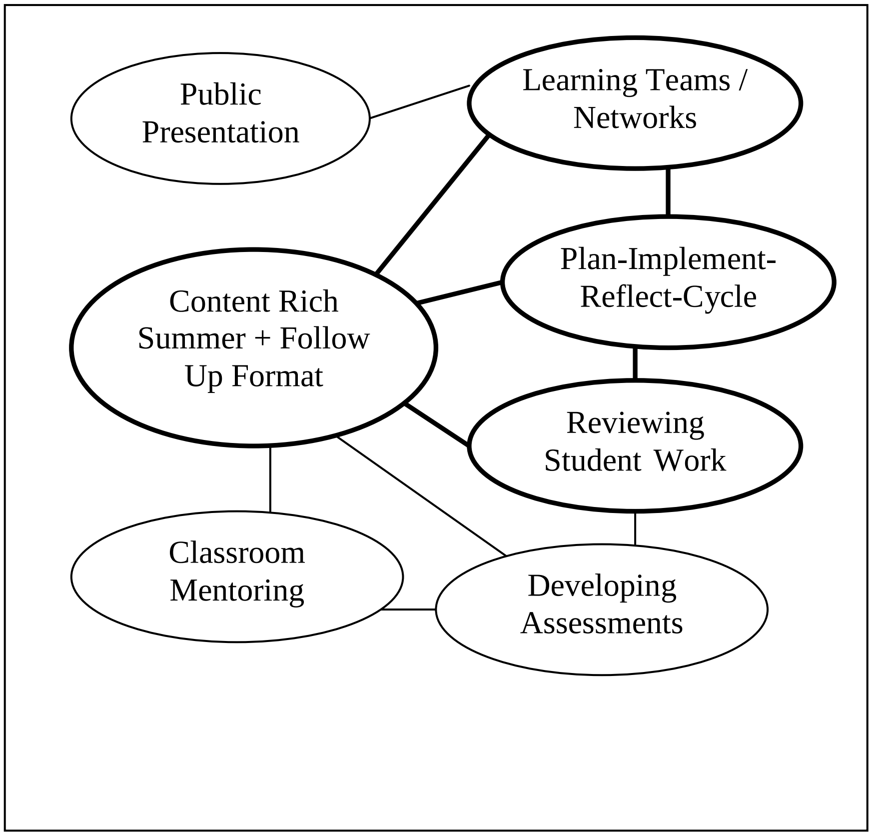

Figure 5. Constellations of effective Professional Development (from Blank & de las Alas, 2009). Darkened set of connected ovals are an example of an effective constellation. Adapted from Deshler et al., 2015).

In his examination of the growth of awareness of student thinking among graduate students working in an Emerging Scholars activity-based instructional environment, Kung (2010) reported that TAs learned different things depending on what artifact of student thinking they considered. Office hour interactions were informative to novice instructors about thinking processes in ways that grading student work was not. However, grading student work gave TAs familiarity with common student slips and errors. Classroom interaction gave an additional kind of information about student risk taking

when in an unfamiliar problem situation--and that risk taking differed depending on the classroom atmosphere (Kung & Speer, 2009).

Graduate student TAs work in an environment that is different from the K-12 setting. Herzig (2002) researched mathematics doctoral students and developed a model illustrating her findings on why these students stayed and finished their PhDs and why some students did not finish. Herzig claims that in order for students to be successful they must feel integrated into two primary communities of practice, the Course-taking Community of Practice and the Research Community of Practice. Herzig noted that after the students “proved themselves” in their classwork they still needed to be accepted to the research community of mathematics. This “acceptance” normally occurred by a professor encouraging or reaching out to the student. If the students did not feel accepted into both of the communities, the student did not finish their degree.

Theoretical Framework

This dissertation project blends the extensive mathematics education research on teacher knowledge and practice development with explicit attention to the emerging literature on college instructor development. In particular, the conceptual framework is built on the foundation of pedagogical content knowledge. Pedagogical content knowledge (PCK) is the collection of knowledge instructors have about the discipline-specific challenges students encounter, strategies for helping students, ways to listen to identify not only learners’ thoughts but also thinking processes, and skills for regulating practice (Ball & Bass, 2000; Shulman, 1986). Novice college mathematics instructors acquire PCK in many ways such as grading, examining their own learning, observing and

interacting with students, reflecting on and discussing practice (Kung, 2010; Kung & Speer, 2009; Speer & Wagner, 2009).

College mathematics PCK is related to subject matter knowledge in that it draws on the foundations of mathematical approaches to thinking (e.g., reasoning, proof, and problem-solving) but is different from such content knowledge in that it involves using these ideas in the context of working with people rather than in working with mathematics. College mathematics PCK includes knowledge about formal and informal mathematical discourse, including teachers' anticipations regarding their adult students' thinking and how to turn teacher intentions into actions (Hauk, Toney, Jackson, Nair, & Tsay, 2013). These ideas are operationalized in this dissertation work by a focus on seeking and responding to student thinking through questions.

The emerging consensus in faculty development is that it is clinical work: instructors must evaluate, diagnose, and prescribe, while also developing their practice (Hinds, 2002; Persellin & Goodrick, 2012). Great success in preparing clinicians in medicine, psychology, law, and education has come through case- or story-based study (Boud & Feletti, 1997). Improving college mathematics teaching can productively start with ways to build instructional self-awareness through opportunities to compare and contrast to other people in a variety of contexts (Mason, 2010). This method has been making its way into college instructor preparation through case-based materials (Friedberg et al., 2001; 2011Hauk, Speer, Kung, & Tsay, 2010; Hauk et al.,).

Framework

This dissertation study extends existing theory about aspects of discourse (e.g., questions as part of math talk; Hufferd-Ackles et al., 2004), types of questions (Mehan,

1979), as well as categories and depth of questions particular to college mathematics instruction (Roach et al., 2010) by documenting and analyzing the occurrence of *question category* and *question depth* as dimensions of interrogative discourse *in context* (*discourse neighborhoods*). Table 2 summarizes each of the question depths and illustrates that question depth crosses question categories.

Table 2

The 4×4 Matrix of Relationships Among Categories and Depth of Questions

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking
Depth 0	Calls for memorization or recall			
Depth 1	Goal is procedural, without connection to concepts			
Depth 2	Purpose is connection between solution and reason/sense-making			
Depth 3	Target is "doing math": create, synthesize, make and justify conjectures			

Attention to all three characteristics, question *category* and *depth* in the context of *neighborhood*, allows a multi-faceted method for documenting question-driven discourse as part of instruction, and for examining change in discourse spurred by questions, over time. Further, the categories and depths are an aid in identifying patterns in discourse. I have theorized that discourse patterns can be characterized productively by question structure (content, category, and depth) and context (discourse neighborhoods). This framework offers a language for doing research on the structure and context of questions and related discourse patterns.

To situate the above framework description, consider the image in Figure 6. Imagine the diagram as a mobile. The video case based activities are analogous to the wind that would blow the mobile and move and adjust the different hanging pieces. The mobile is supported by an individual's understanding of the mathematical topics, in this case calculus. Instructors bring to their teaching a collection of past experiences with both teaching and learning as well as communication behaviors they engage in while planning, instructing, and reflecting on teaching. Given the focus of this dissertation study, the framework represented in the mobile has two primary branches, communication (in this case as articulated in the Math Talk framework) and context (in this case the beliefs and experiences of the instructor). The Math Talk branch represents the implementation of teaching the mathematical topics. Within the Hufferd-Ackles ' et al. (2004) Math Talk framework there are four theorized aspects: mathematical ownership of the ideas being presented, responsibility for learning, explanation of thinking, and questions related to the conversations and communication taking place in the classroom. While communication has many aspects, the focus of this dissertation is on questions, specifically question categories and depths. As Figure 6 illustrates, this dissertation study addresses one small aspect of teaching. However, as is the case with a mobile, when one piece is adjusted or blown by the wind (video case based activities), the entire mobile can shift, move, and/or readjust.

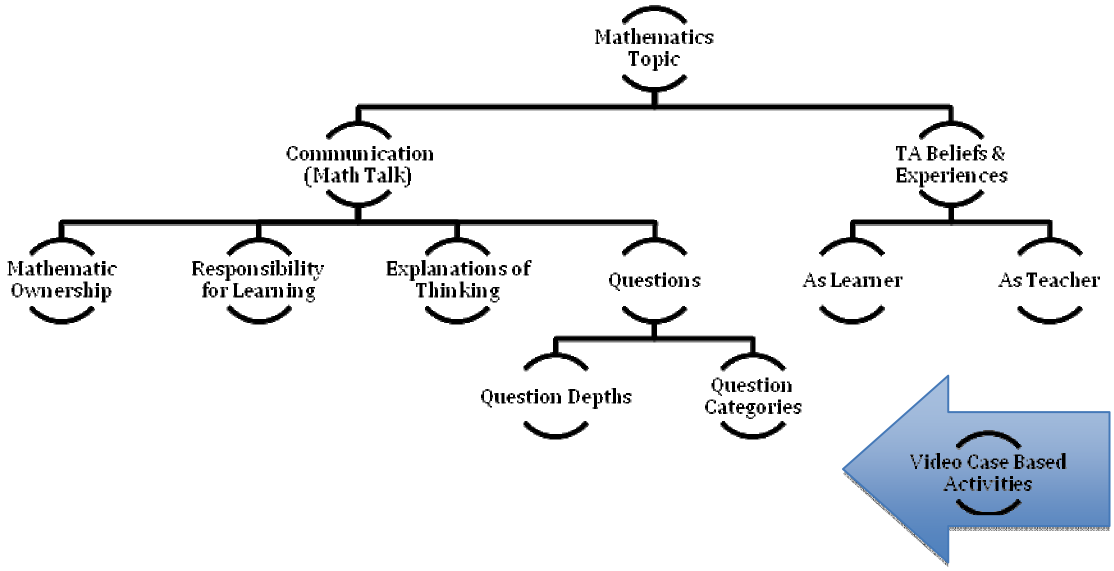

Figure 6. Representation of the dynamic relationships and context of the theoretical framework--a mobile of connected ideas.

Leveraging Best Practices and Emerging Work in Professional Development (PD)

Research in professional development is much more mature at the K-12 teacher level, and this dissertation project adapts many of its best practices. Currently, K-12 work asks teachers to carefully examine the content and syntax of mathematics, of the classroom, school, and community environments, and of teaching and learning (Boston & Smith, 2009; Schifter & Fosnot, 1993; Simon & Tzur, 2004). Several research projects have demonstrated that these K-12 PD practices are effective at increasing teachers' opportunity to learn both mathematics and pedagogy (Borko, 2004; Wilson & Berne, 1999). For PD format, the Blank and de las Alas (2009) work suggested that PD built to include an intensive start and at least two of these constructs shown in Figure 4, spaced across several months, scaffolds instructional awareness and leads to improvements in student learning. The design of TA development at Big Research University (BRU)

begins with an intensive workshop and includes all five constructs in the follow-up work. The dissertation research focused on the promise of case-based work to support instructor learning in each of the areas, with special attention to cases that ask instructors to examine student thinking/student work.

Teaching and learning improve through scrutiny of the content and processes of classroom activities, examination of instructional strategies and student learning, and discussion of ideas for improvement (Ball & Cohen, 1999; Driscoll et al., 2003; Kazemi & Franke, 2003). Notably, such scrutiny is not constrained to live classroom observation and may include analysis of classroom video (Seago et al., 2004; Sherin, 2007).

The foundations of the theoretical framework come from combining ideas from K-12 research on classroom "math talk" (Hufferd-Ackles et al., 2004) and task analysis (Stein et al., 2000) along with college-level explorations about "good questions" in mathematics instruction (Miller et al., 2006). In particular, it addresses questions asked in undergraduate calculus I classrooms.

Example of the Question Depth Framework in Use

Using this body of work, my colleagues and I developed a framework (Roach et al., 2010) to help teachers identify and discuss the types of questions they ask (or want to ask) in a calculus classroom. This framework categorized an instructor's intention of a question by determining whether the instructor was assessing a student's understanding (*Comprehension Check*), discovering what a student is thinking (*Elicit Student Thinking*), or gaining insight into the reasoning behind a student's thought or thought process (*Probing*). These categories have two dimensions: (a) the audience toward which a question is directed and (b) the cognitive demand placed upon the students by a question.

We noted that an instructor might pose a question to different audiences including an individual student, a group of students, or the class as a whole. We took into account the previous mathematical concepts covered prior to the classes of focus, and followed Stein's and Smith's (1998) levels of mathematical activity to determine the cognitive demand a question placed upon the students.

During our initial coding process, we found that teachers utilized questions to explore students' understanding at varying levels. While we were able to use our previously established framework to describe teachers' intention (Comprehension Check, Probe Student Thinking, Elicit Student Thinking) when posing questions to their students, we were not satisfied that it effectively conveyed teachers' attempts to explore and survey the depths of their students' conceptual development of a topic. We addressed this issue by using Stein and Smith's (1998) task analysis guide to identify the depth of mathematical activity (memorization/recall task, procedure without connection to concept task, procedure with connections task, "doing math" task--where sense-making and/or non-routine problem solving is required). In the classroom, a procedures with connections task can be turned into a memorization or recall task by the question a teachers asks.

The more experienced instructor would ask a question that maintained the cognitive complexity of the task. Then he waited for a response. This was his way of trying to get the students to discuss possible solutions or ways to solve the problems. In several cases the TAs would reduce the depth of the task, telling the students the procedure needed to work the problem (e.g., changing the task from procedures with connections to procedures without connections) and then the students would finish the

problem and move on to the next. In some instances, the TAs would not tell the students what to do and would offer some guidance but then walk away from the group. In these instances, the conversation in the student group would be on a deeper level after the TA left the group, the student discussion would continue. The students then excitedly debated the problem until they solved it. Only the experienced professor was observed asking a probing questions which required an explanation from the students. Further, the professor was rarely observed asking a question that turned the task into a recall task.

We also developed a visual tool to aid in observing the question depth and the time frame of the question sequence (Roach et al., 2010). I provide an example below in Figure 7. In this example a teaching assistant, Daniel, was speaking to a group the day the class began talking about antiderivatives. During this line of questioning, Daniel does not elicit the student thinking or probe the student thinking. He begins with a “procedure with connections” Comprehension Check and moves down to a low depth recognition (or memorization) question. This was typical, especially for Daniel, to ask a higher depth question and then immediately follow up and end with progressively lower depth questions. After Daniel left the group, the conversation immediately ended and there was no further discussion by the students about the topic.

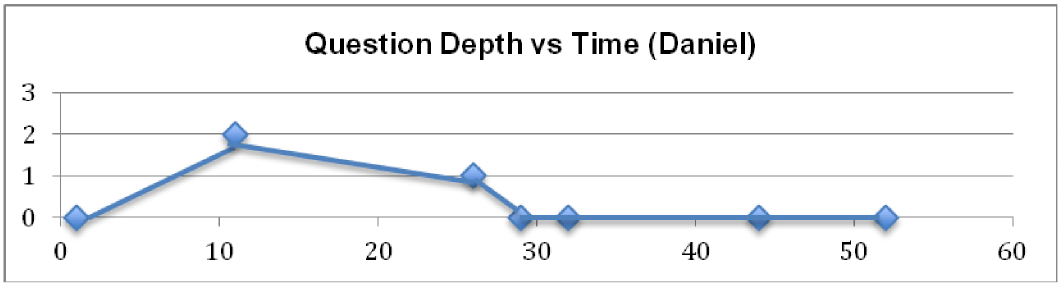

Figure 7. Question Depth vs Time (Daniel). The vertical axis is question level and the horizontal axis is time in seconds.

The TA in the next example, Jennifer, approached a group and began with a lower depth question and ended with a higher depth question (see Figure 8). Jennifer left the group quickly after asking the higher depth question and told the students to think about it. After she left the group, the conversation continued. They were very actively discussing the problem and eventually came to the correct answer.

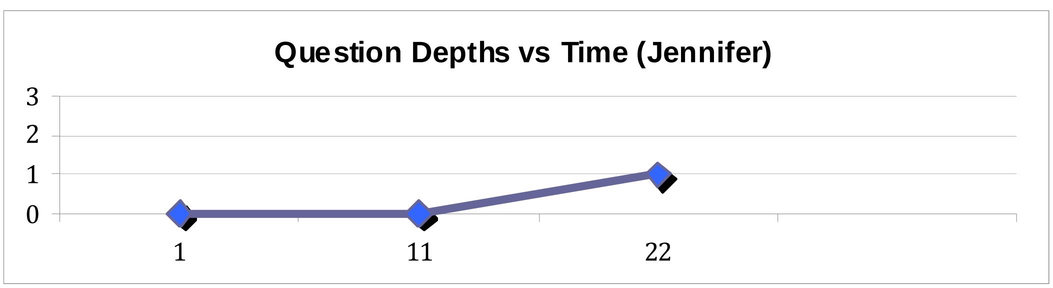

Figure 8. Question Depths vs Time (Jennifer). The vertical axis is question level and the horizontal axis is time in seconds.

These graphs allowed us to visualize and track the level of the questions posed. The second example was an unusual pattern for the TAs. However, it was not unusual for the experienced professor, who often only asked depth two or three questions and normally ended on a higher depth question, usually a depth two or depth three. We

noticed that when the questions ended with a depth two or depth three, the discussion by the students afterward continued in a much more enthusiastic manner and the students would normally come to the correct conclusion with the problems.

The depth of the question seemed to impact directly the discourse that followed. This leads me to believe that there may be a relationship between question patterns and discourse patterns.

Tsay, Judd, Hauk, and Davis (2011) studied patterns of discourse (Gee, 1996) in a college mathematics classroom. The researchers' video recorded one professor's class for an entire semester and found four patterns of discourse: Pattern A, sense-making; Pattern B, establishing or continuing of social norms; Pattern C, lecture pattern; Pattern D, conflict escalation and resolution. The majority of the professor's discourse patterns across the semester fell into the Pattern C category (65% of the class time) and the second most common fell into the Pattern A category (25% of the class time). The authors further claim that these patterns demonstrated the level of questions, as defined by Hufferd-Ackles et al. (2004). In Pattern C, the discourse and question level was likely to reside in Level 1. The professor would ask a question and the students would respond. In Pattern A the discourse and question levels were mostly at the Level 1 and 2 and occasionally Level 3. However these discourse patterns were more likely to fall into Pattern A by midterm and the discourse level resided mainly at Level 1. I take from this research that by examining the Pattern level of discourse it is likely that the question levels will fall into similar categories.

CHAPTER III

METHODOLOGY

This chapter provides detailed descriptions of the research design and implementation for this dissertation project. The project was motivated by my own ontological and epistemological orientations along with a desire to understand how we learn to teach college mathematics. The chapter begins with my ontological and epistemological stances. This is followed by a discussion of the dissertation study's setting, participants, description of the course and intended curriculum, and approaches to data collection, analysis, and reporting. Included are the model for connecting the research questions and data sources, discussion of maintaining rigor in the research, limitations and delimitation of the study, and a timeline of the work.

Researcher Stance

My ontological stance for the study was postpositivist. In this worldview, while there is a reality, people's perceptions of it differ (Patton, 2002). In this paradigm, "it is possible, using empirical evidence, to distinguish between more and less plausible claims, to test and choose between rival hypotheses" and come to defensible conclusions about what is true (p. 106). It was my job as a researcher to interpret individuals' perceptions and report as objectively as I could, based on my personal perceptions. I further claim that the instructors involved in this study held a common shared reality. They were all novice instructors dealing with common anxieties associated with being new to teaching and new to their graduate programs.

My epistemological stance for this proposal was constructivist, both social and radical. I held to the belief that people construct their own knowledge and that knowledge is influenced by their environment. This knowledge can be a shared knowledge within a group, as in social constructivism, or the knowledge can be individually constructed, as in radical constructivism (Schunk, 2004).

Setting

In this section I offer the institutional and departmental contexts in which the study occurred. Participants taught calculus at a research 1, doctoral granting public university, referred to here as BRU. I chose to focus on calculus learning by non-mathematics majors. As noted earlier in Chapter II, most students in college calculus are not mathematics majors, and the early teaching experiences of novice instructors tend to be with this population. The choice of a course that serves a large population and is often taught by TAs was purposeful, so that results might have broad transferability.

I worked with the course coordinator, Dr. Wales, a pseudonym (see Appendix A for letter of commitment). As part of the regularly scheduled coordination meetings (all of which I attended), I facilitated four video case activities with the participating calculus instructors in Fall 2013. These video case activities included watching a video vignette, answering questions in the related materials, responding to discussion prompts about the video, and completing associated activities. While scheduled to meet weekly, the coordination sessions were actually convened at the course coordinator’s discretion and occurred less often. The group met 10 times during the Fall semester. I facilitated use of video case materials during four of the last seven meetings.

Video Case Selection

The video cases were created to illustrate aspects of teaching that may be encountered by instructors (Hauk et al., 2013). Table 3 gives an overview of the available cases. Most focus on how students think about mathematics and how instructors might engage students in discussing mathematics. There are two cases on aspects of classroom norm-setting, *First Day* and *Grades*. Knowing I had time for at most four, I chose them to span the ways instructors and students interact and based on advice from one of the developers (i.e., Dr. Shandy Hauk, co-advisor of this dissertation research) about which cases had been most engaging with novice calculus TAs in field-tests. The priorities in selection were (a) to address a variety of instructional interactions, (b) to involve calculus content, and (c) prior experience in facilitating the case before with TAs.

The first case chosen to facilitate during the study focused on teacher moves in a calculus class (*Facilitating Group Work*). The second case facilitated was the only case that showed a calculus teacher during office hours (*Office Hours*). The third case facilitated was set in a calculus class and eavesdrops on students working together (i.e., no teacher in the video; *Angelica's Group*). The last case was about socio-mathematical norms and assessment decision-making (*Grades).* These four cases satisfied priorities 1 and 2 for selection.

Table 3

List of Available Cases

1.	*First Day* - establishing classroom norms and setting the tone for learning in class.
2	***Facilitating Group Work*** - examining instructor-student communication during group work in calculus.
3	***Angelica's Group*** - exploring student thinking as calculus students work together and discuss a new idea.
4	*Processing Student Feedback* - developing strategies for using student feedback to improve teaching.
5	***Office Hours*** - making the most of this important one-on-one time by leveraging student thinking
6	*Choosing and Ordering Student Work* - strategically selecting and sequencing students' ideas to scaffold a whole class discussion.
7	***Grades*** - exploring various purposes and consequences of different approaches to assessment.
8	*Leading Whole Class Discussions* - orchestrating a student-centered whole class discussion
9	*The Communication Gap* - diving into differences between how instructors discuss mathematical ideas and how their students do.
10	*What Do They Really Get?* - exploring student thinking as students determine whether an infinite series converges.

Note. Cases used in this study are in bold.

Prior experience also influenced the selection of the video cases. I had led the *Facilitating Group Work* case multiple times before. The case focused on how instructors interact with groups of students and the questions the instructors ask to get the students to express what they are thinking. The creators of the second case, *Office Hours*, conducted pilot studies and found TAs valued the conversations stimulated by the case (Hauk et al.,

2011). This case showed two different instructors working with students during their office hours and showed how those instructors address the questions the students have brought for the instructor to answer. The third video case, *Angelica's Case*, was chosen due to the mathematical topic being discussed by a group of students. The case illustrated how a group of students think and talk about antiderivatives. Antiderivatives were going to be taught during the next two weeks of instruction in the classes I was observing, and I decided that this video case would be one that the instructors could relate to the classes they were teaching. The fourth and final video case, *Grades Case*, was chosen because field-tests indicated it was a topic the TAs would find interesting and relevant to their own classes (Hauk et al., 2011). This case was shown at the end of the semester, two weeks prior to the final exam and assigning grades. The case discussed what grades mean and how grades are determined.

One instructor chose not to participate in the study and he did not attend the four course coordination meetings that I facilitated. The graduate students who were TAs at BRU typically taught freshman and sophomore level classes. Each was the instructor-of-record for a course and was responsible for teaching the class and assigning homework. The classrooms focused on in this study were Calculus for Biological Scientists.

Participants

Participants were instructors at BRU teaching Calculus for Biological Scientists. There were five participants in this study. All five participants were novice instructors. Four were graduate TAs and one was a recently graduated instructor. For the remainder of this document, I refer to those who are instructor-of-record (both TAs and other non-graduate student instructors) as "instructors." The five participants in the study consisted

of one first semester instructor, three instructors in their 3rd or 5th semester teaching, and one instructor in her 8th semester teaching (teaching no more than three courses per year). Pseudonyms were chosen for each of the participants. The pseudonyms are Nick, Disha, Omar, Pramod, and Evelyn. The number of syllables in the person's pseudonym is based on their experience. Nick was given a one syllable name since this was his first semester teaching. Disha, Omar, and Pramod, all had two to four semesters teaching and therefore a two syllable name was chosen. Evelyn was given a three syllable name, having eight semesters of college level teaching (see Table 4).

Table 4

Overview of Participant Characteristics

	Department Status	Previous College Teaching Experience	Undergraduate Degree Experience
Nick	TA	None	United States
Disha	TA	4 Semesters	India
Omar	TA	4 Semesters	Pakistan
Pramod	TA	2 Semesters	India
Evelyn	Instructor	7 semesters	Australia

Each of the five participants is discussed in detail in Chapter IV. These instructors were chosen because all taught the same course, Calculus for Biological Scientists. There were six total instructors of Calculus for Biological Scientists, however, one instructor chose not to participate. When asked, this person gave no reason for not participating.

Literature on the development of professional knowledge has indicated that approximately 1,000 hours of professional engagement were required before a fledgling

professional might be considered an inductee into the profession (Dreyfus & Dreyfus, 2004; also note that a basic requirement for applying for National Board Certification in teaching is 1,000 hours of classroom experience, National Board for Professional Teaching Standards, 2013). For the purposes of the dissertation, a "novice instructor" was defined as one who has 1,100 hours or less in the classroom, or approximately four years of teaching at least three courses per semester. Though not direct participants, undergraduate (adult) students of these instructors were involved as part of additional non-sensitive supplemental data collection (i.e., anonymous exam scores and in field notes from classroom observations).

The Intended Curriculum: Calculus

According to the syllabus there were three central goals of the *intended curriculum* in Calculus for Biological Scientists at BRU. These were:

- to learn how to build and read mathematical models of biological phenomena,
- to gain a working knowledge of the key tools of calculus-*derivatives*, which quantify *rates of change* of functions, and *integrals*, which sum up rates of change, and
- to understand key concepts of science such as *equilibrium*, *stability*, and *rate of change*, both in terms of mathematical descriptions and biology.

The syllabus explained that the course used Calculus to study the nature of change in living organisms and to quantify this change by considering questions such as how fast something is changing, how much is changing, and into what is it changing. The text used for the course was *Modeling the Dynamics of Life: Calculus and Probability for Life*

Scientists (Adler, 2012). The first four chapters were covered. The chapter titles were as follows:

Chapter 1: Discrete Time Dynamical Systems

Chapter 2: Limits and Derivatives

Chapter 3: Applications of Derivatives and Dynamical Systems

Chapter 4: Differential Equations, Integrals, and Their Applications

The author states the goal of the book is to teach mathematical ideas, used commonly by biologists, in a way that will make sense to a biology student. The intent is to teach not just techniques of calculus, but concepts of mathematical modeling.

Calculus for Biological Scientists had two departmental midterms (worth 100 points each, making up 40% of final grade), a comprehensive, departmental final (worth 100 points or 20% of final grade), weekly quizzes (worth 100 points or 20% of the final grade), WebWork homework (worth 50 points or 10% of the final grade), and written homework (worth 50 points or 10% of the final grade). The common midterms and final exams were collectively graded by the instructors immediately after the exams were administered. The grading process was that one instructor graded all student responses to Item 1 for all classes, another instructor graded all student answers for Item 2 for all classes, etc. The number of students in an instructor's class varied from 30 to 120.

Data Collection and Procedures

My research explored how video cases as a type of professional development influenced TAs' questioning techniques and the patterns of discourse surrounding those questions in their calculus classroom instruction. As detailed below, the qualitatively driven mixed-methods design examined a professional development "intervention" of the

use of video case materials during course coordination meetings. In addition to providing the intervention by facilitating the use of video case materials during four coordination meetings, I conducted pre-intervention, and post-intervention interviews and classroom observations, collected weekly logs from TAs about planning and instructional practices, observed course coordination meetings, and, as an indicator of potential impact on undergraduate learning, collected student scores to the two mid-terms and the final exam. Below, after an overview of these data sources and the logic behind their choice, I detail the collection of each type of data. In the following sections, I have addressed analysis and reporting. To remind the reader, my research questions were:

RQ1 What is the nature of novice calculus instructors' discourse patterns surrounding questions they ask?

RQ2 What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?

RQ3 How does video case based professional development shape perceptions and intentions about the role of questions in teaching held by TAs?

RQ4 Does professional development that includes video case materials hold promise as a way to improve the learning of college calculus students?

Linking the Data to the Research Questions

For the dissertation study, classroom observation across all the participating TAs provided the primary data source for examining Research Question 1. Offering four multiple video case activities allowed time for participants to think about and discuss the strategies demonstrated in the cases and discussed during coordination, and to decide on and try out ideas (and their adaptations) in their own practice. Across time, as novices built experience, the nature of these decisions could change. Research Question 2 (RQ2) focused on this possibility. Multiple interviews with participating TAs within the

semester, supplemented by regular teacher logs, allowed for tracking potential change and addressed RQ2.

Related to Research Question 2 was the question of how the case content might have been influential. Different video cases focused on different instructional strategies (e.g., group work and whole class discussion) providing differing examples of questioning in the classroom. Research Question 3 (RQ3) attended to this variety and focused on two aspects: instructor *perceptions* about the role of questions and *intentions* for the use of questions. Preliminary interviews provided a baseline about instructor conceptions and subsequent interviews, informed by classroom observation and teacher log information, were aimed at capturing how instructor views might have evolved to provide evidence for RQ3.

Research Question 4 (RQ4) addressed the potential effect of TA development in student learning. If video case use lead to classroom questions that included higher cognitive demand (e.g., process and metaprocess question types or longer dialogic *IRF* strings, discussed in Chapter II), then it might have been possible for student learning to be improved. One way to explore the possible relationship with undergraduate learning outcomes was to examine mean and variation in scores on exams common across instructors. Also, historical data for the course exams were available and provided additional context for the limited information that was available from what were just six participants' classes in addressing RQ4.

A summary of the data sources and how they relate to the research questions is shown in Figure 9.

Data Source / Research Question	Interviews	Classroom Observation (note: focus was instructor practices not student learning)	Online Instructor Logs	Anonymous Data on Student Performance
Research Question 1: What is the nature of novice calculus instructors' classroom discourse patterns around questions?	Interview 1 included participant self-perceptions; additional data from coordination meeting field notes on engagement with case activities.	Classroom Observation protocol captured the text of questions asked, the contextual neighborhood, and the type of interaction.		
Research Question 2: What is the nature of change in questioning strategies within a semester during classroom discourse by these instructors?	Interviews 2 and 3 included probes about how strategies may be changing; additional data arose in field notes of coordination meeting discussions.	Doing multiple classroom observations allowed for comparison across time.	Instructor self-perceptions captured across time through weekly logs	
Research Question 3: How does video case PD shape perceptions and intentions about the role of questions in teaching?	Interviews 2 and 3 included probes about how video case activities might be influencing teacher decisions; data arose in field notes from coordination meetings.	Observation notes informed Interviews 2 and 3; supported shared understanding with participants about their perceptions and intentions.	Logs included questions on strategies discussed in coordination that could be used in class.	
Research Question 4: Does professional development with video case materials hold promise for improving student learning?				Final exams scores were collected were and the mean scores were compared between TAs who asked higher-level questions and those who did not.

Figure 9. Data summary.

Data Collection

I conducted semi-structured pre-intervention, post-intervention, and exit interviews with each of the participating instructors. Instructors completed weekly surveys, in the form of a web-based log, that addressed their perceptions about the video case experiences and how these influenced their questioning techniques during teaching that week (see Appendix B for sample log). Also, I collected from the individual instructors the student test scores for midterms and final exams for all the calculus classes for the study semester. Additionally, the final grades from the previous Fall semester were collected from the department coordinator (these data were regularly shared, without instructor names attached, within the coordination group and the department). Throughout data collection and analysis, instructors were identified by pseudonyms. Student data provided by the department did not include any identifiers other than that they were in an instructor's class, so comparison of student scores across time was not possible (e.g., I could not conduct analysis of student final exam scores controlling for incoming SAT or ACT score).

There were several incentives in place for the participating instructors. First the course coordinator, a person of influence and power in the instructors' teaching community, supported the proposed research and cooperated with me. Second, research has indicated that the majority of new college teachers are eager to see, hear, and talk about other people's teaching and to contribute to that conversation with information from their own instruction. Third, there was peer support within the coordination group as all but one of the BRU instructors teaching the focal course viewed the video case

materials. Finally, I offered a small financial incentive, up to $100, to participate in the study by completing data generating tasks (e.g., logs, interviews).

Data as Related to the Unit of Analysis

The instructor was the primary unit of analysis. All data were related to providing contextual, proximal, and distal information around instructor-level analysis. Teacher log self-reports and some interview questions about instructor experience provide contextual information. Classroom observations and observation-related interview items were the data closest to the planning, reflecting, and implementing of practice and served as proximal information. Coordination meeting field notes and data from student tests were further removed from the immediate classroom questioning of instructor-level analysis and provided the distal information.

Interviews

I conducted three semi-structured interviews with each of the participating instructors as well as follow-up member check interviews after the semester was over. The intake interview (pre-intervention) occurred before instructors encountered the video case materials. A follow-up interview was conducted three weeks after the first video case activity. An exit interview (post-intervention) was conducted at the end of the semester, during the last week of school. Each interview was conducted in the Mathematics Department in a small room that would hold about eight people. This room was generally used for student study groups. In each of the interviews, I emailed the instructors to set up a time for the interview and reserved the room through the Mathematics Department. After the initial email the instructors offered times that they could meet and I accommodated them by meeting during those times. The interviews

lasted no more than one hour. I audio recorded and transcribed each interview. To be respectful of the participants I took very limited notes while interviewing them. The second interview included two short video clips of the instructor being interviewed. These video clips were not more than two minutes long. During this second interview the instructor was provided a transcript of the video clip, without punctuation. The instructors were asked to identify the questions asked and provide information as to why they asked those questions. The video-clip interview protocol is summarized below in Table 5 (see Appendix C for full protocol). It was adapted from Speer (2001). The third interview focused on excerpts from the weekly logs, comments made in previous interviews, how the participants viewed questions, and any perceived changes the participants had in their teaching. This interviewed focused on the perceived changes and why the instructors felt they had made that change. I also asked questions about the video cases and how the instructors thought the cases may or may not have influenced instructional decisions, particularly how the instructors asked questions.

The interviews were primary data for RQ2 and contributed data for addressing RQs 1 and 3. Depending on the log data, the exit interview also provided significant data for addressing RQ3.

Table 5

Summary of Interview Content and Relationships to Research Questions

Research Question	Intake Interview Interview 1	Follow-up Interview 2	Exit Interview Interview 3
RQ1: What is the nature of novice calculus instructors' classroom discourse patterns around questions?	Interview 1 included participant background information, self-perceptions and beliefs about student learning. Beliefs about student learning often influenced how instructors asked questions and how instructors responded to students.		
RQ2: What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?	Interview 1 provided a baseline of instructor perceptions about student learning and I was able to compare responses to the final interview responses.	Interview 2 focused on the types of questions commonly asked by the instructor participants. These questions focused on what the instructor was thinking when asking questions, and what the instructors expected students to get out of the questions. Perception of student learning arose from this interview and was compared to Interview 1. This interview included two video clips of the instructor teaching.	Interview 3 focused on instructor beliefs about learning and reasoning behind asking a particular question. This interview also focused on any self-perceived changes in how the instructor asked questions.
RQ3: How does video case PD shape perceptions and intentions about the role of questions in teaching?		Interview 2 focused on why the instructors asked the questions they asked, i.e. the intentions behind the question and perceptions of the response they expected. Follow-up questions probed how the video case activities may have influenced instruction.	Interview 3 included probes about how video case activities influenced teacher decisions. This interview explored in more depth why an instructor chose to ask a particular question and the purpose of the question.

My note-taking during the video-clip-based interview (interview 2) focused on the comments made by the instructors about their own perceptions of the complexity,

content, and purpose of the question and associated responses (from students and subsequent follow-up from teacher, where appropriate).

Field Notes and Video Cases in Course Coordination

As a researcher, I attended and made field notes at each course coordination meeting. Four times during the semester, instructors engaged in a video case activity (Hauk, Speer, Kung, Tsay, & Hsu, in press). I facilitated the video case activity during the instructors' regularly scheduled, coordination meetings.

The room was equipped with a computer and projector linked to the computer. The room was a conference room used by the department. It had six tables arranged in three rows and had three chairs at each table which faced the front of the room, where the video was projected onto a screen. The room could hold up to 25 people, however the chairs were arranged for 18 people to sit in the "audience." Before each coordination, I arrived 30 minutes early to connect my computer to the overhead projector and speaker connections provided in the wall. I then checked that the projector was working and waited for the instructors to arrive. When I facilitated these video case activities, I served as the course coordinator. I handed out the associated materials (questions to be discussed, transcripts of the videos, and any other written materials describing the case) that were provided by the creators of the video cases. I followed the instructions in the facilitator's guide by explaining the video vignettes, showing the videos, and leading the discussions.

I followed the facilitation guide for each video case. Before each video case session, I printed copies of the participant materials to hand out and set up the computer, screen, and speakers to play the video vignette. Nick, Disha, Omar, Pramod, and Evelyn

usually sat in the same places at each meeting, facing the front of the room. Nick, Disha and Pramod sat at the back of the room. Omar and Evelyn sat on the second row at opposite ends of the room. This allowed for Omar and Evelyn to move their chairs and see the people behind them when they spoke. While the video vignettes were being viewed I stood to the side of the room next to the computer. During the discussions I moved to the front of the room and led the discussions. The participants would often move their chairs so that they could see the other instructors when they spoke. Due to the size of the room, it was easy to hear all the instructors when they spoke and the video was easily viewed at the front of the room on a large screen. Each video case session took the entire meeting time, 50 minutes for each case. Details on each of the four video case-based meetings are included in Chapter IV.

Researcher field notes (generated during and, reflectively, after meetings) focused particular attention on discussion of question strategies (described in more detail in the section on the Writing-Reviewing cycle). I reserved one hour after each video case activity had been completed to journal about how I addressed asking questions during the meeting. The coordination meetings were video recorded (see Appendix D for letters of consent). This served as secondary data used to address RQs 2 and 3.

Classroom Observation

I attended six class meetings for each participating instructor and took extensive field notes using an observation protocol with existing and open-ended categories. Following the approved protocol for the study, I obtained permission from students in all the participating instructors' classes to video record the six meetings for each (see Appendix D for undergraduate and TA consent forms). As with coordination meetings,

detailed researcher notes focused on questions asked by the instructor, context of the questions, and the apparent intent of the instructor. Table 6 summarizes the protocol. See Appendix E for classroom field notes protocol. The purpose of the video recording of calculus class meetings was to serve as a backup to the researcher notes and allow enhanced note-taking after the class visits. Primarily, these observation data were used to address RQ 2 and as a source of video/classroom examples for in the exit interview.

A more experienced research colleague conducted an expert check on my coding and field notes. This expert had helped in developing the observation protocol in previous research projects. I completely coded one video and the expert viewed the video and coded the video separately. The expert and I met in person and discussed the coding of the video. When we did not code questions the same way, we reviewed the video surrounding that question, and discussed the coding until we were in agreement. I then completely coded six more videos. These videos and my coding were checked for accuracy by the expert. He agreed on the coding and I coded the remaining videos. The expert then chose two videos (randomly, literally drawing names from a hat) and checked the coding for those videos for accuracy. He agreed on the coding of those videos. The videos and my coding were also checked by my co-advisor, Dr. Hauk.

Table 6

Summary of Observation Protocol Components

Component	Description/Purpose
Time	Approximated minute of the class the instructor asked the question
Content	Question around which interaction was centered as asked by the instructor (transcribed or paraphrased)
Level	In-context, in-the-moment observer judgment of Level of discourse
Type	*Comprehension Check:* Assessed one or more students' declarative understanding of a topic, procedure, or task (evaluative)
	Probe Thinking: Investigated the reasoning behind or explanation for a given response or procedural work, including prompts to communicate *why* a person or a group thought what they did
	Elicit Thinking: Drew out what one or more students were thinking, including prompts for student(s) to communicate *what, how,* and *why* they thought it to other students or the teacher
	Classroom Management: did not directly affect the instruction. (e.g. 'Could you hand in your homework?').
Context	Used to describe the context surrounding the question, the "discourse neighborhood" of the associated question.
Memo	Used to describe any additional thoughts or things happening in the classroom that could contribute to the question (e.g. how long the teacher waited for a response, or how many students offer to/begin to respond to the question)

After the initial intake interviews, I visited each participant's class. During the class visit I used the observation protocol, which included detailed field notes and post-visit notes about things that I observed in the classroom, particularly relating to how the instructor asked questions. I reviewed classroom video to create a set of enhanced field notes for each first observation. As part of the protocol for each observed class meeting, I documented instances of the instructor asking questions using the criteria outlined in

Chapter II for identifying what constituted a question. This documenting included question depth, categories, and potential nuances of discourse neighborhood related to each question. I reviewed these instances, choosing at least two that I used as interview prompts with the instructor for the video-clip-based interview.

Online teacher logs. Instructors completed weekly online logs. These short (5 minutes to complete) logs focused on participating instructors' perceptions of how professional learning fostered by video case activities influenced their teaching--particularly their question strategies--during that week of classes (see Appendix B for weekly log). At the mid-point of the study I generated a report of responses and possible themes that I shared with instructors as a check of face validity (i.e., to confirm that the instructors perceived the prompts in the way intended). I revised log questions twice, to gather data on topics that emerged from early analysis of interviews. These data were used to answer RQ 3 and inform the design of interviews.

Anonymous summary data on student performance. I collected student scores for the two mid-term exams and the final exam and calculated the mean scores, standard deviation, and sample size for the midterm and final exams for the participants' class sections that I observed. The scores were examined for statistical differences. I worked with the BRU institutional review board (IRB) through a Federal Wide Assurance (FWA) agreement to obtain de-identified student ACT/SAT scores, for each participating instructor's class to determine if the classes were significantly different at the outset (see Appendix F for IRB approval). These data were used to answer RQ 4.

Data handling procedures. All paper data were kept in a locked cabinet in my own or my advisor's office. All electronic data were kept on password protected storage devices. Pseudonyms and alphanumeric identifiers were used in research documents for participants. Accepted protocols for data security were followed (www.citiprogram.org). All student names were removed from my transcriptions of classroom video.

Risks, Discomforts, and Benefits

The risks and discomforts inherent in this study were no greater than those typically encountered during regular class participation, regular classroom teaching, and regular coordination meetings. As with any learning opportunity some instructors experienced some discomfort as they encountered their own limitations in discussing teaching. Instructors reported a sense of having benefited by participating, particularly by gaining insight into teaching strategies from the cases.

Costs and Compensation

The stipend schedule for research participation is described in Table 7 below. Full stipends were given for full participation. Each of the participants completed all research tasks and received the full stipend.

Table 7

Summary of Participant Financial Incentives

Stipend	Requirements	Deadline
$50	1. Completing the initial interview 2. Completing at least 5 of the first 6 weekly logs 3. Providing sanitized copies of student responses to researcher-identified midterm exam questions of interest. 4. Complete the follow-up interview	November 8, 2013
$50	1. Complete at least 5 of the second set of 6 weekly logs 2. Provide researcher with copies of student responses to researcher-identified final exam questions of interest. 3. Complete the final interview	January 15, 2014

Grant Information

Grant funding was not found for this project. The researcher provided the funding.

Data Analysis

As detailed below, the data collected were analyzed through standard constant comparative qualitative methods (Patton, 2002). For the quantitative data, I used descriptive and inferential statistical methods (Gall, Gall, & Borg, 2006). The procedures, for each data set, are described below.

Analytic Inductive Method

The Analytic Inductive Method is a qualitative method of analyzing data. The process is to refine regularly the research hypotheses while analyzing data until all cases that do not fit the original hypotheses are explained. The basic steps, as described by

Merriam (1998, p. 160), began by formulating a hypothesis or explanation for the area of interest for which data were collected, then data were gathered so that potential challenges to the hypothesis were documented (falsifiability). For this study, the unit of analysis was an instructor or “case.” An instructor case was built from the collection and analysis of the types of interview, observation, and document data discussed above. In what follows, first I give a general idea of the pathway through analysis, then I give the particulars for this study in the writing-reviewing cycle, and analysis for each of the types of data collected. Subsequent major sections address reporting and how the research satisfied the basic requirements of rigorous qualitative research.

As observational data were gathered, I selected at least two complex instances and set them aside with no analysis (these were used later in validation). From the remaining data, I systematically examined each instance in the data (e.g., question) to see if the hypothesized explanation fit that instance. If the hypothesis did not explain or fit the instance, then I reformulated the hypothesis. If the hypothesis did fit, I indicated a code for the instance and moved to the next instance. This process continued until an instance occurred that challenged the explanatory power of the hypothesis, then revised the hypothesis. This process continued until the reformulated hypotheses explained all cases and no contradictory cases could be found in the existing data. After this cycle was completed, the validation step began: I examined the two instances/cases that were not included in the early validation--or, in the case of the logs, collected new data--and described using the hypothesized explanation. If the hypothesis was robust, it needed little to no adjusting. If it needed major adjustment, then I identified the limitations of the hypothesis.

In this study, I used this process as I took my existing framework (Roach et al., 2010) and applied it to the classes I observed in Fall 2013. As necessary, I refined descriptors of question levels and categories so that all instances of questioning were explained by the framework. I added in one new category, Hypophora (explained in detail at the end of this chapter) and readjusted the model. The instructor interviews further helped to refine categories and served as a member-check as evidence which supported my claims and validated inductively tuned hypotheses to explain the data.

Writing-Reviewing Cycle

The writing and reviewing process began after the first interviews had been conducted. After transcribing and reading the initial interviews, I made notes on anything that related to the question levels, question categories, and instructor beliefs about learning. After each interview, I reviewed the audio/video recording of the interview to generate a set of enhanced interview notes. For each classroom visit and interview, I analyzed and coded my enhanced field notes using the existing framework. The framework was refined as necessary at each step of analysis.

Every 10 weeks I generated a short (no more than four pages) report of the current state of the explanatory hypothesis. I shared these interim reports with my research advisors. My research advisors reviewed the reports and we discussed my interim findings. My advisors also used these reports to identify where more detail and support was needed. I used this information to reexamine my findings and provide justification for my findings. These reports were also used to inform the final interviews and formed the foundation for a debriefing report to the participants that I shared with them at the end of the school year. For each participant I created a profile. I asked instructors to review

their individual profile and provide feedback on how it might need to change to increase its accuracy in representing their story. This request was a form of member checking to support credibility and transferability of study results (more on this below in the section, "Member Checks").

Once all interviews and observations were completed, I organized the interim reports into cases. These cases were formed by examining the data and looking for similarities across and distinctions among the participants' self-reported perceptions and experiences and observed classroom interactions and teaching behaviors. I reported my findings as cases rather than individual findings. When reporting, interviews were sometimes paraphrased to include different participants' similar views.

Interviews

Each of the interviews were completely transcribed. I immediately qualitatively coded using open and thematic coding as the interviews were completed. Later, I did axial coding on intake, follow-up, and exit interviews to look for patterns of change or stasis. Debriefs with the participants occurred after the intake and exit interviews. After the initial coding of the interviews, I summarized my findings and presented my tentative interpretations to the instructors--meeting with the instructors individually, describing my interpretations, and asking if my results were plausible (Merriam, 1998). I later emailed an updated draft of the profile to instructors to ask if they had any additional thoughts they would like me to add or remove from the summary profiles. Each responded with approval for the profile (and some corrections to typos).

Classroom Observations

Observation notes, completed protocol forms, and classroom video were analyzed using the framework of Roach et al. (2010). I viewed classroom video and partially transcribed, as needed, to provide thick, rich, descriptive detail. The role of the observation data in creating cases was to provide contextual knowledge of specific incidents or behaviors and use these as reference points in the interviews and in reporting the findings (Merriam, 1998). This was because the goal for the cases was to depict "typical" behaviors of the instructors while teaching and to document observed changes in teaching across the six weeks of the video case intervention. During the classroom observations I focused on the types of questions asked by the instructors and took detailed notes about the context of the questions as they were asked. I also noted how the students responded to the questions asked by the instructors. An Excel spreadsheet was used during the coding of the classes, both for the live coding and the more detailed follow up coding from the video. The number of each question asked by the instructors was then tallied by category and question depth for each observation.

Coordination Observations

As soon as possible after each coordination meeting, I generated clean electronic versions of my notes. In my notes I addressed how I may have "pushed" or focused on asking questions in class. I then conducted an open coding on field notes of the coordination session. The focus for me during open coding was to look for emerging themes surrounding questions and note types of questions asked by the course coordinator so that I could look for similarities in the classroom to those questions posed during course coordination. Videos collected served as backup to researcher notes. Video

was reviewed within one week of the coordination to flesh out field notes, and I noted any connections among conversations about questioning and modeling of question strategies that occurred across coordination sessions and noted potential links to the classroom questioning practices of participating instructors. Such links were valuable in developing the cases because the conversations about questioning explained instructors' thoughts and attitudes about questions and beliefs about student learning which offered support when reporting similarities between the participants. I reviewed video and partially transcribed it for documenting frequency of discussion of question strategies to generate descriptive statistics. Descriptive statistics provided supporting evidence for common themes that emerged from the qualitative analysis of coordination meetings.

Teacher Logs

The online surveys ("logs") were reviewed weekly with open coding completed regularly (e.g., monthly summaries of open-coded categories of response were included in the quarterly interim reports to research advisors). I generated a mid-year report to document and share (member-check) with instructors any themes that seemed to emerge. I member-checked more frequently, especially in the first two weeks, with the participants to confirm my understanding of their log entries and clarified the wording of log prompts based on feedback.

Summary Student Data

Appropriate quantitative techniques, including multiple *t*-tests and analysis of variance (ANOVA) were used to compare the student scores across classes and on the final exams. The dependent variables examined in the study were acquired and included: (a) student previous SAT/ACT (data provided by the university were not individual

linked to student ID so association between final grade and preparation was aligned at the level of instructor), (b) student final exam score (by student, by instructor), (c) student final grade (by student, by instructor), and (d) previous Fall's grade distributions for the same course. Where possible, additional variables were included in post-hoc analyses, including drop rates, mean grades from previous semester(s), and student mathematics placement test scores. All exams in Calculus for Biological Scientists were common exams created by the course coordinator.

Data Reporting

The writing-reviewing cycle discussed earlier resulted in some interim reporting on the way to the writing of the dissertation itself. The purpose of this study was to document the change in questioning patterns of novice instructors when video case activities were used in course coordination. I anticipated three main clusters of information from the data gathering and analysis described above: (a) themes about instructor perceptions of learning from log entries, (b) categories of instructor classroom practices/experiences from my observation in classrooms and coordination meetings, and (c) scores of students on common math items. For each participating instructor, all three sets of data were used to generate the interim document of an individual story for that instructor. I organized these individual stories into cases based on comparison and contrast of individuals' experience teaching and/or their perceptions about learning. In each of these cases I used direct quotes and paraphrased compositions of several quotes to illustrate various themes that emerged through the analysis. A novice TA not too long ago myself, my personal experience was included to frame the stories and I included reflections of my own experiences in the dissertation discussion section. That discussion

chapter is organized into five parts, one part addressing each research question and a final part that connects the dissertation to literature and future work.

Meeting Criteria for Rigor in Research

The criteria for rigor in quantitative and qualitative research differ. In quantitative work, the focus is on the validity, reliability, and generalizability of results. I have already noted above, in the section on Summary Student Data, how each of these criteria was addressed. The bulk of the work for this study was qualitative, which focuses on five criteria for rigor in qualitative research: credibility, authenticity, transferability, dependability, and confirmability (Lincoln & Guba, 2000).

Credibility

In qualitative research credibility, parallel to internal validity, refers to how trustworthy or believable the research is. By using a number of techniques, a researcher can defend the credibility of the research. Lincoln and Guba (2000) say that credibility can be addressed through member checking, peer debriefing, expert checks, negative case analysis, progressive subjectivity, and persistent observation. I describe each of these and how I used them below.

Member Checks

Member checking is a technique used in qualitative research in which the participants are asked to verify if they agree with the researcher's findings (Creswell, 1998). I used member checks in two ways: during interviews and at the end of the semester after all the data had been collected. Using member checking during an interview was done by asking the participant a question and then repeating what I thought they said to verify that I was interpreting their comments accurately. Another way to use

member checking is to summarize findings and ask participants if they agree with one's interpretations of the data. Both of these techniques were used for this study.

Peer Debriefing and Expert Checks

Peer debriefing is using a colleague or peer to verify findings. A peer debriefer often serves the role of "devil's advocate" and "keeps the researcher honest" (Creswell, 1998, p. 202). It is the peer debriefer's job to ask tough questions about the methods used, and the interpretations of the research. Expert checks are similar to peer debriefing except that they involve an expert in the field of research to review and verify findings. I used peer debriefing in this study by presenting my findings to former and current graduate students with whom I have worked on various projects, and asked them if, given the backing and evidence I shared for my interpretations, they agreed with my conclusions. I also presented preliminary results to a group of colleagues in seminars about research on college mathematics instruction (March 2014 and January 2015 meetings of the SIGMAA on RUME Working Group for Research on College Mathematics Instructor Development) and solicited feedback. I used expert checks by presenting my findings to my advisors and sought feedback from them about the clarity and reasonableness of my interpretations and conclusions. I also used expert checks by presenting my findings to other researchers in the field to let them verify my results. This was done formally at conferences and informally through the seminars mentioned above.

Negative case analysis. Negative case analysis, or disconfirming case analysis, is deliberately looking for cases that may contradict the hypotheses (Patton, 2002). I used negative case analysis by examining the data and searching for examples that contradicted my framework. I then used these examples to either refine my framework or to identify the examples as exceptions to a primary pattern and discussed them further in the results.

Progressive subjectivity. Progressive subjectivity refers to the researcher's emerging constructions when analyzing the data (Lincoln & Guba, 2000). I have monitored my emerging constructions throughout the study by keeping a log of my findings as they emerged. The quarterly interim reports and end-of-semester member-checking reports were both ways to document this work on my part. By doing this I monitored my subjectivity in the research and understood (and reported on) how my preconceived beliefs influenced my findings.

Persistent observation. Persistent observation is a technique that ensures the researcher has not only spent a lot of time with the data but also has a depth of understanding of the phenomenon being observed. I employed this technique by building relationships with the participants, learning the culture of the department, and looking for misinformation (Creswell, 1998). In this study, misinformation included the instructors' perceptions that their individual classes were harder to teach than someone else's or that an instructor received more support than another instructor. I determined the relevant and irrelevant aspects of the study and focused on the relevant aspects. The relevant aspects included ways in which the instructors used questions to instruct the students, probed understanding, or elicited information. Irrelevant information included conversations that

did not apply to the information being presented in the class or to the class (e.g. conversations about social activities).

Authenticity

Authenticity refers to how genuine or credible the researcher may be. It not only refers to the participants' experience but to the greater shared experience of the "community" of mathematics. Authenticity was addressed through the audit trail, thick, rich description, memo writing, and member checking (Creswell, 1998).

Transferability

Transferability is a qualitative concept aligned to external validity or generalizability in quantitative approaches. It is a way of extending the research from the studied population to a larger population: the ways the findings might be justifiably transferred. This is most often done through thick, rich description (Creswell, 1998). Transferability was addressed by describing the participants and the environment in as much detail as I could, without compromising the anonymity of the participants. In general, findings (interpretations, anticipations, predictions of connections or links among these) were transferable due to commonalities or shared characteristics of the participants, setting, and time (historical and elapsed) of the context.

Dependability

Dependability, parallel to reliability, is concerned with the consistency of the data. It is the researcher's responsibility to report on any inconsistencies or changes with how the data were collected or any changes in setting. I have ensured dependability first by explaining my position as a researcher within the group, explaining how I chose the participants and the context in which the data were collected (Merriam, 1998). I also

created an audit trail that describes in detail how the data were collected, how the categories emerged, and how I chose to make decisions throughout the research process (Merriam, 1998, p.207).

Confirmability

Confirmability, parallel to objectivity, is ensuring the results are based on facts and the basis for conclusions is rooted in the data and not just figments of the researcher's imagination. It is the researcher's job to have an openness to the data. I maintained a willingness to listen to the participants and give a voice to them in reporting (Strauss & Corbin, 1998). Member checking and peer debriefing was used to help ensure confirmability.

Timeline

I anticipated this dissertation project taking approximately one year to complete, four months for primary data collection and preliminary analysis, with the balance of the time for additional analyses, writing, and revision. I kept a researcher's journal where I recorded my experiences with college mathematics instructors and their questioning. I collected data with participants several times during the fall term and completed member checks with participants in spring and summer. While qualitative data analyses were completed to full drafts by fall 2014, delays in the collection of student data extended the timeline for the work. With all data finally in hand in fall 2014, the last cycle of analysis was possible, including statistical analyses and putting together the reporting of quantitative and qualitative results.

Participants were contacted in the first week of school and IRB approval and consent were in place by week 5. They were interviewed as soon as possible after that.

The initial contact occurred in the regularly scheduled coordination meetings every Tuesday of the semester. After all participants were interviewed (in week 6) the first video case activity was part of the coordination meeting. A video case activity was all or part of a coordination meeting approximately every two to three weeks. Four video cases were shown from Week 9 to Week 14 of the semester. The final video case was shown two weeks before the end of classes. The participants were interviewed a second time after two video cases had been shown, approximately two months into the semester (first of November) and the final interview occurred during the last week of classes, before the week of finals (December 15th).

Qualitative data analysis occurred as the data were collected. After all the data were collected came the second round of analysis and generation of profiles to share with participants (member checking) in spring. Spring and summer saw the third round of revisions, with further analyses and revision of profiles, guided by member checking. In fall 2014, with numeric data from the university registrar and historical grades information from the department, statistical explorations began.

Table 8 describes dates for data collection and video case activities. The dates were adjusted as needed to accommodate the course coordinator and exams.

Table 8

Timeline for Data Collection and Member Checking

Timeline	Date	Interviews	Observations	Name of Video Case / Coordination Visit	Weekly Logs	Exams
week 1	Aug 26-30	No Coordination Meetings				
week 2	Sept 2-6					
week 3	Sept 9-13			Visitor to meetings-- post-meeting reflective journaling but no research field notes.		
week 4	Sept 16-20					
week 5	Sept 23-27					
week 6	Sept 30-Oct 4					Exam 1
week 7	Oct 7-11					
week 8	Oct 14-18	Intake				
week 9	Oct 21-25		Observation 1	Facilitating Group Work Case	1st weekly log	
week 10	Oct 28-Nov 1		Observat .ion 2		2nd	

Table 8 (continued)

Timeline	Date	Interviews	Observations	Name of Video Case / Coordination Visit	Weekly Logs	Exams
week 11	Nov 4-8		Observation 3	Office Hours Case	3rd	Exam 2
week 12	Nov 11-15	Follow-up w/member check from log themes	Observation 4		4th: generate a summary of responses and themes that may have emerged	
week 13	Nov 17-22		Observation 5	Angelica’s Case	5th	
No classes	Nov 25-29				6th	
week 14	Dec 2-6		Observation 6	Grades Case	7th	
week 15	Dec 9-13	Exit w/member check from log themes			8th	
week 16	Dec 16-20				9th final log	Final
Spring 2014	May	Member-check, in person				
Summer 2014	July	Email				

Limitations

The limitations of the study included a small number of participants, limited timeframe of the treatment, and limited classroom observations. The small number of participants did not demonstrate all possible negative examples of the framework and constrain the transferability of the results. The treatment of the dissertation study was limited to four cases during a 7-week period (Week 8 through Week 14), which may have limited the opportunity for and observation of teacher change. The limited number of classroom observations did not necessarily demonstrate all the ways the instructor asked questions in class and therefore all types of questions asked by the instructor may not have been observed.

Technical Concerns

During the data collection I encountered one technical issue. After downloading a participant's first observation from the camera, I later discovered that the audio for that day was absent (Disha, Observation 1). Visual data were still available, but the only sound was a high-pitched tone. I was not able to retrieve the audio. Since I attended each class and took notes while I observed, this day's coding is based on the coding done in the classroom and my observation notes from that day. For subsequent days, comparison of my in-class transcriptions and observation notes with video-review indicate that my coding of the questions was very accurate, within the target 10% margin of error. In consultation with my co-advisor, we decided it was reasonable to assume that this day would also be within the 10% margin of error we had set.

Hypophora

While observing classes, I found that many instructors were using a type of question called hypophora. A *hypophora* is a question that speakers pose and then immediately answer themselves. An example of a hypophora is: “Why would we want to take the derivative? (no pause) We want to take the derivative so that we can find the critical points for the function.” I created an additional question type called hypophora and coded those questions as depth 0. This decision was made after discussing with other experts in this area and with my advisor. By immediately answering the question posed the instructor lowered the cognitive demand of the question and was therefore given a depth of zero. Providing an answer to the question also lowered the Math Talk level by taking the responsibility of learning away from the students, keeping it with the teacher.

Observation Selection Process

In the proposal, I stated that I would carefully review and code the first and last observation for each of the participants. After the initial two observations, I found that the coding of Math Talk levels was not giving an accurate representation of the classes. I began to code the videos using the previous observation protocol offered by Roach et al., (2010) which used question depth. This protocol was problematic in live coding and a careful review of the video for each class was necessary in most cases. In Disha’s class, I was able to accurately code her questions during the live observations, however this was not the case with the other four participants and thorough video review was required. After coding the first, fifth, and sixth video for each person, I chose one more video for each person to look for any new patterns or differences in comparison to the other three

videos. The coding process reaches saturation when adding new data, and coding that data, does not substantively change the model.

In Disha’s case, because the sound was lost on the first day, observation two was used. The third observation was a review day for all classes and in the cases of Nick, Pramod, and Omar this day was eliminated since it was not a typical day for them. Further, Omar was ill during his fourth observation so that day was eliminated for Omar and, therefore, his second observation was chosen. Nick’s fourth observation and Pramod’s second observation were selected as typical days. Both Nick and Pramod expressed that their second observation was a “typical” class period and based on my observations and researcher notes, I agreed. Evelyn’s review day was not found to be an unusual day, compared to other observations and her third observation was chosen. This day was determined not to be unusual by myself and by Evelyn. She stated to me that although it was a review day, she did not really do things differently. By choosing the observations in this way, I was able to code at least one of each of the six observations while still accurately representing each person’s questioning practices. Figure 10 shows the observations chosen for each person.

<table>
<tr><th></th><th>Obs 1</th><th></th><th>Obs 2</th><th></th><th>Obs 3</th><th>Obs 4</th><th></th><th>Obs 5</th><th></th><th>Obs 6</th></tr>
<tr><td>Nick</td><td>A</td><td></td><td></td><td></td><td></td><td>B</td><td></td><td>C</td><td></td><td>D</td></tr>
<tr><td>Disha</td><td>A</td><td rowspan="4">Video Case</td><td>B</td><td rowspan="4">Video Case</td><td></td><td></td><td rowspan="4">Video Case</td><td>C</td><td rowspan="4">Video Case</td><td>D</td></tr>
<tr><td>Omar</td><td>A</td><td>B</td><td></td><td></td><td>C</td><td>D</td></tr>
<tr><td>Pramod</td><td>A</td><td>B</td><td></td><td></td><td>C</td><td>D</td></tr>
<tr><td>Evelyn</td><td>A</td><td></td><td></td><td>B</td><td></td><td></td><td>C</td><td></td><td>D</td></tr>
</table>

Figure 10. Choice of observation table and video case timing.

After carefully reviewing observations one, five, and six, and then carefully reviewing a fourth observation, I found no new information, categories, or major differences in questioning practices. Having reached the goal of saturation, I did not code the remaining two videos in detail. I will refer to these observations as Observation A, B, C, or D, respectively.

Delimitations

The delimitations of the study included novice calculus instructors at BRU. I chose to focus on calculus instructors since calculus is a course commonly taught by graduate students during their teaching assistantships. Further, there is a larger body of research about calculus instruction that I have drawn upon to inform my study. Due to the limited amount of research on professional development for instructors teaching classes above calculus, I would have little to build on if including higher level courses. I chose not to observe any classes above calculus. A further delimitation of the study is that I observed calculus for biology majors. This decision was made due to the availability of the instructors and the willingness of the course coordinator in allowing me to conduct the study with his instructors. An area of potential attention in examining classroom questions is attention to wait time. However, in defining the characteristics of questions, I focused on the univocal communication of content in an instructor asking a question in context. That is, the study did not include the dialogic aspect of “wait time.” The video case intervention touched on wait time once. It was mentioned in one of the follow-up questions after viewing the *Office Hours* video vignette and was not a focus of the video case activity. The idea of wait time was clearly new to the participants and they spoke in various ways about it, as “patience,” “scaffolding,” and “making the students answer”

questions (detailed in the discussions in Chapter IV). While attending to this dialogic aspect for every one of the 1,449 questions documented in this study was beyond the scope and purpose of the work, it is a prime area for future research.

Review of Potential Challenges

The IRB process went smoothly and revisions to the IRB document were subject to single-reviewer approval and came back quickly (in under a week). The BRU office of research approved the UNC IRB -- I notified BRU and provided a copy of the approved research protocol from UNC for filing and BRU's office of Research with Human Subjects gave immediate approval; the BRU office staff also said any updates to the approved protocol would be handled in the same rapid fashion. Also, during the dissertation study period, I had obligations related to the work I do as a researcher on the *Pathways to Environmental Science Literacy* project. My research supervisor on that project is Shandy Hauk, who is also an advisor on this dissertation project. The scope of work on that project included work on my dissertation and our regular weekly meetings included discussion of the dissertation study as well as the Pathways research.

At the urging of Dr. Wales and following Dr. Hauk's advice, I began attending the BRU Biology Calculus Course Coordination Meetings when they started in September. I did not conduct any research prior to the approval of my proposal. I attended the coordination meetings as a visitor and Dr. Wales introduced me as someone who was planning dissertation research on college mathematics teaching. When I shared with the group what my plans were, I had enthusiastic support and requests to participate.

CHAPTER IV

RESULTS

This chapter offers the results of the research. Recall the research questions for this study:

RQ1 What is the nature of novice calculus instructors' discourse patterns surrounding questions they ask?

RQ2 What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?

RQ3 How does video case based professional development shape perceptions and intentions about the role of questions in teaching held by TAs?

RQ4 Does professional development that includes video case materials hold promise as a way to improve the learning of college calculus students?

To address the research questions, I first present profiles for each participant. Each profile gives information about participant background, views on mathematics teaching and learning, illustrative snapshots of questioning from their classrooms, and comments from instructor logs and interviews. These profiles address, primarily, research questions RQ1 and RQ2. Next, to address research question RQ4, I discuss quantitative comparisons between classes, including a comparison of pass rates with the previous fall semester. Finally, to address research question RQ3 and illustrate a synthesis of results to RQ1 and RQ2, I conclude with a discussion of the video case experience of participants, present questions common to all the instructors, and give information about the discourse neighborhoods surrounding those questions. The results are presented in this way because I want to develop a story about each person and connect across stories about how each

story relates to the questions asked and present commonalities that may have existed in the associated discourse neighborhoods.

Participant Profiles

The following sections introduce participants by providing some background information related to beliefs and experiences around the teaching and learning of mathematics. After that, each profile offers summary information about a participant's use of questions (type, depth, and context information) followed by illustrative examples from class lectures and supportive evidence from interviews and/or weekly logs. The order of the participant profiles is based on their teaching experience, the least experienced to the most experienced. Nick was the least experienced instructor and his profile is presented first. Then come Disha, Omar, and Pramod, who were the next most experienced and Evelyn, the most experienced teacher, is presented last.

Each participant profile has a different title. The titles are meant to illustrate a typical instructional belief or standard questioning practice for that person. For example, Nick expressed that it was important to him that the students were able to make sense of the information. He would often turn to the class and say, ". . . make sense?" Hence, the title is "Nick: Make Sense?" Omar focused on "cool topics" to engage students with mathematical ideas and saw it as important in teaching to have students be fascinated, hence, "Omar: Do you see how cool math is?" Disha relied on hypophora, the gap-free asking and immediate answering of a question and her profile is titled "Disha: Why do we do this? Because . . ." Pramod struggled with eliciting anything besides expectant waiting for the answer from students, thus, "Pramod: Why do you think that? <silence>."

Evelyn would often allow students to answer questions directed to her, or explain their reasoning, and her title is “Evelyn: Do you agree with him?”

Nick: Make sense?

Context

Nick was a doctoral student in mathematics at the time of the study. He grew up in the United States and completed a B.S. in mathematics at a small private university in the U.S., not the university he was currently attending. In the semester of the study, Nick taught one section of Calculus for Biological Sciences, with 29 students enrolled. Of these, 25 students regularly attended class meetings. Throughout the observed lessons Nick relied on lecture. He said he was open to trying new things when teaching and that he would like to do more group work, but also noted "I don't see how anybody has the time." He also said during his third interview, “I lecture because, well, it’s math.” This quote illustrates his view of what mathematics teaching means; it means to lecture.

Nick tried to use humor in his teaching. He told at least one story in each class I attended. These stories were intended to be humorous in nature. They included stories of his childhood, the classes in which he was currently enrolled, and things that may have happened to him that day. Many of the students would smile or laugh as Nick intended. Though not the focus of the study, in reviewing his classroom video I noticed that Nick regularly used substantial wait times (up to 20 seconds) after questions he asked. If he did not get an answer, he often rephrased the question or asked a simpler question. According to his reflections in the log (Week 2), his intention was to scaffold the students’ understanding. For Nick, when students figured a thing out for themselves, they remembered it better: “My belief is that, in being forced to find the answers on their own,

the students ‘own’ those answers more, and thus learn the material better. Doing is greater than watching” (Week 2 Log). When connecting his teaching to students' learning, he said he got lucky during that semester because “they are just strong students.”

Nick regularly spoke up during coordination and made comments on his weekly logs about how he might have used an idea discussed in coordination. In Week 2 Log he noted:

> In coordination we observed that the teachers in the videos were extraordinarily patient in not just giving struggling students answers. At moments of impatience/frustration, I channeled these teachers, and led the students to the answers instead of giving up and throwing the answers at them.

Nick was cautious about attributing increased student interest in mathematics or deeper mathematical knowledge to ideas from coordination. At the same time, he did report that when he was using ideas from coordination the students “are quicker to answer questions from the board (sometimes), and answer as if the material is easier than before” (Week 5 Log). In commenting about the questions that students asked him, Nick remarked that it was difficult to judge whether his use of ideas from coordination was making a difference, noting that, “occasionally someone will ask a deeper question, but those students seemed already to be motivated prior to course coordination efforts.” Nick reported that he spent a total of 6 to 15 hours each week preparing lectures, grading homework and quizzes (most of his time), preparing class materials, and talking with others about teaching.

Use of Questions

Nick’s 50-minute class meetings included an average of 54 questions per meeting. He primarily asked Comprehension Check (53%) questions that offered a limited choice

such as “Does this make sense?” or asked for a product, like “As *x* goes to infinity, what’s going to be the largest one here?” He also asked occasional Elicit Thinking questions (16%) such as, “So how can we make biological sense of this?” Nick rarely asked Probe Thinking questions (1%) such as, “That’s correct, but why?” The few instances of probing questions were in response to a student offering a solution or a comment and were only observed during Observation B. In Nick's view, asking questions helped students become more engaged in class. For example, in his second interview, he remarked on why he asked a particular question, “Well, this one, yes engagement. Always engagement. That’s the whole purpose of questions as opposed to be just shouting at them, right?” Nick also said engagement of students related to confidence. In his Week 6 Log, when discussing waiting for students to respond to a question, he remarked: “When they force themselves to engage they seem far more certain of things.”

Table 9 summarizes Nick’s percentage of questions in each category for each of the four focus classes and across classes. The majority of Nick’s questions each day were Comprehension Checks. Across the observed lessons, the distribution of his question types varied (see Figure 11). His use of Comprehension Check, Content Check, and Elicit Thinking questions fluctuated over time. In fact, during the last observation, Nick asked proportionately fewer Elicit Thinking questions than in the previous classes.

Table 9

Nick's Question Category Percentages Per Class

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking	Hypophora	Classroom Management
Obs A	52%	0%	15%	0%	19%	15%
Obs B	41%	18%	27%	4%	2%	9%
Obs C	56%	9%	18%	0%	5%	11%
Obs D	62%	2%	5%	0%	7%	24%
% Total[a]	53%	7%	16%	1%	8%	15%

[a] Due to rounding, not all rows add to exactly 100%.

Across all four focal observations, the majority of Nick's questions were Comprehension Checks (53%), and these tended to be shallower questions (i.e., 88% were depth 0, and 12% were depth 1). Nick's Elicit Thinking questions tended to have greater depth. Overall, though only 16% of his questions were Elicit Thinking questions, 29% of these were depth 1 and 71% were depth 2.

Taking a slightly different look at the data, Figure 11 illustrates the question category percentages per class period. Though the relative proportion of questions asked of each type varied across the observations, Nick continued to rely heavily on Comprehension Checks.

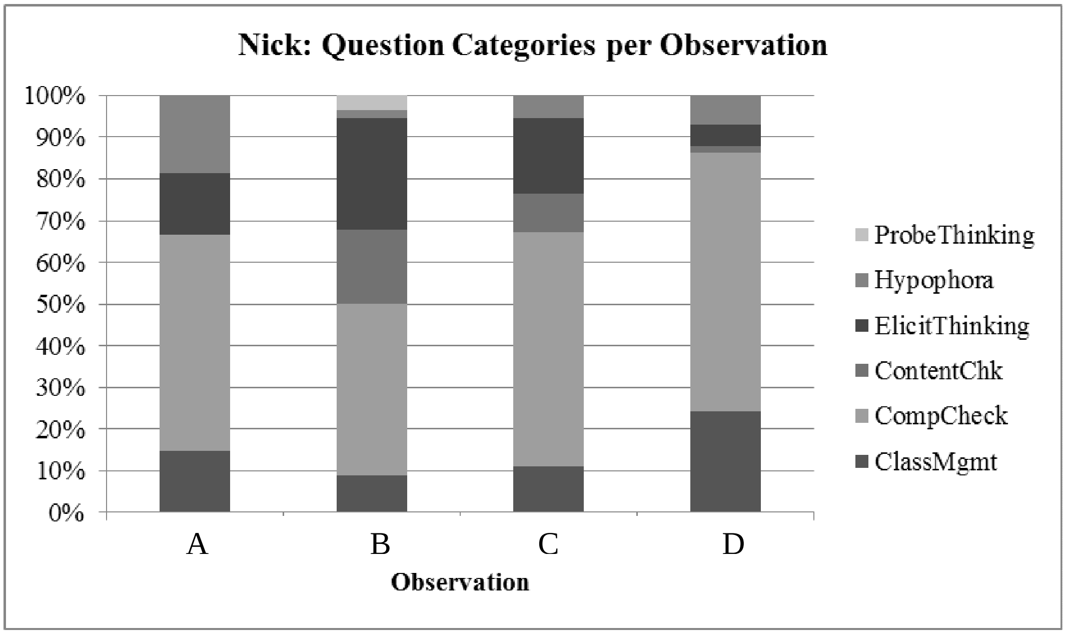

Figure 11. Relative frequencies of question codes in observations for Nick.

In terms of the depth of questions across all four focus classes, Figure 12 shows relative percentages of the depth of the questions Nick asked per class. Classroom Management questions did not have a direct effect on the instructional practices and therefore were removed from the totals listed in the figure. The number of questions of each depth is listed within each section of the bar graph. From the graph we can see that the majority of questions were of depth 0. It is notable that during Observations B and C, Nick asked a greater percentage of depth 1 and 2 questions than in observations early and later lessons in the study (Observations A and D). Like the question categories, Nick's question depths fluctuated across the four focus classes. As was true for every instructor in the study, Nick did not ask any depth 3 questions.

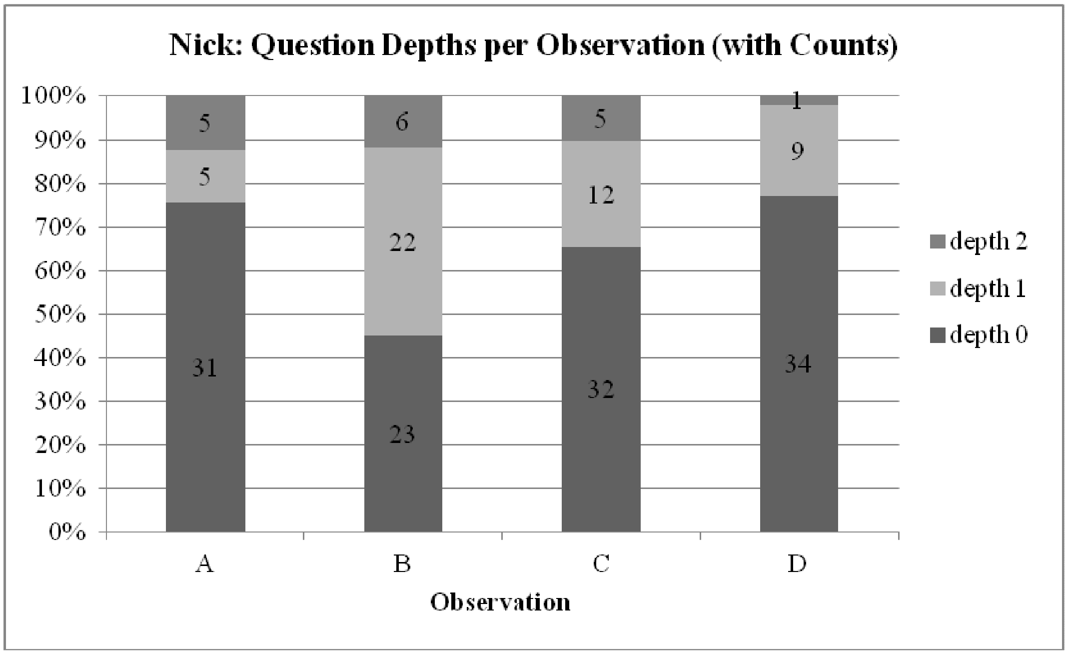

Figure 12. Relative frequencies of question depth with raw counts of number of questions for each depth shown in each segment of a column for Nick.

It was important to Nick for his students to understand the purpose behind the problems they were working. He wanted the students to see the usefulness of things. He stated in his second interview "... the purpose [of this course] is far more focused on the biology of this. So remember what this variable is, interpret your results. So it's trying to get them to interpret what we're looking at . . . I wanna make it useful for them."

Nick also thought that if students could connect new information to something they learned in the past or to something they were interested in, it would help them learn the material better:

> *Nick:* I mean the idea-I think I want, I think I've heard or read or maybe just thought this about those things. If you are learning a new thing and can relate it to an old thing, you'll remember the new thing better. So you'll retain the new one better. Yes, helps you learning it. And that if you can build it on top of something you're very comfortable with, it's . . . that's . . . it got roots. It was down at a more solid concept. So yes, I think if you can relate this to something that they know or

> they're comfortable with, it helps with retention and learning and whatever metric you wanna use. (interview 2)

During Nick's first observation his most common question was a Comprehension Check, depth 0. This was often in the form of a "do you understand" type of question and typically to wrap up a problem or process within a problem. In one instance Nick worked out the procedure to find the equilibrium points. After he worked the problem on the board (explaining the steps as he went, for example, "now I divide by *r*") he spent 22 seconds erasing the board, turned and looked at the class, and asked "Any questions on how I got those equilibria?" Nick waited 11 seconds before continuing then said "No? Good? Comfortable?" and then continued with the problem. This illustrates both the context and his use of depth 0, Comprehension Check questions.

Nick stated in his second interview that it was important for the students to understand what their answers actually mean. An example of this, and of how he used Elicit Thinking questions, comes from Observation A.

After finding the equilibrium in a problem, Nick stopped and turned to the students:

> *Nick* [points to the board and immediately turns around to the class while asking]: "Ok, so what is this guy? If my equilibrium is at zero, what does that represent biologically?
> *Student*: Well, no, I don't know.
> *Nick*: No, go for it! Say it. Say it. Come on, do it.
> *Student*: Everyone is dead?
> *Nick* [smiling]: Yeah, everyone is dead! Extinction, right. If we have no individuals, then the percentage of the maximum that we can have is zero. Nothing. Everyone is dead. We can't reproduce, [spitting sound, while acting like he is squashing something between his hands] stuck there. [The discussion then continues with what a different equilibrium point might mean.]

The first two questions were the same question, just rephrased. This was treated as one question since there was no pause between the questions and the second question was rephrasing the first, perhaps to clarify what the question was. This was a typical scenario in Nick's classes throughout the study. He would often wait for students to answer and after they had answered he would repeat the answer or add to the answer, often using humor or sound effects as he did here. The question was coded as an Elicit Thinking question, depth 2 because he was trying to draw out what the students were thinking about an actual value and how they might interpret that value biologically. He was asking for the meaning behind the answer and attempting to connect that answer to a biological concept.

During Observation B, Nick was introducing differential equations to the class. He pointed out that given a derivative they will need to know from what function that derivative comes (antiderivative). It is important to note that at this point in the semester, the students had not covered antiderivatives. Nick did not explain during this class period the procedure to find an antiderivative. In the following excerpt, from Observation B, the students were given the differential equation $\frac{d}{dt}(b(t)) = 2b(t)$. The students were guessing what the function $b(t)$ might be to make the equation true.

> *Male student*: There's got to be an easier way than just guessing.
> *Nick (laughing)*: This is more fun, for me. [Students laugh.] So I want a function that looks like itself when you differentiate it. [Nick writes on the board "$\mathbf{b(t) =}$ ". Without lifting his chalk he continues to speak] Ok, so someone said *e* to the *t*. [Nick writes $\mathbf{e^t}$ on the board, turns to the class] Should we try that?
> Several students: No.
> *Nick*: Why not?
> *Male student*: It won't work.
> *Nick*: Why not?
> *Several students*: Because it won't double it.

Nick: Ok, so how can I double it?
Student: [indiscernable] so e^{2t}?
[At the board, Nick changes the equation to $b(t) = e^{2t}$. Many students begin to speak at once sounding like some are agreeing and some are saying it still won't work.]
Nick: Let's see what happens. [Nick writes on the board $b'(t) =$] What is $b'(t)$?
Male student: 2 *e* to the 2*t*. [Nick writes his response on the board.]
Nick: What is 2 times *b* of *t*?[while writing "$2b(t) =$ " on the board.]
Several students respond: $2e^{2t}$.
Nick turns to the class and smiles.
Female student: So it doesn't matter what you plug in as long as once you get there you get that?
Nick [furrows brow as if confused]: What do you mean it doesn't matter what you plug in?
Female student: We don't have to have *b* at the end.
Nick, still looking confused: What do you mean we don't have *b* at the end? [2 second pause] We do have *b* at the end, it's sitting right here [he draws a box around e^{2t}.] This is two because we could write this two *b*.
Female student [moves her hands as if to say her head was exploding] Do another problem . . .?

Nick began by attempting to draw out whether or not the students think that trying this function will work, Elicit Thinking. He did not ask for a reason, so the depth is 1. He asked "Should we try that?" After the students said no, and it would not work, he responded with a Probe Thinking, depth 2 question, "Why not?" This question was a prompt for the students to communicate why they thought the initial answer would not work. He wanted an explanation for their reasoning. The question "What is $b'(t)$?" asked for a simple derivative. At this point in the semester taking the derivative of e^{2t} should have been a simple memorization task and this was coded as a Comprehension Check, depth 0. Similarly, "What is 2 times *b* of *t*?" was also a Comprehension Check, depth 0. After Nick completed the problem a female student in the class asked a question he did not appear to understand, and he responded, "What do you mean it doesn't matter what you plug in?" This question and the following question "What do you mean we don't have *b* at the end?" were both coded as Elicit Thinking, depth 2 questions. Nick was

trying to get the student to communicate what she was thinking and explain her reasoning for saying "it doesn't matter what you plug in."

Disha: Why do we do this? Because . . .

Context

Disha was a doctoral student in mathematics at the time of the study. She grew up and went to school in India. She completed her undergraduate degree in mathematics from a major university in India. Disha saw the instructor's responsibility as presenting knowledge to students while it is the students' responsibility as taking that knowledge and making sense of it on their own.

In the semester of the study, Disha taught one section of Calculus for Biological Scientists with 30 students enrolled. Of these, 20 students (67%) regularly attended class meetings. Disha relied on lecture throughout the observed lessons. She indicated that she did not like group work because it seemed to her that inevitably "one person will end up doing all the work." She believed that students learn mathematics best by working individually.

Disha regularly spoke up in coordination and stated in informal conversation with me, that she enjoyed coordination meetings. Her weekly logs indicate that she often used ideas from coordination with individual students, small groups of students, or in the classroom. Working with individual students, or small groups of students occurred during her office hours. She also indicated she felt that the ideas presented in coordination *sometimes* increased student confidence in mathematics, led to a deeper understanding of the mathematics, and helped increase student interest in mathematics. She also noted a particular instance of an instructional idea she used from a video case:

> *Disha:* It was from the video sessions . . . that I was influenced to break down a problem to simpler depth. I tried using it while teaching Euler's method. I was pleasantly surprised by the class participation and enthusiasm when the students knew answers to smaller problems and could weave the concepts themselves. (Week 5 Log).

In her first interview, Disha said she believed that asking questions caused the student to think and that it was important to her that they think about the mathematics. Disha’s Week 6 Log also gave some insight into her beliefs about learning. She said “learning is fun only when it is active. It is important for me that the students are actively engaged in thinking rather than passively learning.” Disha reported that she spent between 6 and 15 hours each week preparing for class, grading homework or quizzes, discussing ideas with other instructors, and preparing materials for class with most of these hours spent grading.

Disha asserted in interviews and in coordination meeting comments that she wanted to improve her teaching while also indicating on more than one occasion that she felt she was a good teacher and did a good job with her teaching. She expressed that she was willing to try different things in her classroom. During a member-check conversation with Disha, where we reviewed the initial profile of her that I had written, she said that she wanted to let the students have more control and wanted the students to become more independent learners. However, she was not sure how to do this.

Disha’s avowed love of mathematics showed in her teaching. When presenting new topics she smiled and explicitly stated how “cool” the mathematical ideas were. She also asked, “Isn’t this exciting stuff?” She appeared to genuinely enjoy herself in the classroom. This was Disha’s fifth semester (first semester of her third year), teaching.

Use of Questions

Across the four focus classes, Disha asked an average of 128.5 questions per class period. Most of these (74%) were Comprehension Checks, the most common two questions being “Is that ok?” and “Do you understand what I am saying?”

Table 10 shows Disha relied primarily on Comprehension Check questions during the observed lessons. Disha asked few Content Check and Elicit Thinking questions and rarely asked Probe Thinking questions. The most notable change for Disha was a change in the use of Hypophora after the first observation. During her first observation, 25% of her questions were hypophora. On subsequent days the percentage of hypophora was less than half the percentage from her first observation.

Table 10

Disha’s Question Category Percentage Per Class

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking	Hypophora	Classroom Management
Obs A	67%	3%	5%	0%	25%	0%
Obs B	75%	0%	1%	0%	11%	12%
Obs C	76%	3%	7%	1%	12%	1%
Obs D	77%	6%	0%	0%	10%	5%
%Total[a]	74%	3%	4%	0%	14%	5%

[a] Due to rounding, rows may not add to exactly 100%.

However, the per-class distributions of these and other types of questions varied over time (see Figure13).

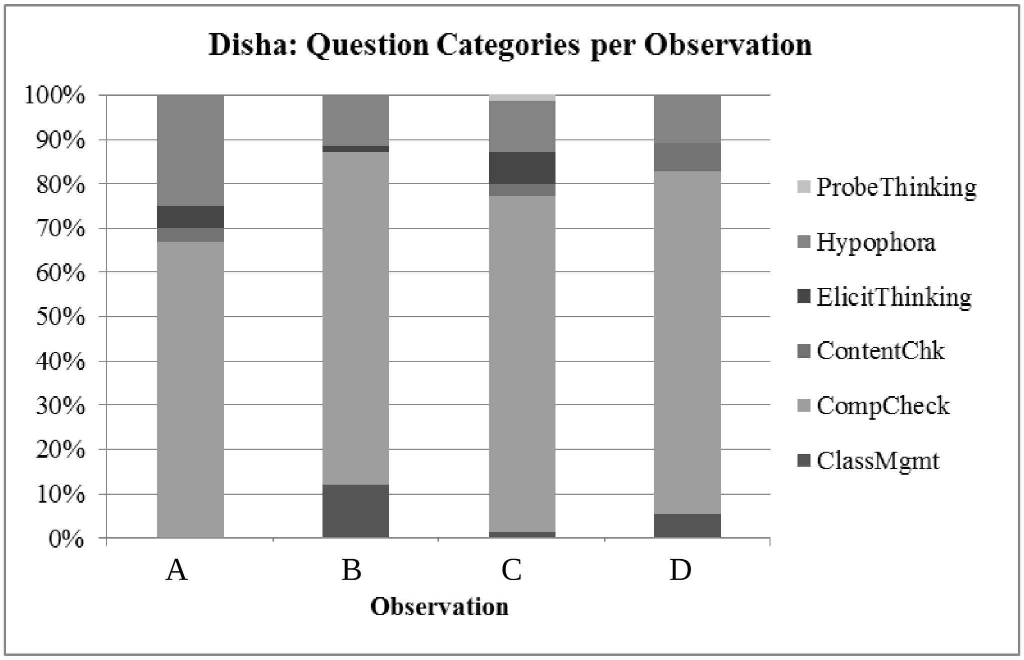

Figure 13. Relative frequencies of question codes in observations, for Disha**.**

During Observation C, Disha had the greatest number of Elicit Thinking questions such as, “What would you think differential equations are?” and she asked Probe Thinking questions such as "Why not?" after students responded “No” to “Will this represent the given situation?” A change in hypophora was notable across the study. In the first observation, she used the greatest number of hypophora, 25 hypophora (25%). During subsequent observations, it was less likely for Disha to answer the questions she posed. Instead, she waited for students to answer. In at least one situation she asked a question and stepped away from the board and waited 30 seconds for students to respond. In Interview 3, I asked about her choice of which questions to use and why wait longer for answers on some. Disha said, “those were the questions I thought of when I [as a student] learned the material and I thought the students should think about those questions as well. I thought it would help them learn the material better.” I did not gather information about how each of the instructors learned specific calculus concepts

themselves. In this particular case, the questions Disha used were those she had when she was a student. I return to this, below, in discussion of what Disha valued as a "good" question.

Figure 14 shows percentages of the depth of the questions asked per class for Disha. Classroom Management questions were removed from the totals. The number of questions of each depth is listed within each section of the graph. From the graph we can see that the majority of questions were of depth 0. It is notable that after the first observation, Disha asked a greater number and higher percentage of depth 1 questions. Like Nick, she asked the greatest number of depth 1 and 2 questions in the middle of the observations. Disha did not ask any depth 3 questions.

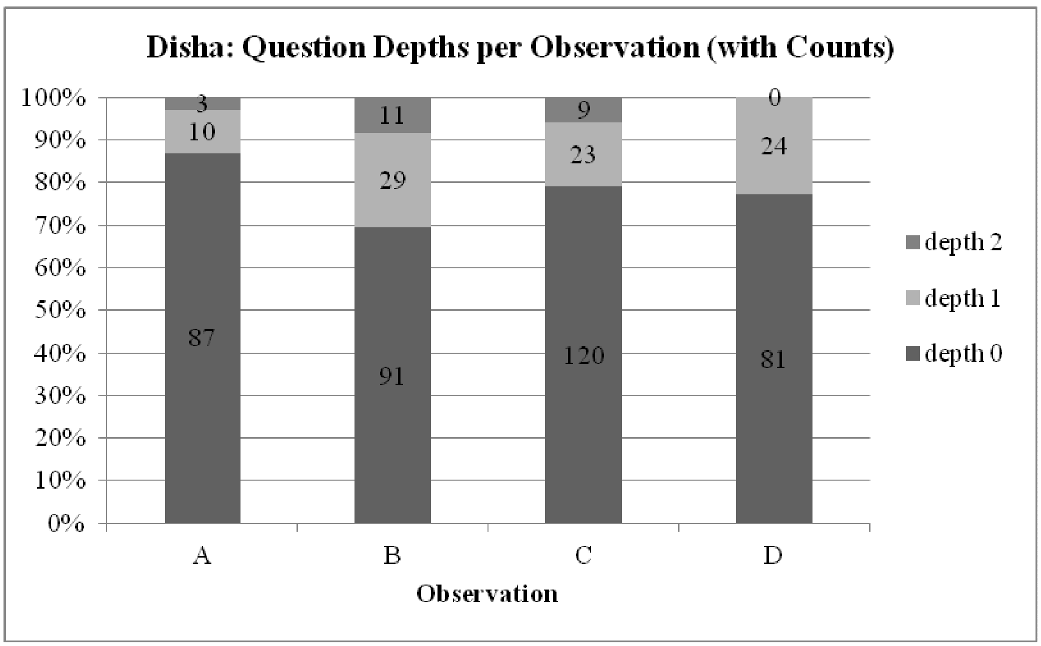

Figure 14. Relative frequencies of question depth with raw counts of number of questions for each depth shown in each segment of a column, for Disha.

Disha most frequently asked, “Does that make sense?” “Is that ok?” or “Do you see what I am trying to say?” The next most common questions were depth 1 Comprehension Checks and hypophoras. Below is an example of her use of hypophora*:*

> *Disha*: “What do we have in stability criteria? [no pause] We start with *dt/ds* [“dee tee dee ess”], ok. We start with *dt/ds*, I’m not going to do a bunch of examples here, ok. Now if *m* is the measurement, then this is how the *dt/ds* is represented by [pointing to “*f*(*m*)” written on the board]. Right? [no pause] then we will figure out equilibrium point. Why? [no pause] Because we are trying to find the stability of the equilibrium points.”

This kind of reflective exchange was common for Disha during her first observation. It is important to note that Disha did not pause after asking a question and immediately continued with the answer to the question she posed. It is not clear that much cognitive demand is made of students during a chunk of hypophoric lecture. It appeared to have the same effect as a statement on the students. While it was unusual for students to attempt to answer these questions, I did observe at least one instance in which a female student attempted to answer a hypophoric question posed by Disha. Disha did not acknowledge the student in any visible way when she attempted to answer, but continued with her answer to the question.

The observational data show a shift in the proportion of hypophora. Earlier in the study, Observation A, when Disha posed a hypophoric question--many of which had the potential to be of higher cognitive demand, such as a depth 2 Elicit or a Probe Thinking question, she gave students no time to answer. In Observations B, C, and D Disha was giving time to the students to answer these questions--they were no longer hypophora and were coded accordingly (e.g., as depth 1 Elicit Thinking).

In Observation B, when a student provided an incorrect answer, Disha did not acknowledge the answer and turned her gaze away from the student who offered it.

However, during Observation C, Disha spent approximately 15 minutes of a 50-minute class period exploring incorrect solutions that the students had offered. This was evidence of a significant change for Disha. Looking across the qualitative coding of her four classes, I saw that in early observations (A and B) she rarely acknowledged answers that were not correct and did not use more than a couple of minutes total of class time to explore them. She sometimes explained what was wrong with an incorrect solution, but never spent much time on engaging students in a conversation about incorrect solutions.

Another thing that emerged from the qualitative coding of Disha's questions and their discourse neighborhoods was what Disha valued as a "good" question from a student--a question was good if it would have occurred to her. For example, in Observation C, when Disha asked if anyone had any questions about a u-substitution problem in which she made $u = \sin x$ so the du was $\cos x$. A student asked why they did not let $\cos x$ be the u since $\sin x$ is the derivative of $\cos x$ (which was the reasoning Disha gave for choosing $u = \sin x$). She responded with "That is a good question because that is a question that I would have thought of." This in-class remark echoed similar comments she made in interviews and course coordination. In Interview 2 she said "I chose to ask those questions because those are the questions that I thought of when I was learning the topic." And in course coordination she said, "those are the type questions they should be asking." Combined, these data suggest that what Disha saw as worthwhile when it came to using and responding to questions relied heavily on how well aligned a question from a student was to her own way of thinking. As noted in Chapter II, and discussed further in the next chapter, research on novice teacher development has documented that early career teachers (across grades) rely primarily on their own ways of thinking.

Omar: Do you see how cool math is?

Context

Omar was a doctoral student in mathematics at the time of the study. He grew up and went to school in Pakistan. His undergraduate degree was in mathematics from a small university in Pakistan. He related his teaching to how he learned. Omar said that if something helped him learn, he thinks at least some of his students will learn in a similar way. Omar also stated in his first interview that his undergraduate teachers were very “formal,” expecting the students to listen to the teacher, take notes, and not ask questions. He did not feel this helped him in class, so he said he tries to have a more relaxed environment in his classroom.

Omar enjoyed mathematics and liked many of the topics he taught. He said they “are cool” so he wants the students to learn how to do it because “it’s just cool”. The semester of the study was Omar’s third year of teaching, his sixth semester.

Omar acknowledged that different people learn in different ways and said he tried to teach in a way to reach different people. At the same time, when asked about the connection between his teaching and students' learning, Omar said he just had a "strong class" and that was why they did well on exams.

Also, he was very open to noticing the cultural differences between his own undergraduate experiences and that of his students. What the differences might mean for him and for his students were something he was still working to understand.

Throughout the observations, Omar’s instruction was through lecture. He said he did not like group work because “in order to really learn math you have to do it on your own,” which was his perception of how he learned to do mathematics. Such “real

learning" could be facilitated by working with a more knowledgeable someone else, as when he learned mathematics by working with his sister and discussing ideas with her. The difference between group work and working with his sister was that he felt she was more of an expert on the topic, since she had the class before, and was there as a resource for his learning, like a teacher, to answer his questions.

Omar's responses to the weekly logs indicated that he sometimes used ideas presented in coordination in the classroom or with an individual student. He was cautious in asserting that the ideas presented in coordination helped increase student interest in mathematics or helped students gain deeper mathematical knowledge. He mentioned in Weekly Log 2 "I used it in office hours with a student. [I] gave the student more time to think." He continued "I'm not sure [if it influenced student learning]. There is no measure to see if it helped that one student more or less." Omar reported that he spent between 3 and 9 hours per week preparing lectures, grading homework and quizzes, and preparing material such as quizzes and homework for class. He noted that most of his time was spent grading because he had taught the class before.

Use of Questions

Omar's lectures included an average of 63 questions per class. Across the observations Omar had subtle changes in the content and focus of his questions. Omar primarily asked Comprehension Check questions (78%) such as "Any questions on this?" and "How do you calculate potential critical values?" He asked Elicit Thinking questions such as "What would happen to the limit if you have infinity over zero?" and "Why are the endpoints [in this function] interesting?" He said that asking questions made some

students think, which he felt helped them learn the material. Other students, he said, “will go home and reread the book and their notes and will learn it that way.”

Table 11 shows the percentage of question categories per day for Omar. Omar asked a Probe Thinking question during the second observation. Throughout, he asked Elicit Thinking questions, but relied on Comprehension Check questions.

Table 11

Omar’s Question Category Percentage Per Class

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking	Hypophora	Classroom Management
Obs A	70%	3%	17%	0%	10%	0%
Obs B	91%	0%	3%	1%	5%	0%
Obs C	74%	10%	8%	0%	7%	1%
Obs D	72%	7%	4%	6%	10%	0%
%Total[a]	78%	5%	8%	2%	8%	0%

[a] Due to rounding, rows may not add to exactly 100%.

Taking a different look at the same data, Figure 15 summarizes the distribution of questions by category across the study. Omar asked primarily Comprehension Check questions and he also asked a variety of questions in each of his classes. Omar did not ask any Probe Thinking questions in his first observation but did ask Probe Thinking questions during Observations B and D. He asked the greatest percentage of Probe Thinking questions during his last observation.

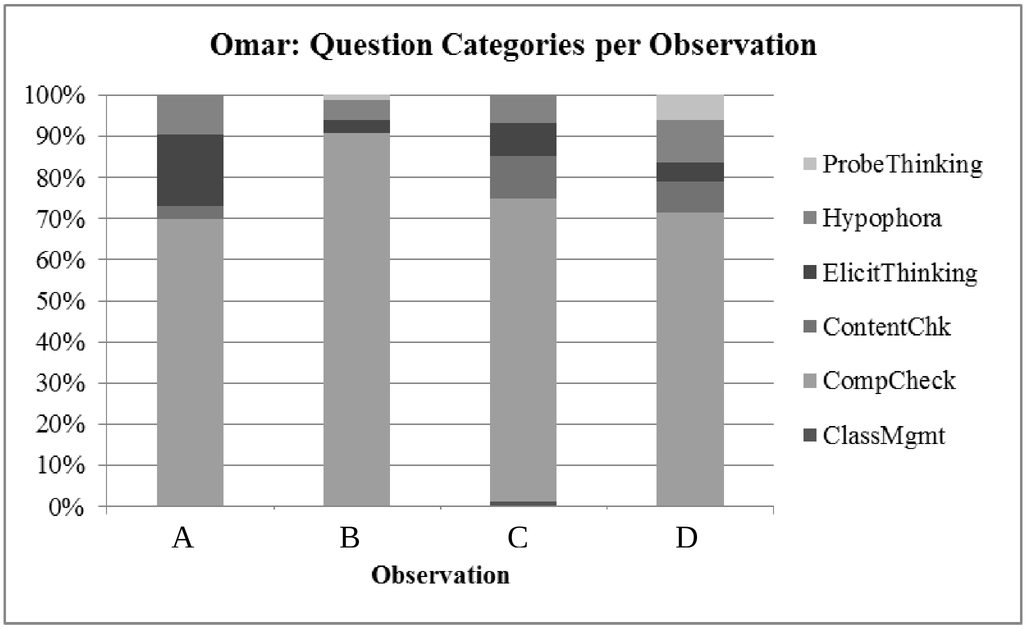

Figure 15. Relative frequencies of question codes in observations for Omar.

Additionally, Figure 16 shows Omar's daily percentages of the depth of the questions asked per class. Classroom Management questions were removed from the totals listed in the figure. The number of questions of each depth is listed within each section of the bar graph. Different from the other instructors, Omar asked a higher percentage of depth 1 questions. In fact, the majority of his questions in Observations B and C were of depth 1 and, summing across all four focus classes, 174 of the 314 questions asked (55%) were of depth 1. Depth 0 questions were his next most common. It is also notable that Omar asked depth 2 questions in all of the four focus classes.

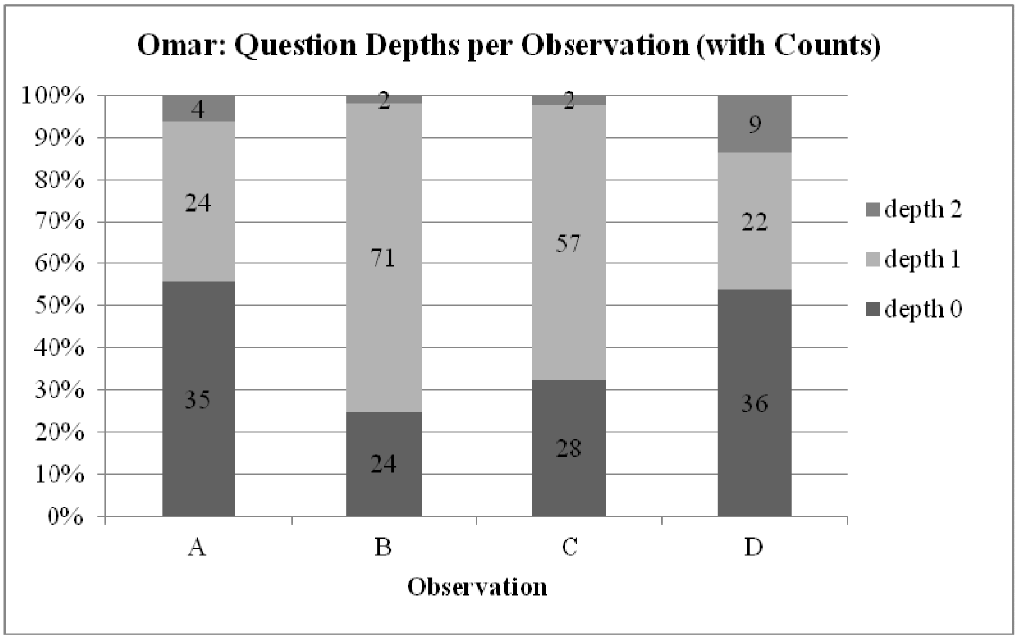

Figure 16. Relative frequencies of question depth with raw counts of number of questions for each depth shown in each segment of a column for Omar.

Omar's most common questions were depth 1 Comprehension Checks. The transcript below is an example from Observation 1. When asking questions Omar commonly asked for the next step in solving a problem:

Omar: "Once you find the equilibrium, what's your next step?"
Several students: "Find the derivative."
Omar: "Find the derivative of the discrete time dynamical system. And what side of the derivative do you use? Is this [pointing at a constant] involved in the derivative or not?"
Male student: "No."
Omar: "This is not involved in the derivative. Basically we can write this function as a function of x_t. We can write $R(x_t)$ is equal to $x_t + 1$ which is equal to $x_t e^{-x_t}$."

The first question is a depth 1 Comprehension Check. This was a very common question for Omar to ask. After the students gave the answer he repeated the answer and

then asked a depth 0, Comprehension Check question. Both types of questions were common for Omar to ask in the beginning and throughout my observations.

Omar also asked Elicit Thinking questions in every class period I observed. These were often to point out some particular pattern in a problem or to engage the students in what Omar referred to as "really cool stuff."

> *Omar*: What is my objective? What do I want to do over here? What do I want to find?
> *Student*: [Student responded with what sounded like "find the derivative."]
> *Omar*: I want to find this, right [looking at the room, and pauses about five seconds]? What if I rewrite this . . . What if I write this as $2x + \frac{1}{2}x$, where x is this thing over here?[three second pause, while scanning the room] I want to solve this right? So if I replace this entire term with x , I get $2x + \frac{1}{2}x$. And what do I need to do?
> *Student*: Solve it?
> *Omar*: Solve for x , right?

The initial three questions, in Omar's first statement, were treated as one question, rephrased (he did not pause between the questions). He paused after the third rephrasing of the question and then continued after a student responded. This initial question was coded as a depth 2, Elicit Thinking question. I assigned a depth 2 to it because the question involved not only a procedure but also a request for the reason behind the procedure. The following questions were each coded as depth 1, Elicit Thinking questions, until the final question, "Solve for x , right?" which was coded as a depth 0 Comprehension Check. The intermediate questions were coded as depth 1, Elicit Thinking questions because Omar reduced the original question to procedural steps but was still attempting to get the students to communicate their thoughts on the problem. The last question Omar tells them what to do, solve for x , and then just checks that the students agree that this is the correct procedure.

If Omar did not get a satisfactory response, as illustrated here, he regularly rephrased the question or asked a lower depth question. By asking these questions he continued to try to get the class to respond, but he asked simpler questions which turned the original question into a more procedural question or even a memorization question.

During the observed lessons Omar occasionally asked Probing questions as illustrated by the following exchange from Observation 2.

> *Omar*: So if you're trying to find the leading order behavior, as *x* goes to infinity, which term would you choose?
> *Several students*: e^{-x}.
> *Omar*: e^{-x}, sure [pauses and looks around the room]. Why is that?
> [Several students respond by laughing, looking around the room, or shrugging.]
> [Omar smiles and continues with an explanation of "faster functions" and "dominant functions."]

Omar began this exchange with a depth 1 Comprehension Check question. This was coded as a Comprehension Check question because Omar had spent some time on a previous problem discussing a similar function. After he got the answer from the students, he looked around the room. He did not appear to be satisfied with the answer even though it was correct, and he followed up the depth 2 Probe Thinking question, "Why is that?" This question was investigating the reasoning behind the students' response. He may have been attempting to connect a reason behind the answer given by the students. There were no Probe Thinking questions in his first observation and five (6%) in his last observation (see Figure 15).

Pramod: Why do you think that?
<silence>

Context

Pramod was a doctoral student in mathematics at the time of the study. He grew up and went to school in India. His undergraduate degree was in civil engineering from a

major university in India. He also completed a master's degree in computer science from the same U.S. institution where he was a doctoral TA during the study. Pramod mentioned that, for him, Engineering and Computer Science were just applied math, so the transition to the math PhD program was a natural transition and "just made sense" for him to pursue the mathematics PhD. Pramod was in his second year as a PhD graduate student at the university. It was his 3rd semester teaching as the instructor of record. In past semesters he taught Calculus for Biological Sciences and Calculus II.

In addition to being a Ph.D. student and instructor for calculus, Pramod's out-of-school responsibilities were significant: he and his partner had their first baby that semester. Pramod reported that it meant that he did not get much sleep. He also noted on more than one occasion that at times he felt overwhelmed with his responsibilities. Pramod originally asked to "think about" participating in the study because of being a new father. Later, when he confirmed he would participate, he said it was because he felt that participating in the study was important and he wanted to learn more about teaching.

For Pramod, his main responsibility as a teacher was to offer knowledge to students. He considered it to be the students' responsibility to take in the knowledge and make sense of it. Pramod cared about his teaching while also reporting that he felt pressed for time in getting all the material covered. During his master's degree work in computer science, Pramod oversaw undergraduate lab sessions. He liked the lab format and pointed to that positive experience as a reason to teach using group work.

Throughout the study his primary instruction was through lecture. In the four focal classes, 80% of class time was lecture format. That format included an average of

86 questions per class meeting. In his first interview, Pramod said he believed that asking questions made students think and that helped them to learn.

Pramod's responses to the weekly logs provide some insight into his perceptions of teaching, learning, and learning to teach. Pramod reported that he generally used the ideas from coordination in the classroom (as opposed to during office hours). Pramod expressed interest in the idea of "engaging" students. He commented that, he engaged students "by asking them questions to assess how well they are understanding what is being taught" [Week 2 Log]. He also noted that asking questions "made them engage better with me as an instructor, and they were more active learners that way" [Week 4 Log]. That is, Pramod mentioned the student engagement idea on two separate occasions (2 out of 8 logs). He also reported, in the Week 4 log, that he used problem solving in groups prior to a quiz and asked questions about student understanding. He stated that both of these ideas, group problem solving and pre-quiz questions, helped students understand concepts better. Pramod reported that he used ideas from coordination often and that his perception was that his use of ideas presented in coordination often helped his students gain deeper mathematical understanding and helped increase student interest in mathematics. He reported spending 9 to 15 hours (sometimes more) each week preparing for class; preparation included grading, preparing lectures, quizzes, and worksheets, as well as talking with other people about teaching (e.g., in coordination meetings, informally with other instructors). Most of these hours came from grading. His logs indicated that preparing questions to ask students was helping him teach better.

Use of Questions

Across the study, Pramod had variety in the content and focus of his questions. He primarily asked Comprehension Check questions (71%) such as “What does the second derivative tell us?”; “Does that make sense?”; “What is the leading behavior of the top term?” He also asked Elicit Thinking questions during three of the four observations analyzed, such as “What do you think is going on with this function?” and “How would you approach this second problem?”

Table 12 summarizes the categories of questions per observation for Pramod. During Observation B, Pramod only asked Comprehension Check questions. However, during observation C he asked the greatest number of Elicit Thinking questions, 25%.

Table 12

Pramod’s Question Category Percentage Per Class

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking	Hypophora	Classroom Management
Obs A	68%	0%	16%	0%	5%	11%
Obs B	100%	0%	0%	0%	0%	0%
Obs C	59%	6%	25%	0%	6%	3%
Obs D	68%	0%	11%	0%	2%	18%
%Total[a]	71%	1%	14%	0%	4%	10%

[a] Due to rounding, rows may not add to exactly 100%.

It can also be seen from the table that Pramod, like the other instructors, relied heavily on Comprehension Check questions.Taking a different look at the same data, Figure 17 summarizes the distribution of the categories of questions across the four observations. As discussed above, Pramod relied on Comprehension Check questions

throughout the study. With the exception of Observation B, he used a variety of question categories.

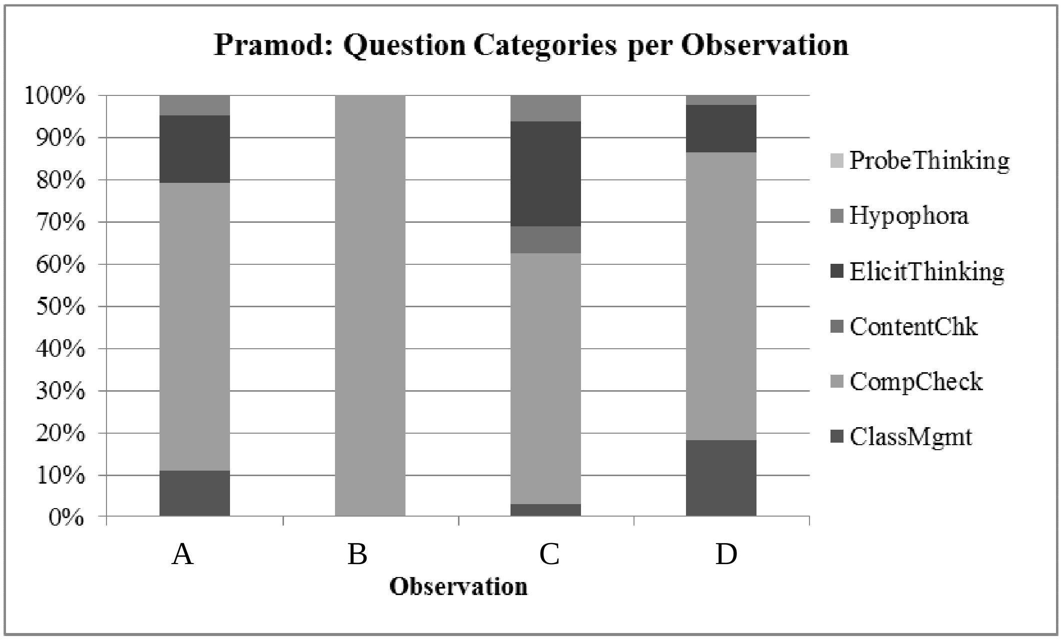

Figure 17. Relative frequencies of question codes in observations, for Pramod.

Figure 18 shows Pramod's daily percentages of the depth of the questions asked per class. Classroom Management questions were removed from the totals. The number of questions of each depth is shown within each section of the graph. It is notable that Pramod asked depth 2 questions in each of the four focus classes though the proportion of depth 2 questions fluctuated across the observations. Pramod did not ask any depth 3 questions.

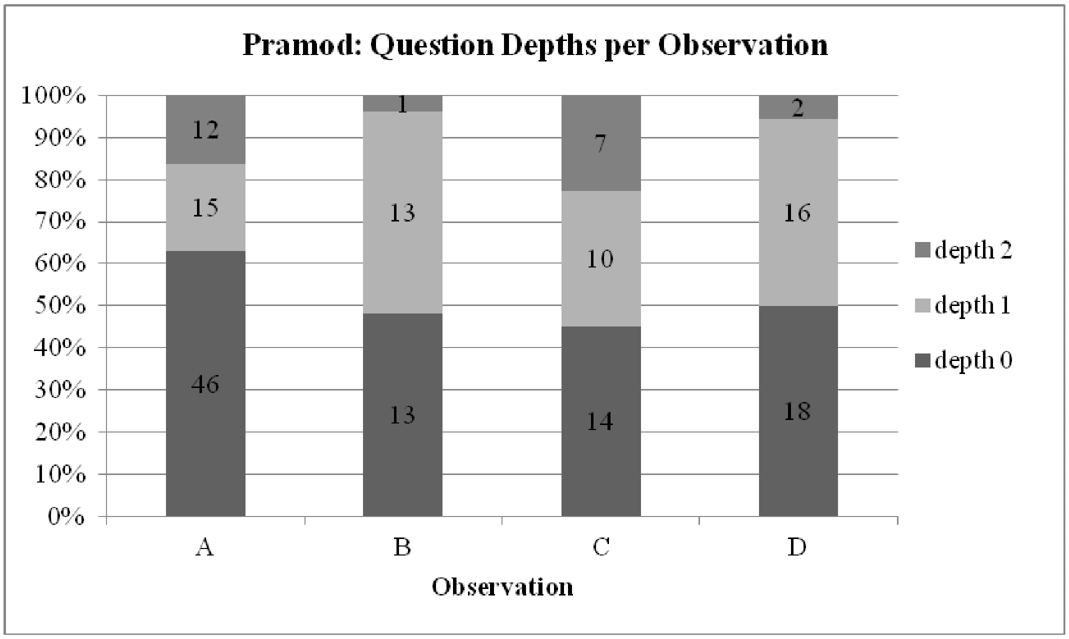

Figure 18. Relative frequencies of question depth with raw counts of number of questions for each depth shown in each segment of a column, for Pramod.

Pramod asked several Comprehension Check, depth 1 and some Elicit Thinking questions, as illustrated below.

> *Pramod*: You see there is only one equilibrium here, which is zero. So we have our *x* star equaling zero, but what happened to the other one? [pauses for 4 seconds while looking around the room] We have two equilibrium points, right? We aren't seeing the other one. What do you guys think happened to that? [waits for 6 seconds while looking around the room] Let's find out what happened. How would you do that?
> *Male student*: Plug in zero point five.
> *Pramod* [nodding]: Plug in zero point five there. So what does that become?
> *Female student*: Negative one.
> *Pramod* [nodding and writing on board]: Negative one. [turns to the class] So negative one as an equilibrium point does not make biological sense. You cannot have your population going in the negative. So that's the reason we don't see it here [points to graph on the board. Looks around the room for 4 seconds]. Does that make sense?

The first question, "What happened to the other one" was coded as an Elicit Thinking, depth 2. Pramod attempted to draw out what the students were thinking about an

equilibrium point that had disappeared. He was also asking for an explanation. He did not get any response from the students so he clarified “We have two equilibrium points, right?” He was pointing out and confirming that the students saw that there were originally two equilibrium points, this was a Comprehension Check, depth 0. Then he attempted again to get the students to communicate what they think may have happened, “What do you guys think happened to that?” He received no response, so after a pause, continued with his example and asked “Let’s find out what happened. How would you do that?” He was asking for the students to tell him a procedure (plugging in a value) and checking to see that they knew to do this. When he asked “So what does that become?” he was asking for a simple calculation, and this was coded as a Comprehension Check, depth 0. He then explained why the equilibrium point is not visible in their graph and concluded with another Comprehension Check, depth 0 question, “Does that make sense?” As illustrated here, in many instances Pramod asked questions and waited (sometimes up to 15 seconds) for a response. In general, students waited for him to continue, and answer his own question, rather than responding to his question.

During the final observation of Pramod’s teaching, he chose to have the class do problem solving in groups for the majority of the class period (the last 30 minutes of a 50-minute period). He told me during an informal conversation prior to the class that he had covered all the required material for the course. He felt by letting them work problems he could ensure that students understood the material and could ask questions when they needed help. I asked Pramod if the students liked having class periods like this and he replied, “Oh yes, they love it.”

During his final class period the students broke into groups. They did this quickly and without help from Pramod, suggesting that such activity was well-practiced. After Pramod wrote the initial problem on the board for them to work, they immediately began discussing the problem in their small groups. I heard the students saying things to each other like “What would be a good way to start?”; “Wait, how did you get that?”; “Why did you do it that way?”; “Oh I get it.” I also observed the students gesturing and moving their hands to illustrate ideas; for example, they motioned in the shape of the graph. At the beginning of the class time, Pramod spent about 2 minutes at the podium flipping through his book. He then wrote a second problem on the board for the students to work on. After writing this problem (approximately 3 minutes had passed) on the board, Pramod walked around the room. He watched the groups from the front of the room or walked past a group and listened for a few seconds, keeping far enough away that his presence was not an interruption. He sometimes asked a group of students if they needed any help. If they answered yes, he stayed and answered questions from the group. Then he continued to the walk around. There were seven groups ranging from 2 to 4 people in each group. At least five of the groups called Pramod over to ask him a question at some point during the class. Pramod usually spent 2 minutes (on average) with the group, answering their question(s). Pramod did not ask very many questions when he was with most of the groups. Instead, he pointed out important aspects of the problems and answered students’ questions. During this class period the students worked together when in the groups and explained things to each other. It appeared they only asked Pramod questions when they disagreed or got stuck on something. Pramod chose not to interfere with the discussions unless the students asked.

During one exchange, Pramod asked a question and then pointed out something about the problem to help a student figure out how to find a derivative.

> *Female student* [calls Pramod to her group and says]: I struggle with the fraction, the integral.
> *Pramod*: Mm-hum.
> *Female student*: Um, does that look right?
> *Pramod*: Which part are you working on?
> *Female student*: The um, D. To find the exact change.
> *Pramod*: Ok. So…
> *Female student*: So I took the four out and did the integral and then I did the integral of that.
> *Pramod* [nodding]: Mmmm, yeah.
> *Female student*: And then, so I think that I got two *t* squared over two plus the natural log of *t* squared. Does that make sense? [Looks up at Pramod while she is talking. She seems unsure of her answer.]
> *Pramod*: How did you get that?
> *Female student*: Um . . . that's my question. [student laughs and then Pramod laughs] I know that the antiderivative of *t* is *t* squared over two.
> *Pramod*: But that doesn't help. See this is a complicated function.
> *Female student*: Yes it is.
> *Pramod*: We don't know exactly the integral of this function.
> *Female student*: Oh, so I should do the *u*-substitution.
> *Pramod* [nods]: Exactly, there you go.
> *Female student*: Got it.

The first question, "Which part are you working on?" was to get himself oriented to the problem. This was a clarification question and was coded as a classroom management question. The second question Pramod asked, "How did you get that?" was coded as an Elicit Thinking question, depth 2. It aimed at the process the student went through on the problem and her explaining the connection behind her work. After listening carefully to her, he realized where she made her mistake in reasoning and points out the flaw "this is a complicated function…we don't know the integral of this function." She immediately says "Oh, so I should do the *u*-substitution."

On this day, Pramod spent approximately 16 minutes (about 32% of class time) in front of the classroom lecturing. Students worked together in groups for about 30 minutes

(60% of the time). Although Pramod did not ask as many questions (a total of 45) this day, as other days, the climate of the classroom was much different. Pramod expected the students to ask and answer each other's questions and the students appeared to be aware of and complying with this expectation. I did not observe any other instructor spend this much of a class with the students working and discussing problems with each other.

Evelyn: Do you agree with him?

Context

Evelyn was an instructor in the mathematics department at the time of the study. She recently had completed a PhD in Mathematics Education at the university where she was teaching. Evelyn grew up in Australia where she completed two undergraduate degrees, one in pure mathematics and one in computer science, from two different, major universities. In her previous job at a financial institution she had multiple responsibilities. She was a programmer, did analysis, and she designed and wrote computer systems for financial applications. While at this institution Evelyn trained and taught new employees how to do their jobs, something she found to be very enjoyable. She did this type of teaching for approximately 15 years. Because of this experience, she chose to pursue a graduate teaching degree in Australia. She completed teacher preparation and taught mathematics at the secondary level for approximately 7 months. After moving to the U.S. she had an opportunity to grade high school calculus exams for a grant funded project. While grading exams for the project focused on meeting the requirements of the No Child Left Behind act (No Child Left Behind Act of 2001: Qualifications for Teachers and Professionals, 2008), Evelyn became very interested in the difficulties calculus students were having and she chose to pursue her PhD in mathematics education at the university.

Evelyn was in her 5th year teaching at the university. Prior to the term of the study all her instructor-of-record university teaching experience was as a graduate student while taking graduate classes. This was her first semester, post PhD, as an instructor. Evelyn saw her experience teaching that semester as different because she was no longer taking classes and she was getting paid more.

For the study semester, Evelyn taught the largest sections of biological calculus. One section enrolled 110 students (roughly 85, 77%, attended regularly) and the other section had 90 students (about 75, 83%, attended regularly). The focal class for this study was the second, slightly smaller section. Evelyn stated in informal conversation that she really enjoyed the large classes and expressed that they were fun to teach. However she also said that the layout of the classroom posed challenges. It had fixed seats. It was long and narrow with a walkway down the middle, seven seats in each row on each side of the walkway (i.e., a total of 14 seats per row), and total of 20 rows. Evelyn found the layout inhibiting. She remarked in an informal conversation with me, that because the class met in a lecture hall with fixed seats, she felt she could not do as much group work as she would like.

Evelyn used lecture as the main form of instruction for the observed lessons. She commented in interviews that she wanted students to be engaged, and said she believed that engagement in the material/lecture would help students learn. Her effort to engage the students frequently took the form of demonstrating how to solve a mathematical problem and then telling the students to try a similar task on their own. While the students were working, Evelyn would encourage them to turn to their neighbor and discuss what they were doing. She would walk around the room and when someone was

working alone she would say to that person "[Student name], instead of trying by yourself, turn to [student name] and discuss it." In the four focal class meetings I visited, an average of about 86% of each was lecture format: three class meetings were 90% lecture, and one was 75% lecture. During the class period that was 75% lecture, Evelyn began class by handing out a white slip of paper (half of an 8½ by 11 inch sheet of paper). She wrote a problem on the board and told the students to work in groups of two or more on the problem. She wanted only one sheet of paper per group to be turned in with everyone's name in the group on it. The students immediately turned to their neighbors and began discussing the problem. While they were working, Evelyn walked around the room and listened to student discussions and encouraged the students to work together (if they were working alone). After 15 minutes she asked the students to turn in the paper. She told me later that she liked doing this type of assessment periodically because it seemed to engage the students and it gave her a chance to look at their work and see where there appeared to be misunderstandings. She said that she would address those misunderstandings in class the next day.

Evelyn's responses to weekly logs indicated she sometimes used ideas from coordination in the classroom, individually with a student, and with small groups of students. Her perception of groups and group work was evident in her answers to the Week 5 log. Evelyn stated that she began class with an activity and that activity "really engaged the class" and helped "focus their attention on the work at hand." When it came to preparing for class, she reported spending 9 to 15 hours each week (sometimes more) preparing lectures, grading quizzes and assignments, meeting with students, answering emails, and, during some weeks, leading review sessions for exams. Evelyn enjoyed

teaching and stated in her Week 6 Log, when describing a classroom discussion, "[the students] responded with a collective 'Oh!' Light bulbs going off all over the room! I love the sound of someone (or a group) finally understanding what's going on!"

Use of Questions

Evelyn asked, on average, about 60 questions per class period. She mainly asked Comprehension Check questions (73%), such as "Any questions so far?" and limited choice versions such as, "What's going to dominate here, my constant or my variable term?" She also asked Elicit Thinking questions, although rarely (1% of questions), such as "Can you explain why that happens?" and "What do you notice first [about the function]?"

Table 13 shows the percentage of question categories by observation for Evelyn. As with the other instructors, Evelyn primarily asked Comprehension Check questions. It is notable that Evelyn did not ask any Probe Thinking questions; however, coding of the discourse neighborhoods related to her questions included the fact that Evelyn's students had a habit of offering explanation about why they thought the way they did without Evelyn asking them to do so. As noted above, this expectation was evidenced by her regularly encouraging students to turn to another and "discuss" and was part of the socio-mathematical norms Evelyn promoted her classroom. It is also notable that after the first observation Evelyn asked fewer Hypophora (21% in the first observation and less than 10% in the subsequent observations).

Table 13

Evelyn's Question Category Percentage Per Class

	Comprehension Check	Content Check	Elicit Thinking	Probe Thinking	Hypophora	Classroom Management
Obs A	71%	5%	0%	0%	21%	2%
Obs B	68%	11%	3%	0%	6%	13%
Obs C	76%	12%	0%	0%	4%	8%
Obs D	79%	3%	3%	0%	7%	7%
%Total	73%	9%	1%	0%	8%	8%

Figure 19 summarizes the distributions of questions by category across the semester in Evelyn's coded observations. It can be seen from the figure that Evelyn relied primarily on Comprehension Check questions. The distribution of Evelyn's question categories was fairly stable (did not vary much) across observations. This was different from the other participants.

On the next page, Figure 20 shows Evelyn's daily percentages of the depth of the questions asked per class. Classroom Management questions were removed from the totals listed in the figure. The number of questions of each depth is listed within each section of the graph. From the graph we can see that, like all of the other participants, the majority of Evelyn's questions were of depth 0 (62% to 74%). It is notable that, like Nick, Disha, Omar, and Pramod, during Observations B and C, Evelyn asked a greater percentage of depth 1 and 2 questions than in the early and end of study observations. However, more than half of her daily questions were depth 0. Similar to the question categories, the distribution of Evelyn's question depths had little variation across the observed classes.

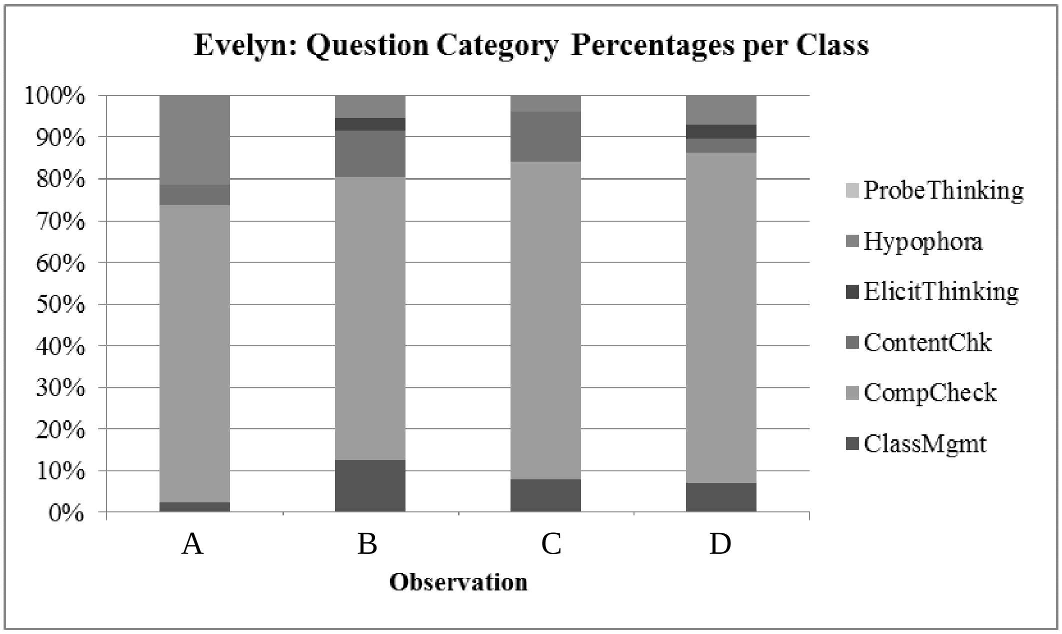

Figure 19. Relative frequencies of question codes in observations, for Evelyn.

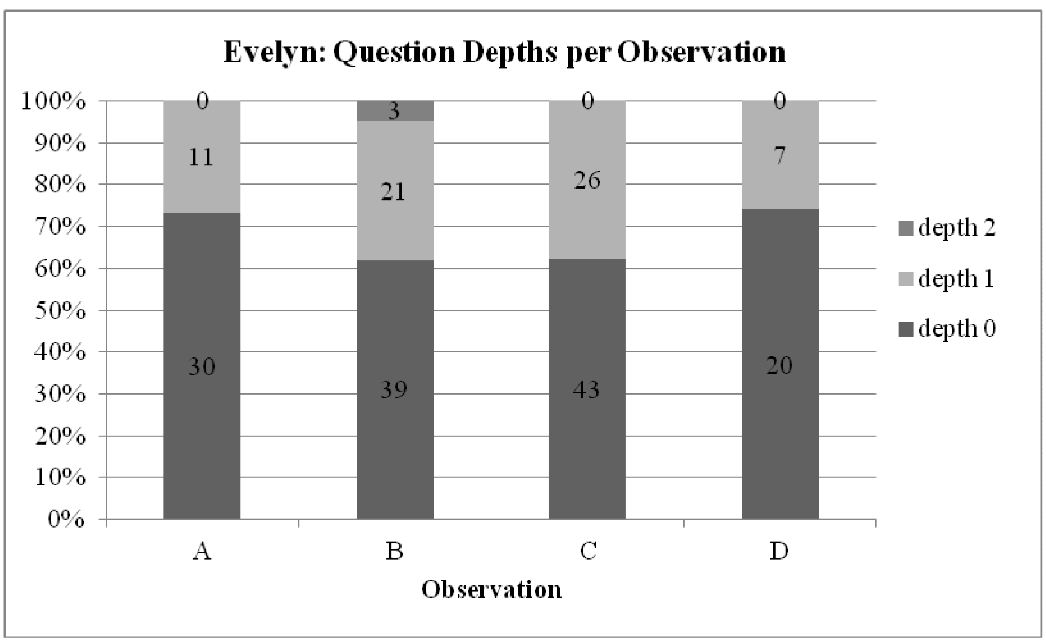

Figure 20. Relative frequencies of question depth with raw counts of number of questions for each depth shown in each segment of a column, for Evelyn.

Evelyn said that asking questions got, at least some of, the students engaged in the material. She also said she relied on questions to learn whether they were understanding, as a way to help her in making her in-the-moment decisions about what to do next while teaching. For Evelyn, asking questions not only kept the students involved but also kept her from going off on her own and ignoring the students. Evelyn spoke with a high volume, and prompted students to speak loudly so all could hear--recall that her classes were larger than the other participants' classes, with about 80 students typically attending the class. Evelyn was very energetic while teaching, for example, she gestured broadly, walked back and forth across the front of the room, and, when students were working together, she walked around the entire room listening in on students. She waited for student responses when she asked questions. It was common for Evelyn to ask a question such as "Are you getting this?" then turn towards the class and look around the room for responses. She would not continue until she received some form of verbal or non-verbal response from the majority of the students. Many students would simply nod, or give a thumbs-up response. Evelyn's students were very interactive, often stopping her to ask questions about various aspects of the mathematics.

Again, Evelyn's most common questions were Comprehension Check questions. I offer the following as an example, from Observation A, of a common exchange for Evelyn. The entire exchange lasts 15 seconds.

> *Evelyn*: I need to find the derivative so I can use my theorem. Which rule? [Evelyn turns to the class as she asks the question and waits for an answer, approximately 2 seconds before someone answers.]
> *Male student*: Quotient.
> *Evelyn*: You people over here, you agree with him? [turns towards the room and waits 2 seconds] Do I see some nods?

It is important to note that Evelyn did not continue until satisfied by the student responses that it was okay for her to go on with the problem. The first question “Which rule?” is a depth 1, Comprehension Check. She asks for a declarative understanding of a procedure with no connection. This question focused on what needed to be done. The second and third questions are essentially the same question. These are depth 0, Comprehension Checks. These illustrate how Evelyn used a “do you understand” type of question. Consonant with what she stated in her first interview, Evelyn appeared to be using this question to gauge whether to go on with the problem. This exchange illustrates both Evelyn’s typical type of question as well as her wait time for responses. It was very common for Evelyn to turn to the class, ask a question, and look around the room, appearing to look at each person’s face to get some sort of visual or verbal feedback.

Cross-Instructor Analysis

Student Preparation

The BRU office of Institutional Research provided de-identified ACT and SAT scores for each student. The five focal classes originally enrolled 216 students. For 25 of these students no ACT or SAT score was recorded, those entries were removed from the list of 216. Of the remaining 191 student scores, 131 had only an ACT score, 26 had only an SAT score, and 34 had both scores. In order compare mean scores, all the scores were adjusted to percentages (e.g., an ACT score of 28 was changed to 77.8%, as the maximum score is 36). If the student only had one score listed that percentage score was used in the calculations. If the student had two scores listed, then the average of the percent scores was used in the calculations. It should be noted that in all cases when the students had both ACT and SAT scores, the percentage scores for each were within five

points, so changing the scores to percentages in order to compare the mean scores still gives and accurate representation of the student population within each class.

Since there was a need to compare the mean ACT/SAT scores across different classes, an ANOVA was used to analyze the data. Assumptions must be met for the ANOVA to be considered an appropriate analysis: (a) randomness, (b) independence, (c) normality, and (d) homogeneity of variance (Huck, 2008). A discussion of each follows.

The first assumption, randomness, states that the population sample should be a random sample of the population. The assumption of randomness is not strictly satisfied, but even though all available scores were used the ANOVA is robust when this assumption is violated. The second assumption, independence, means that one person's score is not influenced by another person's score, and this assumption is satisfied.

In addressing the issue of normality, descriptive statistics were performed in SPSS (IBM Corp., 2013). The results are in Table 14. As can been seen from the table the maximum skewness is -0.532 and the maximum kurtosis is -0.470, which is within the bounds for normality to be assumed (Tabachnick & Fidell, 2013).

To address the assumption of homogeneity of variance, a Levene's test was performed. The Levene's test for equality of variance found the variances were not significantly different from each other, with a *p*-value of 0.830 ($p > 0.05$ required to assume homogeneity variance). Equal variance could be assumed, and therefore the required assumptions to perform an ANOVA were met with this data set.

Table 14

ACT/SAT Descriptive Statistics

					Skewness		Kurtosis	
	N	Range	*M*	*SD*	Statistic	Std. Error	Statistic	Std. Error
Nick	30	30.7	68.43	8.25152	0.114	0.427	-0.470	0.833
Disha	27	35.6	68.15	8.70545	0.340	0.448	-0.271	0.872
Omar	32	33.3	71.21	8.53867	-0.532	0.414	-0.432	0.809
Pramod	30	30.0	70.55	7.58236	-0.134	0.427	-0.435	0.833
Evelyn	72	44.5	69.58	8.97958	0.151	0.283	-0.304	0.559

To examine the difference between the student ACT/SAT scores an ANOVA was performed and the test found no significant differences in the scores [$F(4, 186) = 0.712$, $p = 0.584$]. Thus, it may be interpreted that each of the classes was not statistically significantly different (i.e., stronger or weaker).

Student Performance

Final exam. Since there were no significant differences found in the pretest (ACT/SAT) scores, no adjustments were needed when examining the final exam scores for each class. After the final exam scores were obtained from the instructors, it was observed that the data sets had several students with scores of zero listed for their final exam score. It was verified by checking the number of grades given in the course and/or speaking with the instructors, that the students who had a score of zero did not take the final exam and those scores were removed from the data sets. After removing the scores of the students who did not take the final exam there were 182 total final exam scores. Broken down by class, there were 27 student scores in Nick’s class, 24 in Disha’s, 29 in

Omar's, 30 in Pramod's, and 72 in Evelyn's. Since there was a desire to compare mean final exam scores across the different classes, an ANOVA was used to compare the mean final exam scores. Again before an ANOVA can be considered valid for analysis there are assumptions must be met. A discussion of each follows.

The first assumption, randomness, was not strictly satisfied. However, in this study all the available scores were used. So, again, even though the sample was not a random sample, ANOVA results are robust. The second assumption, independence, was satisfied as there were no overlaps of students (e.g., no exams were administered in groups).

In addressing the issue of normality, descriptive statistics were performed in SPSS. The maximum skewness is -1.336 and the maximum kurtosis is -1.389, which is within the bounds for normality to be assumed (Tabachnick & Fidell, 2013).

Finally to address the assumption of homogeneity of variance, a Levene test was performed. The Levene's test for equality of variance was found to be violated with a *p*-value of 0.015 ($p > 0.05$ required to assume homogeneity variance). Equal variance could not be assumed, and, therefore, the required assumptions to perform an ANOVA were not met with this data set.

When the assumption of variance is violated and the other three assumptions are met a comparison of means can still be performed using a Welch's Robust Test of equality of means (Huck, 2008). A Welch's Robust test was conducted and found that significant differences in mean final exam scores did not exist [$F(4, 68.258) = 2.059$, $p = 0.096$].

Course grades. The BRU mathematics department provided grade distributions from both Fall 2012 and Fall 2013. A *z*-test for two population proportions is a test used to determine if two groups or populations differ significantly on some single characteristic. The requirements to perform a *z*-test for two populations are (a) a random sample of each of the population groups and (b) the data must be categorical. The first assumption was not strictly satisfied, but the *z*-test is robust and the entire set of scores was used for the comparison. The second assumption was satisfied as the data were grades, which are ordinal categories, and frequencies used in the analysis. Each of the five focus classes' pass (grade A, B, or C) and DFW (grade of D, F, or withdrew from course) rates were compared to the rates of all the sections of the Fall 2012, Calculus for Biological Sciences. The results are summarized in Table 15.

Table 15

Pass and DFW Rate Comparison Per Class

Instructor	Total students	Total Passing Grades (A, B, C)	Total Failing Grades (D, F, W)	DFW rate vs. Students not in instructor's class (*z* score)	*p*-value
Total Fall 2013	*356*	*239*	*117*	*[basis for comparison]*	
Nick	31	23	8	-0.876	0.379
Disha	26	19	7	-0.670	0.503
Omar	34	22	12	0.317	0.749
Pramod	31	19	12	0.354	0.726
Evelyn	87	54	33	1.157	0.246

Table 15 shows that for the Fall 2013 classes, no instructor's DFW rate was significantly different than the total DFW rate among students not in that instructor's class. Similarly, a comparison of the Fall 2012 DFW rate with that in the five focus classes DFW and overall Fall 2013 rate is summarized in Table 16. The tests found no significant differences in the DFW rate from 2012 to 2013, overall. Additionally, both Disha and Evelyn taught a section of Calculus for Biological Sciences in the Fall 2012 semester, which allowed for comparison of rates across semesters. In both situations, the test found no significant differences in the pass/fail rates.

Table 16

Pass and DFW Rate Comparisons with Fall 2012

	Total students	Total Passing Grades (A, B, C)	Total Failing Grades (D, F, W)	DFW Rate vs. 2012 (*z* score)	*p*-value
All Classes Fall 2012	*349*	*239*	*110*		
Disha 2012	*26*	*18*	*8*	*[basis for comparison]*	
Evelyn 2012	*106*	*68*	*38*		
All Classes, Fall 2013	356	239	117	0.3826	0.70384
Focus Classes	209	137	72	0.7148	0.47770
Disha 2013	26	19	7	0.3061	0.75656
Evelyn 2013	87	54	33	0.2984	0.76418

Question Depth

To provide the big-picture for what follows, the next three tables summarize the information on question depth coding from the observations (see Appendix G for total counts for each instructor). The totals in the table are for the four observations for each instructor that were carefully reviewed from the video-recordings. Table 17 gives a total count of each depth of question, broken out by question code, for each instructor. For example, across the four observations summarized in the table, Disha asked a total of 514 questions while Pramod asked a total of 185. For Disha, after removing the Classroom Management more than half (294 out of 514 (57%) of her questions were depth 0 Comprehension Checks and 72 (14%) were depth 0 Hypophora. Notice that each instructor did use Hypophora at least some of the time, but Disha did so 10 times as often as Pramod, who used Hypophora the least, and at least three times as often as every other TA. Also notable in the totals in Table 17 are the facts that Omar asked the most depth 1 questions and that there is no record of a depth 3 question for any instructor.

Aggregating the data the distribution and counts of question depth (of all categories of questions) is shown in Table 18. These sums across question types foreground the distinction between Omar and the other TAs--he more often asked a question of depth 1 than depth 0, but the others more often asked a question of depth 0.

Table 17

Question Counts by Depth and Code for Each Instructor

Depth	Code	Disha	Evelyn	Nick	Omar	Pramod	*Grand Total*
0	ClassMgmt	26	18	32	1	18	*95*
	CompCheck	294	96	89	86	81	*646*
	ContentChk	12	18	12	12	2	*56*
	ElicitThinking	1	0	2	1	1	*5*
	Hypophora	72	18	17	24	7	*138*
	ProbeThinking	0	0	0	0	0	*0*
1	CompCheck	76	62	26	153	45	*362*
	ContentChk	2	1	1	4	0	*8*
	ElicitThinking	7	2	21	17	9	*56*
	ProbeThinking	1	0	0	0	0	*1*
2	CompCheck	12	1	0	6	6	*25*
	ContentChk	0	1	3	0	0	*4*
	ElicitThinking	10	1	12	6	16	*45*
	ProbeThinking	1	0	2	5	0	*8*
3	CompCheck	0	0	0	0	0	*0*
	ContentChk	0	0	0	0	0	*0*
	ElicitThinking	0	0	0	0	0	*0*
	ProbeThinking	0	0	0	0	0	*0*
Grand Total		514	218	217	315	185	1449

Table 18

Distribution (and Counts) of Question Depth Codes by Instructor and Overall

Depth		Disha	Evelyn	Nick	Omar	Pramod	Grand Total
0	% of Total Count along Depth	77.66%	66.00%	64.86%	39.17%	54.49%	62.41%
	Count	379	132	120	123	91	845
1	% of Total Count along Depth	17.62%	32.50%	25.95%	55.41%	32.34%	31.54%
	Count	86	65	48	174	54	427
2	% of Total Count along Depth	4.71%	1.50%	9.19%	5.41%	13.17%	6.06%
	Count	23	3	17	17	22	82
3	% of Total Count along Depth	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Count	0.0	0.0	0.0	0.0	0.0	0.0

A third way of organizing the data, shown in Table 19, aggregates the information by observation. While not the focus of this study, it is interesting to note that most instructors' question density (number of questions per class meeting) varied, except for Nick. Nick, the most novice of the instructors, asked an average of about 1 question per minute at each class meeting.

Table 19

Question Counts Per Observation by Instructor

Observation	Disha	Evelyn	Nick	Omar	Pramod
A	100	42	48	63	82
B	149	72	56	97	27
C	154	75	55	88	32
D	111	29	58	67	44
Grand Total	514	218	217	315	185

Discourse Neighborhoods

In this section I discuss discourse neighborhoods surrounding common questions that the instructors asked in the classes observed. Across instructors, questions of two types were common: “Do you understand/Does that make sense?” and “What’s the next step?” Their frequency means there are many instances that allow examination across instructors. As noted above, though instructors occasionally elicited and probed student thinking, they generally followed the evaluation Initiation-Response-Follow-up (IRF) patterns common among novice teachers (Groth, 2013; Mehan, 1979; Truxaw & Defranco, 2008). Recall from Chapter II, a *discourse neighborhood* is made up of a question and the related discourse that precedes and follows the question, and may include preceding topic(s) as well as utterances, gestures, or actions and any associated utterances, gestures, or actions following the question.

In the following example from Omar’s class, Observation B I have underlined the “do you understand” types of questions. The example illustrates this type of question in a

discourse neighborhood that starts out with rich mathematical content from the instructor, but contains no detailed confirmation of student comprehension about that content.

> *Omar:* So what you want to do is draw the function, the way it behaves at infinity, draw the function the way it behaves at zero. [Pointing to the graph of a function on the board] Extend that to infinity, and extend the infinity to zero, and you sort of get like some sort of intersection point in between those lines. Okay. Any questions on this? [Most of the students shake their heads, no] We're good? [A few students nod and Omar continues with a discussion of the type of problem a student might see on a test.]

In some situations, when the students were asked a "do you understand" type of question, the students would respond by asking the instructor a question. This is illustrated by the following example from Evelyn's class, Observation B where I have underlined the "do you understand" types of questions. The example illustrates a discourse neighborhood where the unspoken communication by the instructor of working a problem on the board precedes an interaction that extends the neighborhood across several student and teacher questions. This discourse neighborhood contains quite a bit of mathematical content.

> *[Evelyn works a problem on the board, completes the solution, and turns to the classroom to ask the question]*
> *Evelyn*: [Are] all the bits and pieces there?
> *Female student*: So when a constant lies on the outside of a trigonometric function you take it out the front and just bring it down all the way?
> *Evelyn* [nodding]: Yes, yes, yes. That's just a constant multiplied by a function. You can take the function out the front and deal with the rest. [Several students begin talking to each other while Evelyn is talking. She looks around the room and seems concerned.] Frowns. Are you guys happy?
> *Different female student*: Did you use the chain rule?
> *Evelyn* [points at the board]: Chain rule to get this, yes. This is your outer function, evaluated at my inner. Let's get a red pen and highlight that [draws around the inner function on the board]. This is my outer function. That was my inner function. And this is the derivative of my inner function. [Evelyn pauses and looks around the room.] I see some nods. As I said, anything we ask you to find the derivative of, you should have the toolkit to do so. What you need now is the confidence. [Evelyn continues by explaining to the students how they can build that confidence, by

practice, reviewing old homework assignments, reviewing quizzes, practicing on blackboard, and working examples discussed in class.]

In both of the above examples after the instructor had finished an example the instructor asked “Any questions on this?” or “Are you guys happy?” This illustrates the most common situations when the instructors asked for confirmation from the students on whether they were following along with the lecture. In both situations, the instructors looked around the room for confirmation from the students. Omar received that confirmation with head nods from the students, he repeated “We’re good?” and then continued with his discussion. Similarly, Evelyn saw something (frowns on the students’ faces) and asked for confirmation that they understood. One student replied with a question about a procedure on the problem. Evelyn then explained what she had done and again looked at the students and paused. She saw nods, which seemed to confirm that they now understood the problem and she continued with her discussion.

Another similar technique used by the instructors was to ask for the next step of the problem. These type questions were coded as depth 1 Comprehension Checks. When asked for the next step of a problem, it was common for the students to answer the question. It appeared that they were more comfortable answering “next step” questions since multiple students would offer answers to these questions and the students would offer an answer almost every time a “next step” question was asked. This is illustrated by the following example from Disha’s class, Observation C.

Disha [after completing a derivative with a *u*-substitution]: But then we started with *x* and we ended up with *u*. Not acceptable, so <u>what should we do</u>?
Several students talking at once: Re-substitute back in.
Disha [nodding]: Re-substitute back. [Begins writing on the board] So negative log of, what is *u*?
Students [whispering]: Cosine.

Disha: Cosine x plus c. [turns toward the class] Is that good? [Students nod and Disha begins erasing the board so that she can begin the next problem.]

Questions and responses like the examples above were observed in all classes.

Across the five instructors in this study, discourse neighborhoods for questions tended to be small and local, focused on procedure or correctness. For the 1,449 questions coded across the instructors, 83 were about course housekeeping, not mathematics (see Table 20). Of the 1,366 mathematics content related questions, 95% (1,299) were local--either narrowly focused on the next step in a problem-solving process or constrained to discussion about a single problem. The other 5% (67) included linking across problems or to a topic for the day. None of the coded question neighborhoods linked to a larger topic.

Table 20

Total Count by Instructor of Type of Discourse Neighborhoods

Code	Disha	Evelyn	Nick	Omar	Pramod	Grand Total
NextStep	272	79	97	114	60	*622*
Problem	209	100	88	187	93	*677*
DayTopic	13	21	6	13	14	*67*
LargerTopic	0	0	0	0	0	*0*
NoMath	20	18	26	1	18	*83*
Grand Total	514	218	217	315	185	1,449

Around questions of depth 0, the form of discourse neighborhood was usually isolated to the instructor alone (hypophora) or a single IRF cycle where the initiation was by the instructor asking a depth 0 question. As in the examples above, in some few cases,

a discourse neighborhood might be longer in time in a related set of cycles of IRF (e.g., Disha asking about the *u*-substitution).

Instructors saw understand/make sense questions as a way of checking-in on students being attentive. For some students, such a question was an invitation to intellectual engagement and a student might use the pause in instructor speech occasioned by asking “does that make sense” as an opportunity to ask a question that had been on the student’s mind for several minutes. So, the student’s comment or question might be about something that happened in a *different* discourse neighborhood than the one in which the instructor asked the “does that make sense” question.

Instructors saw “what is the next step” as a specific invitation for students to talk about the mathematics being done. This IRF-product-based prompt tended to produce student response. The majority of the time, when instructors asked for the next step, students responded with mathematical content-usually on the small scale of an immediate process in problem solving rather than an idea about an overall strategy or approach. Omar asked next step questions regularly and was the instructor with the greatest collection of deeper and higher questions. Evelyn prompted for the next step *and* developed a socio-mathematical norm in her class that she was the recorder for the entire class. That is, the expectation was that students would speak the steps, tell her what to do as the next step in writing the solution to the problem on the board, and she would write it. Most of the time she initiated the writing of a solution and turned to the class from time to time for their direction on next step. Like Evelyn, in Nick’s class, it was more common than in the other three instructors’ classes for students to stop the instructor and

ask for clarification. In Disha, Omar, and Pramod’s classes the students waited for the instructor to pause and explicitly ask something (e.g., make sense or next step questions).

All the instructors used a “does that make sense?” or, similarly, “do you understand?” type question. However, depending on the instructor and context, the discourse neighborhoods for these types of question varied. In most cases, despite differences in the discourse neighborhood, I coded these types of questions as depth 0 Comprehension Check. As indicated earlier, this type of question could be phrased many ways, for example: “Do you see what I’m trying to say?”; “Are you following me?”; “Do you have any questions on what I just did?”; “You got it?”. In most cases, the students gave no verbal response or responded with some form of gesture of action, such as a nod or thumbs up.

Video Cases

Below, for each case, I give a description of the case content and information on how it went at the coordination meeting. The case delivery reports provide detail on how instructors engaged with, reacted to, and otherwise commented on the cases at the meetings. Where applicable, I have enhanced the case delivery description with additional participant responses/interactions noted outside of the particular coordination meeting in which the video case was the topic. The section closes with the results of data analysis aimed at understanding instructors’ response to the cases, including how they say themselves implementing ideas related to the case experiences. This will address RQ3.

Case 1: Facilitating Group work

Description of case content. The first video case, Facilitating Group Work, was done on October 22, 2013. The case focused on two calculus instructors as they interacted with students working in small groups. The case is designed so that participants can consider verbal and non-verbal cues used by each instructor, to focus the attention of the participants on the mathematics and encourage them to work together. The video clips were shown three times, first with audio only, second with video only, and third with both audio and video. Discussion questions after watching the video clips focused on what the instructors said or did to facilitate discussion, who was involved in the discussion, and how the instructor might have done things differently.

Description of case delivery. I prepared for the case by watching the video, reviewing the handouts, and carefully reading the Facilitator's Guide. The guide stated that the goal of the activity was to look for and notice the things that teachers do and say. It encourages the facilitator to not focus on whether or not group work is good or bad, but to keep the focus on the teacher's words and actions. While most of my participants were open to the ideas presented in the video case, there was a brief discussion about how they felt about group work. Evelyn and Pramod both indicated that they liked group work. Nick indicated that he did not see how anyone had the time for group work. Omar and Disha said they did not like group work because inevitably, one person ends up doing all the work. I let them voice their opinions and then redirected to what the instructors were doing, rather than the students working in groups. This seemed to work well. Everyone but Disha participated in the discussions and many aspects of what the instructors did were discussed. My participants noted that one instructor talked directly to one student

and the other instructor talked to the group as a whole and gestured to people not speaking and asked them a direct question.

The discussion went quite well until the end of the coordination meeting. I had noticed that throughout the coordination Disha sat back in her seat and remained quiet for most of the hour. At the end of the hour, I asked the group what they thought about the verbal and non-verbal cues they had just witnessed. The overall feedback was that they thought it was interesting. Disha replied “I don’t like group work.” This was the only thing she said the entire coordination meeting. I felt deflated, and said that I understood, “but there’s a whole lot going on besides just group work, don’t you think?” My participants smiled and agreed. However, as I reflected back I felt I could have done a better job setting up the case before they viewed it. Perhaps I could have turned the focus away from the group work in the beginning and then everyone could have focused on the verbal and non-verbal cues as was intended. However, I do think most of the participants positively benefited from the discussion.

Case 2: Office Hours

Description of case content. The Office Hours case was done on November 5, 2015, two weeks after the first video case. During the Office Hours case the participants are asked to watch two different instructors interacting with a student during office hours. One instructor stands at the board and works a problem while speaking with a seated student. In the other, the instructor is in his office sitting at a table working with a seated student. The participants are asked to notice the prerequisite knowledge of the students, how the interactions are similar and different, questions the instructors asked, and the wait time of the instructors. The purpose of this activity is to develop an awareness of

questions to ask and pauses to take when working one-on-one with students during office hours. An affordance of office hours, according to the case, is the chance to probe student thinking.

Description of case delivery. I prepared for this case by watching the video several times and trying to anticipate the participants' responses. Originally, I was not very excited about this case. I did not feel it was as strong as some of the other cases. When I began the activity I started by handing out the participant worksheets and a transcript of the videos we were about to watch. The participants immediately began to read the transcripts. As it turned out, this was a good thing. The second video was inadvertently edited and the beginning minute was not shown to participants. However, since they had read the transcript prior to watching the video they followed along very well and even had comments about the parts of the video they did not see. Strangely, we all felt we had seen that part of the video and did not realize we had not actually viewed it until I replayed the video.

I was pleasantly surprised by the participants' reactions to the video case. They spoke at great length about the professor who sat at the table working with the student. They were all impressed with his wait time when asking questions. Nick mentioned this in his weekly log and said he tried to mimic what he saw that professor do. Disha also mentioned to me that, while she was in office hours, she had been trying to use longer wait times with the students as well. Evelyn mentioned that she tried to let the students do the work in her office hours rather than doing the work for them, as the instructors in the video had done. Pramod and Omar also remarked about the instructor's patience with the student and how they had tried to be more patient with their students. All the instructors

mentioned in their weekly logs, interviews, or in informal conversations how impressed they were with the instructor, who was sitting with the student, and his wait time. This video case seemed to have the greatest impact on the instructors.

Case 3: Angelica's Case

Description of case content. The third case was done on November 18, 2013. Angelica's Case is about a group of students discussing antiderivative problems. The focus of this case is to listen to the students and understand what they are saying. The participants are asked to pay attention to the terminology the students are using. The frequent use of the word "it" is discussed.

Description of case delivery. I was initially very anxious about doing this case. I felt it was a good case and there were many good points, but it showed students working in a group. Knowing Disha's earlier response to group work, I was very uncomfortable about showing participants this case. I made it a point at the beginning of the session to say that even though the students were working in groups, group work was not the focus of this case. The focus of the case was the student thinking and how they were talking about the problems. The atmosphere in the room seemed better with this case than the first case and everyone contributed to the discussion.

Case 4: Grades Case

Description of case content. The fourth and final video case was done on December 3, 2013. The Grades Case is a series of instructors talking about how they make decisions about giving grades. The case begins with a round table discussion of several instructors talking about grades and the question of mercy grades comes up. After the discussion, the case offers video of interviews with several professors where each

discusses personal views on giving grades and what grades mean. The point of this case is to spark discussions about grading, giving grades, and what grades mean.

Description of case delivery. I prepared for this case as I had done the previous cases. I watched the video several times and tried to anticipate my participants' responses. I did not feel prepared for this case because I could not anticipate how my participants would respond. However, the case went very well.

The discussion turned very quickly from what grades mean to the idea of mercy grades. Nick especially felt that it was important to be firm with giving grades. He felt that, by giving someone a higher grade than they had earned, it made other people's grades or degrees less valuable. The majority of the participants seemed to agree and they came down hard on the side of absolutes, and no mercy. Then, as in the case, a cautious word was offered to challenge the "no mercy" approach. Pramod was the exception. He referenced the idea of unusual, extenuating, circumstances illustrated in the case and said "there are some things going on in people's lives that make it appropriate to round a 69.4 to a C." He was the instructor who just had a baby. Disha mentioned this discussion in her weekly logs and noted that she was going to have to think more about how she made grading decisions. Overall, I was very pleased with this case and the discussion.

Across the Cases

Across the study, the participants indicated that the video cases influenced their thinking about teaching. For each instructor, the notable aspect of a case differed. Nick believed that the coordination sessions helped him think more about wait time but also stated that he was already aware of his wait time.

> *Nick:* So, I was aware that that's the thing you should do but I think that that session reminds you of it. So, I think that any change would be one of more I more often do that, to wait longer. I think I still did that to an extent before but I wouldn't think about it as much and it's habit just to keep moving. So, I think the change would be not necessarily that something new happened but that something better happens in a more regular basis. (interview 3)

Omar was also cautious about his thoughts on the cases. When asked if he thought the way he asked questions had changed over the semester he responded “They’re more slow and delayed. I think that’s the biggest thing I can even think of” (interview 3). I also asked if he thought how he responded to students had stayed the same or did he do things differently over the course of the semester. He responded:

> *Omar:* Not consciously because -- well, when I’m answering at that particular point, I don’t- I’m not thinking about, oh, we discuss this in coordination, maybe I should answer. It mostly comes out directly. But, yeah, like the small things have, I guess, a subconscious effect. Like when I started delaying my answer, I did not plan that, but it turns out that way. I guess to have a subconscious effect, but apart from that, I can’t really recall. (interview 3)

Disha was very reflective when talking about her teaching, the cases, and coordination meetings. She recalled the Office Hours case and talked about how it made her think more about what she did in class.

> *Disha:* Then, the instructor started with ‘Okay, let’s go to the basics of derivatives. What is-what do you do when you have sum of functions. What do you do?’ I think what I liked the most was the way he-as soon as he gauged the student’s ability, he got down to the basics and he started asking questions at which point-which started pointing him towards the right direction… That’s what I liked the most about that, breaking down rules so that the problem didn’t seem really humungous to the student. (interview 3)

Disha also noted that the coordination meetings helped her think more about her teaching. “So, for example, I sat through that video session that you put and then it made

me go back and think about stuff" (Disha, interview 3). She went on to say that she would often go to other instructors teaching Calculus for Biological Sciences and discuss her thoughts or ideas. She concluded by saying "every interaction makes me think about what I am doing" (interview 3). In Disha's classes this thoughtfulness was evident. As the semester progressed, she gave the students more time to answer questions and, as she mentioned, broke the problems down into "smaller" parts.

Similarly, Pramod was reflective about his teaching. He often spoke up in coordination and voiced opinions that differed from those of the other instructors. When asked if he felt his questions had changed since beginning the coordination efforts he responded,

> *Pramod:* I think, that is a good question actually. I think, it's been a learning process for me also. I am sure all the others also in the study are with you. I think, I have become little more conscious of this thing [asking questions] and you know, I am now, little, I am being little more conscious in trying to ask more questions than probably what I was doing. And you know, being conscious I sometimes when I, even preparing for the lecture, I visualize a few questions I'll ask, so, which is something that wasn't happening earlier. (interview 3)

Pramod continued his reflection on his teaching saying "

> *Pramod:* I think, a conscious investment, if you like, into making this change of, you know, of improving my interactions and stuff, I think I feel more of a, I don't know, I feel better, I feel better about myself. . . . I feel more of a real teacher now [laughs]. (interview 3)

Evelyn felt the coordination meetings had influenced her teaching, but she was unsure how. When asked if she felt the way she responded to students had changed she said,

> *Evelyn:* Yes, but I'm not quite sure tangibly how. I do believe in reflective teaching because this is what they teach you back in the [previous university]. The only thing that you can really change is yourself, your reaction to the students. You can't change them. So, you always reflect on it, but it would be hard to put my finger on it. I know this semester, I have tried to keep up my energy levels for the entire semester, because I know, the previous semesters, there's often been a slump and it's often because I've been doing courses as well at the same time and I'm exhausted. (interview 3)

All the instructors stated that on some level the coordination meetings did make them think more about their teaching. However, their perceptions of "thinking" varied. Additionally, all the instructors asked fewer Hypophora after the first observation.

Math Talk Level

Each instructor had observations coded as Math Talk level 0 and level 1 at some point during the observations. As noted in Chapter III, my live observation protocol allowed me to identify the Math Talk level for a class meeting, so I have that information for every one of the classes I visited (6 for each instructor). Table 21 summarizes these data, with the most common Math Talk level as level 0. Only Nick and Omar's first observations were primarily in the Math Talk level 1 category. The question categories, along with the question depth, allowed me to examine the more subtle details of asking questions that might help in progressing through the Math Talk levels.

Table 21

Math Talk Levels by Instructor Per Day

	Nick	Disha	Omar	Pramod	Evelyn
Observation 1	1	0	1	0	0
Observation 2	0	0	0	0	1
Observation 3	0	0	0	0	0
Observation 4	1	0	0	0	1
Observation 5	0	1	1	0	1
Observation 6	0	0	1	1	0

The first observation came *before* any use of video cases. Reading down Table 21, notice that after video case use began, each instructor had at least one class meeting coded as level 1. Nick, Disha, and Pramod had just one of their subsequent observations at coded level 1, Omar had two, and Evelyn three at level 1.

Summary

Recalling the framework of the study depicted as a mobile from Chapter II, I have gathered data about TA beliefs and experiences, and questioning practices of each of the five participating instructors. The following illustrates where various aspects from each teacher “fit” into the mobile. As each instructor’s experience was different, they each have different mobiles. Anything that dangles from Question Depth is about the instructor's role when working with students who are negotiating the cognitive demand in a problem situation. For example, Disha's comments on the instructor in the Office Hours case focused on the scaffolding that the case instructor did while Nick's attention, and later "mimicking" was about the patience the case instructor displayed in working with

the student. Evelyn said she already did what the instructor did, having the students do work while she observed. Like Nick, Pramod and Omar remarked on their efforts to be more patient.

Figure 21 is a visual for Nick. After course coordination efforts, Nick mentioned he believed things in his teaching had changed in ways depicted in the mobile. However, he also stated that he was unsure how they changed. Although his beliefs may have been perturbed as wind does a mobile, his practices did not appear to move significantly during the study.

After Nick's first observation he asked probing questions in the second observation (4% in Observation B), but this practice was not sustained. In his interviews and logs he referred to the importance of students "engagement" in class, noting "connection" among ideas (e.g., context of biology and mathematical representation) and "usefulness" as drivers of his communication efforts in the classroom as he worked to get students "doing math." Also, for Nick, the categories of questions he asked were content-based and aimed at students "making sense of the meaning" and good "interpretation" of mathematics. He had a change in the depth of questions asked from Observation A to Observation B, but returned to similar levels by Observation D. Initial change is illustrated in the figure with additional hanging pieces. These pieces would be sites driving additional "movement" in the mobile. This change did not persist throughout all the observations and the number fluctuated throughout the four focus classes.

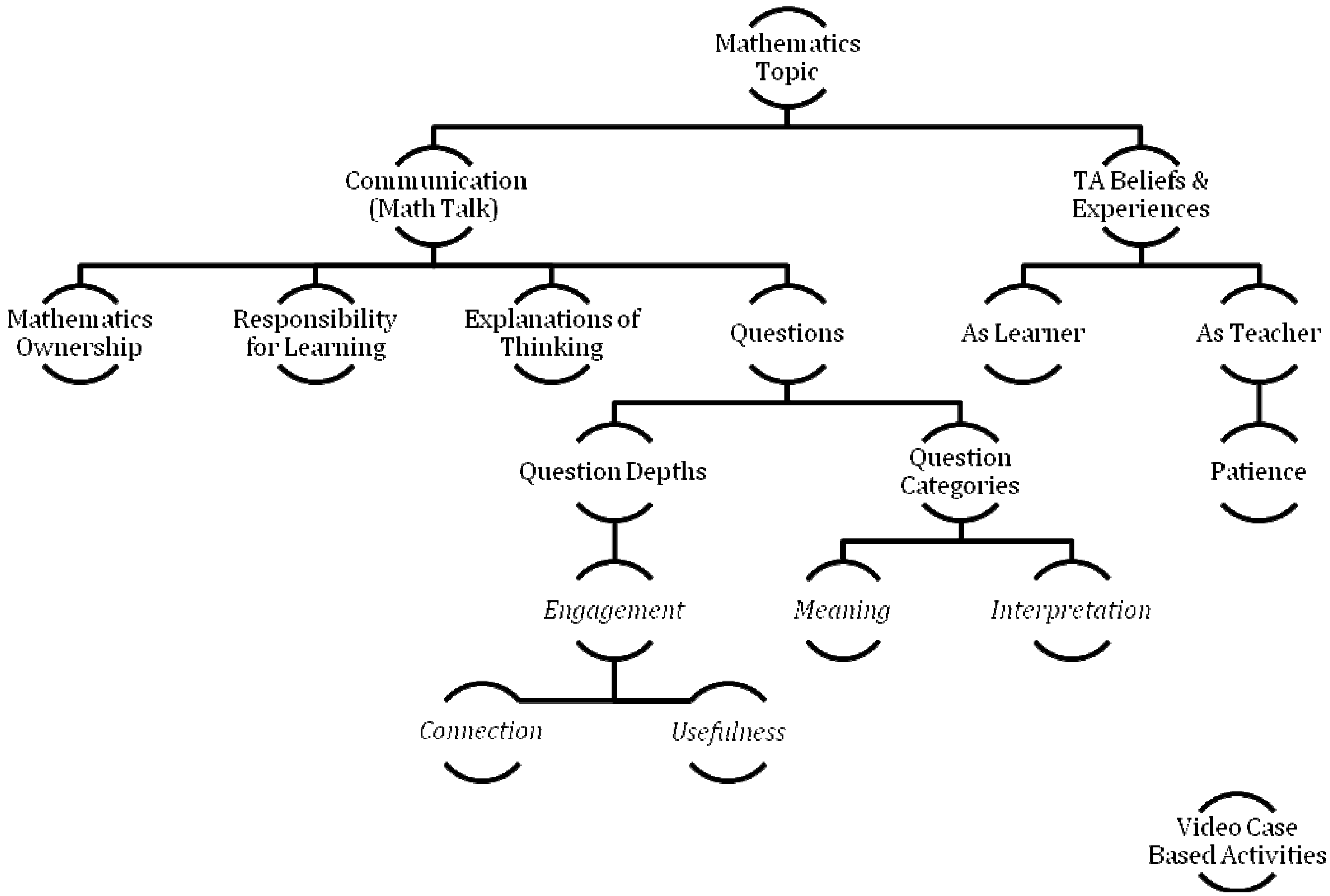

Figure 21. Summary framework visualization for Nick.

Figure 22 illustrates Disha's changes in her questions and beliefs. Disha had a decrease in hypophora. Her use of Elicit Thinking questions varied, and by the end of the study she had attempted to ask probing questions. The group work case brought to the foreground, again, the aspects of Disha views (as learner and as teacher) that the individual was important and group work not valued. This is represented in her respective framework diagrams in the disks "individual" under As Learner and As Teacher. For Disha, in particular, that individual activity in the classroom needs to be active engagement through "thinking." I am not sure how the grades case pushed on Disha's belief system, though I asked her to elaborate. Nonetheless, it was clear that she "had to think about it" and that the need to think was a response to the case.

Disha also stated in her interviews that the video cases influenced her teaching decisions, specifically with scaffolding the material for students. She stated in her third interview that she believed that breaking things down "into smaller pieces" for students, as was her perception of what occurred during a video case, was a better instructional practice and one she intended to continue to utilize.

Similar to Disha, Omar's view that one learns individually was made evident by the group work case. Different from Disha, Omar believed that an individual could benefit from another who was more of an expert. This is represented in their respective framework diagrams in the disks "individual" under As Learner and As Teacher (Figure 23). Omar also has a disk under As Learner to represent the expert help one could benefit from.

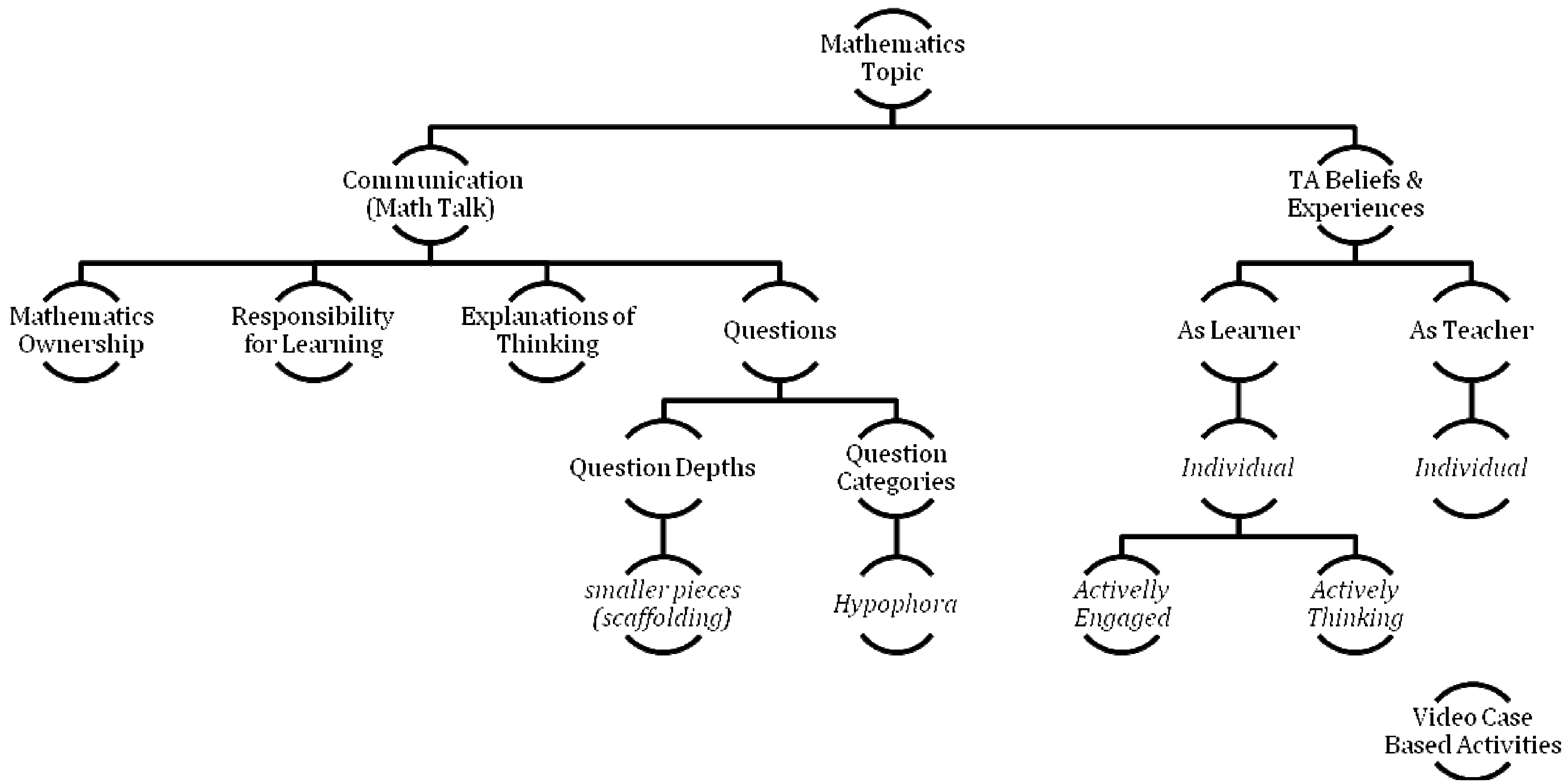

Figure 22. Summary framework visualization for Disha.

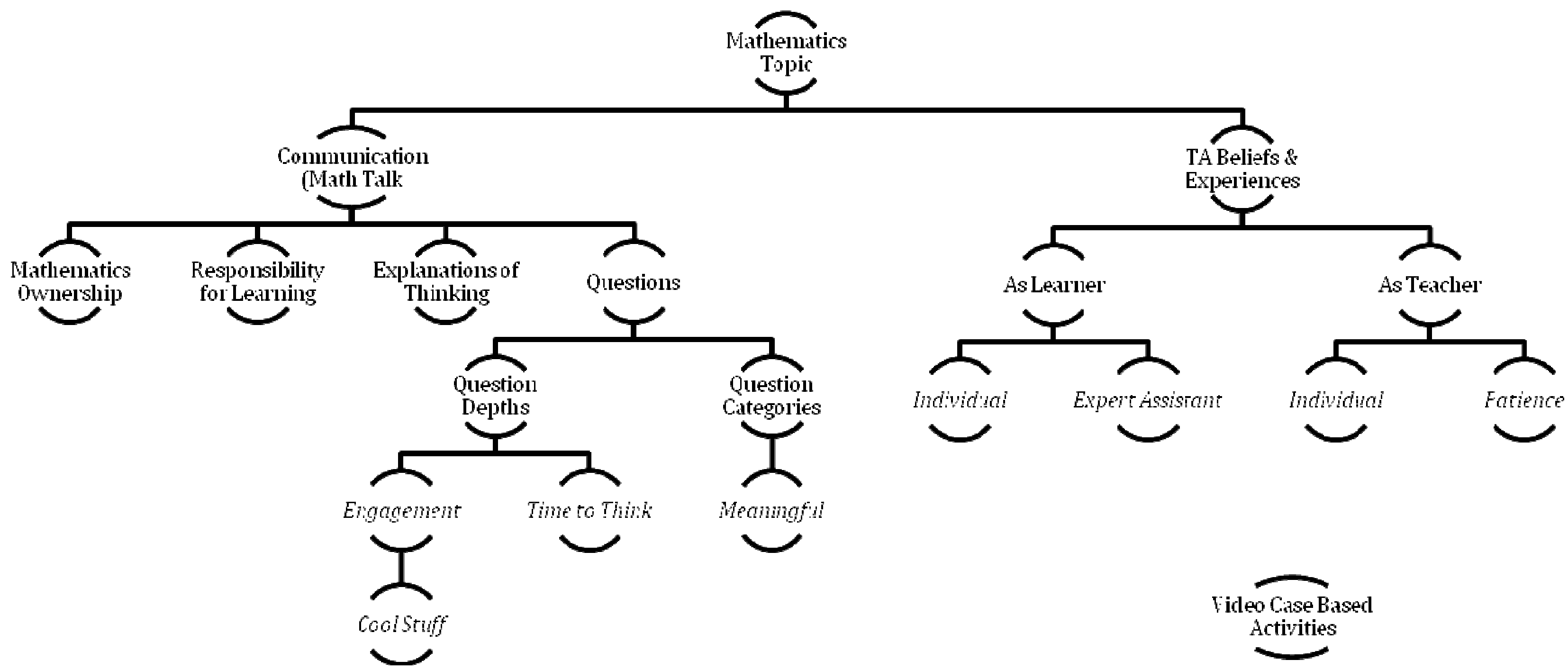

Figure 23. Summary framework visualization for Omar.

Represented in Figure 24, Pramod frequently mentioned in his interviews and weekly logs that he felt questions could engage the students and lead to a deeper understanding of the material. He also felt that by asking different questions he could further engage the students to participate and he could use the student responses to assess the understanding in the room. Pramod believed that students learn when they are actively engaged.

Evelyn believed that a teacher needed to be encouraging and she expressed that she was trying to be more patient with her students (as she perceived the instructor in the Grades Case). Evelyn said activities helped engage students and focus their attention on the mathematics. She primarily used questions to keep students involved in the class and to assess the understanding of the students. While the types of questions Evelyn asked fluctuated across the study, and her comments suggested this was an area she paid attention to, the distribution of her question depths was similar across the observations. This absence of observable influence or change is represented in the absence of any disk below “Question Depth” in the mobile (Figure 25) for Evelyn.

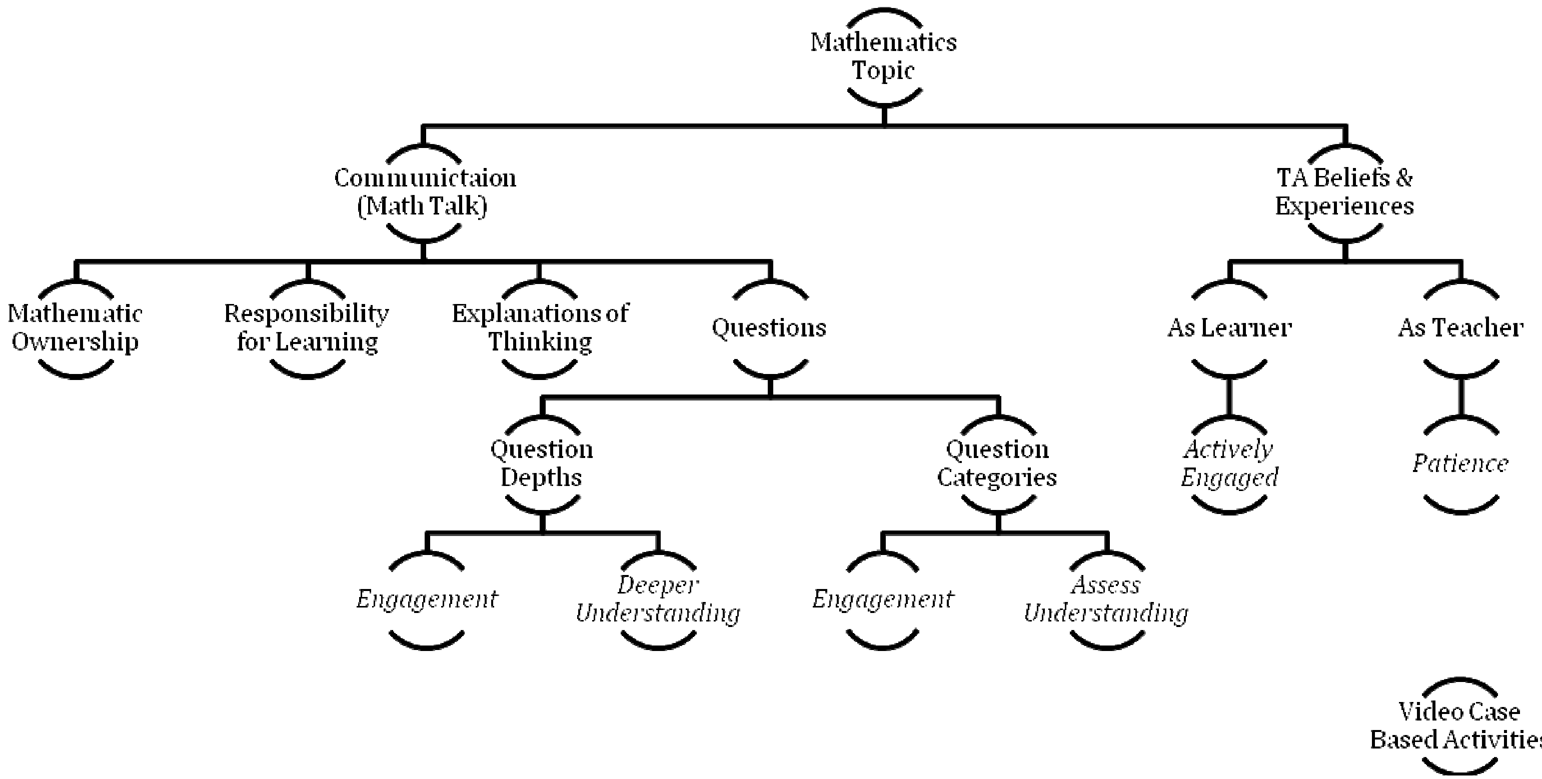

Figure 24. Summary framework visualization for Pramod.

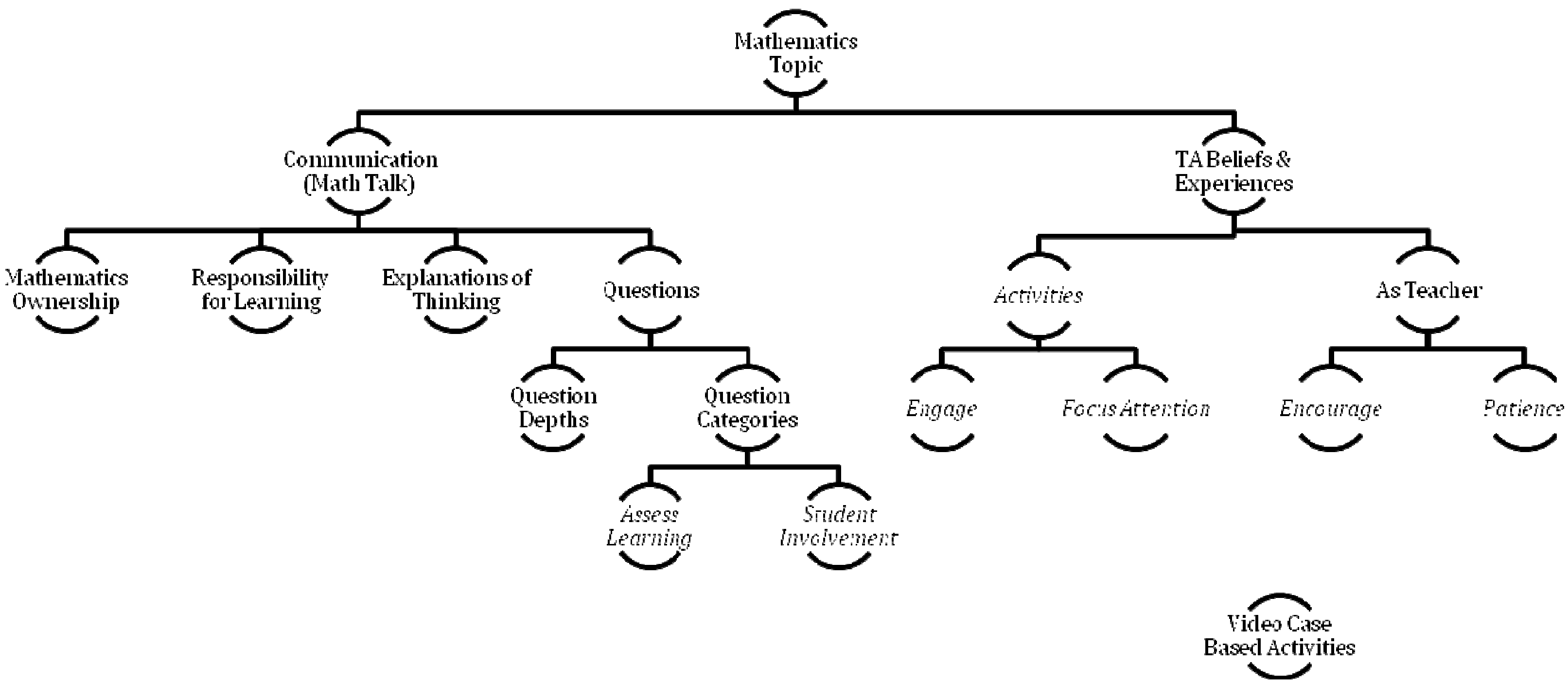

Figure 25. Summary framework visualization for Evelyn.

The main results of the qualitative work are the detailed profiles of novice instructors, an investigation of whether final exam or course grades would be sensitive to the kinds of changes in instruction that novices might implement when participating in video case-based professional development, and examination of novice instructor's experiences of video case-based professional development. In the next chapter I discuss how these results address the target research questions and connect this dissertation work to the literature and future work.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion of Results

The goals of this dissertation project were to examine how novice calculus teachers use questions in their classrooms, how those questions and their use might change after video case based course coordination, and what evidence of influence on student learning might be seen in student achievement. In particular, this research adds to the existing body of research by focusing on one way to elicit student ideas--by asking questions--and how professional development might facilitate asking questions as a way to learn about student thinking.

To examine questions, context must be considered. Questions, void of context, can have very different meanings (Sorto et al., 2009). The work reported here addressed this issue of context, considering each question and the surrounding discourse neighborhood in coding. In cross-instructor comparisons it was clear that there were common discourse patterns common to the participants related to two types of questions (i.e., “Does that make sense?” and “What’s the next step?”). Also clear was that each participant had unique discourse patterns as well. In every case, when participating TAs talked about their teaching, they aspired to be effective while also worrying that they were not sure how to *do* the effective thing at the right moment.

As noted several times, participating TAs were not sure of the value of understanding what students are thinking. Yet, the participants also reported a greater

sense of connection with students when their questions got student responses. Somewhere in the midst of their uncertainty, TAs were sure that communication with students was an important aspect of effective teaching. For most of the participants, especially the most novice teachers of calculus, instructional perspectives on student thinking were just emerging and the video case activities were thought-provoking for them.

As noted at the outset, in Chapter I, my aim was to learn more about how we use questions in teaching college mathematics. In Chapter II, in creating the initial model in Figure 6 (p. 41), I argued that an important contribution to the literature could be made by focusing on novice perspectives in the strand(s) depending from the “Questions” disk. Because of the existing but sparse research results about college teacher development, in that initial model (Figure 6) I included TA beliefs and experiences as part of the balancing act of learning about teaching. The results of observations, interviews, logs, and coordination meetings in Chapter IV support that inclusion. It was clear that working with video cases led to TAs to “having to think about it [teaching and learning]” as Disha said. Also, to contribute to the literature and shape future research, my close examination of questions and their neighborhoods was an intentional effort to uncover what the nature of questions and question strategies were for each participant (RQ2) while seeking to learn what similarities in question-based discourse patterns might exist across novice instructors (RQ1). The research questions at the center of this work were:

RQ1 What is the nature of novice calculus instructors’ discourse patterns surrounding questions they ask?

RQ2 What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?

RQ3 How does video case based professional development shape perceptions and intentions about the role of questions in teaching held by TAs?

RQ4 Does professional development that includes video case materials hold promise as a way to improve the learning of college calculus students?

Research Question 1

What is the nature of novice calculus instructors' discourse patterns surrounding questions they ask?

For this study, discourse pattern referred to the regularly recurring questions and discourse neighborhoods that were characteristic for an instructor. Two main results related to Research Question 1 emerged from the data. On the large scale, all the TAs tended to follow the teacher initiated-respond-follow-up (IRF) pattern, focused on evaluating and fixing student responses. These results reflect and extend to the college level the K-12 research literature, which has demonstrated that novice teachers begin with evaluative IRF practices (Groth, 2013; Mehan, 1979; Truxaw & Defranco, 2008). At the same time, the general nature of discourse in each class was as unique as the instructor. Chapter IV also gave results on the smaller, classroom scale, that TAs had their own ways of enacting some shared discourse patterns, in particular around questions like "Do you understand?" and "What is the next step?"

General Discourse Patterns for Instructors

As noted in Chapter IV, the profile titles epitomized the general classroom communication patterns for each person. Nick wanted the mathematics to be meaningful to the students and for the students to be able to make sense of what they were doing. Disha used hypophora extensively, posing and then immediately answering her own questions. Omar wanted the students to be excited about the mathematics and see the "coolness" of it. Pramod asked some questions to try to engage students in a

mathematical conversation, seeking to elicit what the students were thinking, but the students rarely answered his questions. Evelyn encouraged students to explain their thinking to each other and followed up to make sure students understood the explanation. These general discourse patterns are not characteristic of every question asked by the individual instructors, but each was a repeated way these particular instructors used questions.

Question-centered Discourse Patterns Common across Instructors

Two common discourse patterns surrounding “Do you understand?” types of questions emerged from the data. In one case, the majority of student response to this type of question was either no response, a short verbal response (e.g., “yes”) or brief visual or gestural response (e.g., thumbs-up or nod), indicating that they understood. As indicated in their respective mobiles in Chapter IV, in what instructors reported, such a depth 0 question was aimed at “student involvement” (Nick, Pramod) and had the purpose to “assess understanding” (Evelyn, Pramod). Similar to the first, the second pattern also happened when an instructor explained a procedure or problem. However, in this second pattern, *cycles* of questions and answers occurred: students responded by asking for explanation of some part of the problem that had just been presented (or, less common, they might ask for explanation of some other aspect of the mathematics presented that day); this was followed by an instructor answering and then again asking if students understood, repeating the pattern until students expressed that they understood. In the classes observed for this study, this cycle rarely repeated more than two times. Participants interview and log comments, represented I their respective mobiles in

Chapter IV, indicated that TAs felt these interactions helped with making "meaning" (Nick, Omar) and "student involvement " (Pramod) or "engagement" (Omar, Evelyn).

Like the practices of secondary teachers in Truxaw and DeFranco (2008), these instructor-student interactions were "univocal" (conveying meaning) in nature rather than "dialogic" (constructing meaning *through* dialogue). Skovsmose (2014) suggested that interactions that are dialogic in nature, versus univocal, are more powerful in contributing to conceptual understanding. Univocal interactions occurred in every observed class period with every instructor in this study both before and after their participation in video case activities. Another common discourse pattern emerged in response to asking for the next step in a problem. Like the "make sense?" patterns, "next step" questions were procedural in nature and involved IRF interaction. However, most "next step" prompts were product-eliciting rather than yes/no choices. Participants used them to "engage" (Omar) students as part of "breaking things into smaller pieces" (Disha) and as an opportunity to ask students to do the work of "interpretation" (Nick) about why to do a step or at the end of a problem to "make sense of the meaning" (Nick) of the result.

Research suggests that much of students' secondary school experience in mathematics is driven by teachers asking choice and product focused queries (Stigler & Hiebert, 2004; Wood, 1994). This study found similar patterns among the participating instructors. Moreover, in Pramod's case we saw an instructor attempting deeper questions with limited success in getting student response. Preliminary research in this area in college mathematics has noted that in addition to the difficulty teachers face in adding deeper questions to instruction, it can be quite challenging to students to learn to

participate in IRF interactions that go beyond choice and product questions (Nickerson & Bowers, 2008).

Like early career teachers in K-12 settings, the novice instructors in this study focused on the correctness of student responses (Groth, 2013; Mehan, 1979; Truxaw & Defranco, 2008). In the observations before the first video case, it was common for instructors to give little attention (if any) to incorrect answers. In Disha's first observation, when an incorrect answer was given, she waited, without acknowledging the incorrect answer, until someone answered the question correctly. Nick, Omar, and Pramod responded to incorrect answers by asking if anyone else had a solution. In all four of these instructors' classes, if the instructor did not receive the correct answer, they explained the answer themselves and asked a question like, "Did you get that?" In later observations, after the video cases had become part of course coordination, instructors gave more attention to incorrect answers. Nonetheless, in later observations, whenever instructors asked questions that elicited or probed thinking, the IRF interaction still included evaluation for correctness. For example, in Evelyn's Observation C, she wrote a rational function on the board and asked the Elicit Thinking question, "What do you first notice about this?" Some students responded by saying that there were numbers that would cause the denominator to be equal to zero. Evelyn's follow-up was evaluative: "Good job!"

In the case of Nick, after two video case activities (*Facilitating Group Work* and *Office Hours*), his questions around incorrect solutions also probed how students arrived at those solutions. When introducing differential equations, Nick spent almost an entire class period letting the students conjecture about antiderivatives. He allowed the students

to make suggestions and explored those suggestions in detail. While Nick did explore incorrect solutions, he mentioned to the students that sometimes working things out incorrectly helps you learn how to do it correctly. So, even though he explored the incorrect solution, his follow-ups still focused on an evaluation of the student responses.

By comparison, after the second video case, in Observations C and D, Disha had more questions exploring incorrect solutions and follow-ups that left open the question of evaluation through several IRF turns. When introducing integration by parts, she worked problems following suggestions elicited from the students to find antiderivatives. In this back-and-forth IRF cycling with students, she allowed their suggestions to run to the logical, and invalid, result. She ultimately used these incorrect consequences to demonstrate that another method, integration by parts, was needed to find some antiderivatives. Thus, the discourse surrounding the questions asked was more complex. As noted above, an IRF interaction can be univocal (conveying meaning) or dialogic (constructing meaning), this one example from Disha's class had follow-up (the F in IRF) that was supportive of sense-making and, at the end, evaluative.

The process of developing awareness and responsiveness to others' ways of thinking is quite challenging (Belnap & Withers, 2009; Parker, Bartell, & Novak, 2014). Research on novice teacher development has documented that early career teachers rely first on their own ways of thinking (Kung, 2010). The instructors in this study demonstrated a similar approach while also giving some evidence of exploring student thinking, through their occasional use of Elicit Thinking and Probe Thinking questions. In observations of the instructors after their participation in two or more video case

activities, more discourse neighborhoods included incorrect answers and how the students arrived at those answers.

Though at an early stage, some reflection on instruction was emerging for the novice instructors in this study. After video case activities, each instructor talked about their own views of teaching and how they were learning as instructors. However, they did not talk much about questions. Recall that none of the video cases in the study directly addressed questions and questioning. In fact, Pramod was the only one to specifically talk about questions, noting in interview 3 that when he prepared for teaching he tried to imagine types of questions he might ask. And, once students shared their thinking by responding to a question, the participating TAs showed little evidence that they knew how to use the student response. In most cases, the instructor responded with “good job,” or “that’s close, but could we try…” Once a student shared their thinking, the immediate IRF pattern tended to be short and evaluative (yes or no or here's how we fix your thinking).

Research Question 2

> What is the nature of questions and change in questioning strategies within a semester during classroom discourse by these instructors?

The major results related to Research Question 2 are the detailed participant profiles, which discuss the participants’ question strategies, perceptions of questions, and beliefs about learning. By understanding the individual instructors’ views about learning, and perceptions of questions, it is possible to talk about transferability to other instructors with similar views, perceptions, or cultural backgrounds. The results in Chapter IV and the small case reports presented below are two forms of qualitative research result. The large and small individual cases and associated across-case summaries are a way to

extend the K-12 research literature by providing rich descriptions of question categories and depths and related Math Talk levels.

Nick

Nick explained that after the video case activities started he felt he allowed students more time to answer questions. He noted that he just waited for students to answer, rather than giving them answers even if he felt he had waited a long time. On one occasion, when students were not answering a question he had posed, he remarked to the class, “I can wait all day.” I also observed Nick exploring students’ incorrect answers more often after the first two video case coordination sessions.

Disha

The most notable change in Disha’s questioning techniques was a change in her use of Hypophora, 25 (25%) in her first observation (before video case activities) and 12 (11%) in her final observation (after four video cases). Disha was impressed with the “wait time” of one of the instructors in the second video case shown during coordination (*Office Hours*). Rather than being patient, she seemed to relate this “wait time” to “breaking things into smaller pieces” or scaffolding the information. After this case, Disha, declared her intention to give more time for students to answer questions. I also saw Disha giving the students more time to answer questions. In Observation A, if Disha asked a question that could be considered an Elicit Thinking or Probing question, she would immediately answer, making the question a Hypophora. However, after course coordination efforts, she gave time for students to answer questions. She stated in her final interview how impressed she was with the instructor observed in the *Office Hour* video case and that she used his methods of “breaking things into smaller pieces” and

waiting for an answer, while working with students during office hours. At the same time, she rejected the idea that this video case changed her classroom teaching in any way.

Kung (2010) observed that one way TAs learned about student thinking was through interacting with students watching them work problems and listening to them discuss mathematical content, as one would during office hours. It is possible that Disha gained an understanding of student thinking while in office hours that translated to her classroom instruction. The influence of the video case may have been indirect: as a moderator of her perception of her own office hour experiences, which were in turn a moderator of her classroom practice. Similar to Nick, Disha also spent more time exploring incorrect answers with students and, in observations after video case activity began, asked questions of a greater depth. By exploring incorrect answers and asking deeper questions, it is likely that Disha was gaining further insight into student thinking (Ball, 1997; Carpenter & Fennema, 1992; Fennema et al., 1996).

Omar

Unlike the other instructors, Omar's questioning techniques in most observations included Probe and Elicit Thinking questions. Like the other instructors, he relied heavily on Comprehension Check questions; with the exception of Observation B, the percentage of these questions was similar across observed lessons. Omar included mathematical content that was not required for the course, because it was "just cool" and he thought at least some of the students would like it. Omar was aware of cultural differences and often spoke to me about how the culture of the mathematics classrooms in Pakistan differed from the culture of the mathematics classrooms in the United States. Omar wanted his

classes to be less formal than the classes he took as an undergraduate in Pakistan. He said he wanted the students to feel like they could ask questions during class because he thought this helped in learning the material.

Similar to the participants in Kung's (2010) study, Omar noted that when he prepared for class he thought about how he made sense of the mathematics but also noted that this did not always work. Omar was hesitant to credit any of the video case activities or course coordination discussions to changes in his teaching but also said that he liked the videos and they often made him think about his teaching.

Pramod

Pramod used Elicit Thinking questions and his Comprehension Check questions were at a higher depth after the after the first two video case coordination sessions (*Facilitating Group Work* and *Office Hours*). Although Pramod asked a variety of questions during his classes, the students sometimes did not respond. In these situations, Pramod would pose a question and wait, usually several seconds, for a response. If no one responded, he might try to reword the question or say "Does anyone have a suggestion?" If he still received no response, then he would say "Well, let's find out," or something similar. It is possible that the questions Pramod asked were not accessible to the students. Van Zee and Minstrell (1997) reported on a type of questioning technique called a *reflective toss*. The instructor, Minstrell, described this process as "catching" what the students said and then "throwing" a question back to the students. He claimed that by doing this the responsibility for learning was given to the students. When students do not respond to questions asked, it could be that the students do not see a responsibility for their learning. Pramod's situation, of dealing with silence from students in response to

questions leads me to wonder about an interesting follow-up study: were there any patterns in when the students responded to Pramod and when they did not?

Evelyn

The most experienced instructor, Evelyn had the least amount of variation in question categories and depths during the study. The most notable change was that she had fewer Hypophora in the observations after the video case activities started. Evelyn's most common questions were "do you understand" types of questions. It was common for Evelyn to explain a problem or concept and then turn to the class and ask, "Are you getting this?" She would not move on until she received some sort of verbal or non-verbal indication from the students that they understood. Evelyn was more likely to direct the students to tell her something, rather than ask the students a question (e.g., "Tell me why you think that."). Evelyn was the only instructor with a teaching certificate. She was often reflective about her teaching and said the video case activities confirmed for her what she already thought about teaching. She said her decisions about what she did in class were often intentional. It may be that her training as a teacher influenced her decisions to instruct students to respond rather than to ask questions.

Across Instructors

In summary, the group as a whole asked fewer Hypophora, some instructors asked Probe Thinking questions, and deeper questions were more common, for Nick, Disha, Omar, and Pramod, after the video case activities were introduced than in the initial, pre-case observations (e.g., Chapter IV, Figures 11, 13, 15, 17). All the participants noted in one or more post-case interviews that they felt they were either giving the students more

time to answer questions or they were trying to be “patient” and let the students answer the questions rather than giving them the answers.

Connecting to and Extending the Existing Research Literature

Mehan (1979) identified four types of questions (Chapter IV, Figure 4): choices, products, processes, and metaprocesses. Choices and products are evaluative in nature while processes and metaprocesses are eliciting in nature. The questions I witnessed in this study fell largely into the evaluative category. In particular, only the Elicit Thinking and Probe Thinking questions fall into the eliciting category. This research expands Mehan’s work to the context of college mathematics. The instructors in this study started with IRF patterns that were largely evaluative and univocal, and after one or more video case activities, demonstrated some IRF patterns that included questions of greater depth, but were not necessarily eliciting or dialogic in nature. By including the concept of *question depth*, the framework used in this dissertation study extends Mehan’s framework and offers language to discuss nuances of the cognitive demand of questions (i.e., the descriptions of question depth in Chapter II, Figure 3).

The Math Talk framework (Hufferd-Ackles et al., 2004) has been enriched with this dissertation research. Hufferd-Ackles and colleagues provide a way to examine classroom discourse, but their framework does not capture the subtleties of questions within the classroom. For example, Evelyn primarily asked Comprehension Check questions and rarely asked Elicit Thinking or Probing questions, however, she had three Math Talk level 1 classroom days. Looking at only the Math Talk levels one might conjecture that Evelyn asked deeper questions or that she asked more Elicit Thinking or Probing questions than other instructors who had fewer level 1 days. This was not the

case. By attending to both question depth and the question categories, we find that her question uses were similar to other instructors. Why is that the case? A socio-mathematical norm that was distinct from the other, more novice TAs seemed to exist in Evelyn's class. Rather than ask the students what they were thinking, she would instruct the students to tell her what they were thinking. Her students often answered each other's questions rather than waiting for Evelyn answer. Evelyn encouraged this behavior. That is, she appealed to other pedagogical skills in the Math Talk framework besides questioning (sharing ownership of mathematical ideas, communicating a joint responsibility for learning, and valuing explanations of thinking). Her training as a teacher meant she had these in her professional toolbox. The other instructors did not. By combining the details of the questions model used here with the Math Talk framework, a clearer picture emerges of the ways questions and attention to them in professional development may be particularly important for mathematically trained novice instructors. Math Talk skills are all valuable, but not every mathematics graduate student has the pedagogical training that Evelyn did. Questions and questioning are foundational to the culture of post-secondary mathematics teaching (hence the focus of this study) while the other aspects of Math Talk are not. This opens the door to wondering how the other Math Talk skills might be developed among novice college mathematics instructors who work in the question-answer focus of the post-secondary mathematics environment.

Research Question 3

> How does video case based professional development shape perceptions and intentions about the role of questions in teaching held by TAs?

The major results related to Research Question 3 are that each of the TAs reported video cases made them think about their teaching and this thinking was evident in

instructors' discussion of their teaching and in the discourse in their classes. How this thinking influenced the instructors varied.

	Obs 1	Facilitating Group Work	Obs 2	Office Hours	Obs 3	Obs 4	Angelica's Group	Obs 5	Grades Case	Obs 6
Nick	A					B		C		D
Disha	A		B					C		D
Omar	A		B					C		D
Pramod	A		B					C		D
Evelyn	A				B			C		D

Figure 26. Spacing of Observations and Video Cases.

As a reminder, Figure 26 shows the spacing of cases and observations. For example, the distribution of depths of Nick's questions after the first video case was quite different from the first, pre-video case, observation (Figure 12) whereas the variation for Disha was in question categories--with far fewer hypophora per class after the video case activities began (Figure 13) and for Pramod simply far fewer question after the video case work than before (Figure 18). The evidence of usefulness of video cases for enriching learning from one's teaching experience extends Kung's (2010) research by providing another way for TAs to build their understanding of student thinking and instructional practice. The video cases provide a venue for TAs to listen to and observe students and instructors talking about mathematics. All the instructors in this dissertation study expressed similar views to Borko et al.'s (2008) participants who said that observing video clips of colleagues teaching gave them a chance to reflect upon their own teaching. Echoing a similar view, each of the instructors in this dissertation study expressed the view that the video case based activities caused them to "think about" or "reflect on" their teaching.

Evelyn remarked on the importance of being “patient” and Nick, Disha, Omar, and Pramod acknowledged that waiting was something they had not considered much previously in their teaching, but it was an interesting aspect to consider in their teacher-student interactions. Disha, rather than associating waiting with patience (as Nick, Omar, Pramod, and Evelyn did), said paying attention to breaking down problems and waiting for students to respond was something she did in her office hours, and, though not a focus of this research, I observed an increase in waiting for response (evident in fewer hypophora) in her teaching. Both Nick and Omar commented on being “patient” and Pramod on the importance of waiting for students to think about hard (deeper) questions. Wait time is an important area for more research and development at the college level. The K-12 research already indicates it can contribute to student learning by allowing learners time to organize their ideas and adjust their thinking about a topic (Huck, 2008).

Omar commented that the cases made him think about his teaching, more broadly. When asked if he thought his questioning had changed, he commented that his questions were more slowed and delayed. When pressed further about whether he thought he did things differently, he was cautious in his response stating that he did start delaying his answers, and waiting for the students to respond, but that was not something he planned. He said the video case activities may have had a “subconscious” effect.

Pramod noted in his weekly logs that “preparing questions to ask while teaching has helped me teach better.” He also stated that he “will continue to involve students in class by encouraging them to ask questions.” This is evidence of Pramod’s belief that questions can “engage” students, including questions that students ask him.

Nick also felt the video case activities in course coordination had influenced him to be more patient with the students, allowing them to take their time to "figure out" what is happening in answering questions. He stated in his weekly logs, "I forced them (as a class) to come up with answers to problems they should already know; there was a moment where we had 10 seconds of silence, but it motivated them to actually figure out the problem on the board." He credited video case work by stating that he did allow students time to answer questions before video case course coordination efforts, but that coordination caused this to happen more often. Nick viewed this as a positive change in his teaching.

Evelyn expressed that she enjoyed the coordination meetings and liked discussing different aspects of teaching. She said that the coordination meetings made her think more about what she did in class. In her weekly log she stated the she used an idea from coordination by trying "to be more patient to drag the ideas out of the students asking questions of me" rather than answering herself.

Four of the five the instructors believed that they had an increase in their attention to being patient or waiting and they connected this to the video vignettes (all but Disha). In this limited sense, the video case based coordination may have spurred at least some of the instructors to be more intentional about rapid evaluative response or filling in of silence when asking questions. Their perception, from seeing waiting by an instructor play out in the video case, was that allowing students "time to think" about "smaller pieces" and letting students answer a question (as opposed to answering a question themselves) was "more engaging" and, according to Pramod at least, a better instructional practice. Some participants also noted overtly that the video case course coordination

caused them to think more about their teaching. Asking questions and waiting for student responses is a way of interacting with students. Interacting with students, and thinking about, reflecting on and discussing their teaching can increase an instructor's PCK, particularly through attention to student thinking and planning for the time needed for teaching (Kung, 2010; Kung & Speer, 2009; Speer & Wagner, 2009).

Research Question 4

> Does professional development that includes video case materials hold promise as a way to improve the learning of college calculus students?

The purpose of Research Question 4 was to explore possible connections between student achievement and questions asked in the classroom. Given the short duration of the study and small sample size for number of instructors and number of observations, statistically significant results would have been surprising. However, the data detailed in previous sections indicates that the video case based activities may have contributed to change in the instructors' questioning strategies and patterns, albeit in small ways, by pushing them to think about and reflect on their use of waiting and attention to student thinking. There is no work at the college level on the boost to student learning arising from teacher professional development when it includes attention student thinking as there is in the K-12 literature (e.g., Carpenter & Fennema, 1992; Fennema et al., 1996; Peterson et al., 1989). Future studies could build on the K-12 work and theoretical model from this study and examine in more detail how students perform on different types of exam questions as well as comparing mean scores of students in the classes of novice instructors involved in video case based coordination versus a control group.

In a second comparison, of grade distributions from the semester of study to the previous Fall semester, no significant differences were found. As noted in Chapter IV, the

rigid constraints on common exams, scoring, and awarding of grades at the university where the study took place was designed to ensure similar grade distributions each semester. Each semester the grades were "curved" by having the same adjustment applied across all instructors. While it is impossible to state definitively, especially with only anecdotal evidence from the course coordinator, it is interesting to me that in the semester of the study, the adjustment was by six points--each student had a six point addition made to their final exam score while in past years the adjustment had been as high as 20 points (according to Dr. Wales).

Implications for Practice

This dissertation study offers a framework for discussing and categorizing questions. At the collegiate level, little research has been done in looking at how instructors ask questions. By using this framework, a language has been offered to help focus on and discuss various types of questions and their potential for improving discourse in college mathematics teaching. Two specific implications for practice in using video cases arise from this work: the sequencing and timing of case use with novice instructors.

When implementing the video case based activities I found that at least two of my participants "did not like group work" as discussed previously. Reflecting back on the video case based activities, the *Facilitating Group Work* case should not be the first case with novices. Facilitating this case first meant at least two of the participants did not respond as I had hoped from that particular coordination meeting. Also when facilitating this case, it might have been helpful to preface the activity by stressing that the

participants should pay attention to the instructor/student interactions rather than the fact that students are working in groups.

The video case based activities did seem to provide a platform for the instructors to observe students working problems and discussing what they think about those problems. Kung (2010) found that when graduate students learned more about student thinking and interacted with students, then instructor PCK increased. Participants in this study may have been increasing their PCK, but not enough to show change in the measure I was using: changes in question strategies. Nonetheless, participants clearly enjoyed the conversations (if sometimes uncomfortably) spurred by the video case activities. By providing coordination that includes video case based activities throughout an entire school year (typically two semesters) it may be possible to further increase instructor PCK to an extent that is measurable and measurably faster than the growth of PCK among novices who do not engage in such activities. This idea is taken up again under Implications for Research.

An additional recommendation would be to provide the first video case based activity within the first two weeks of the semester. I believe starting earlier in the semester could have a greater impact on novice instructors. By starting earlier in the semester, the discussions of the video case based activities can act as a bridge across the weekly coordination meetings and provide time for the participants to notice things in their own instruction. Also, adding peer observation to coordination activities would give a way to triangulate reflections on their own teaching, observations about the strangers in the videos, and what they have noticed in the teaching done by those who are near peers.

Also, more time for each case could provide reflection on their thoughts, which could contribute to better discussions.

Learning to notice aspects of classroom interaction through video-based activities has been shown to influence K-12 teachers' attention to their own classroom interactions, including questioning (van Es & Sherin, 2008). This study extends the idea to the context of college instruction, among teachers who do not (generally) have the same pedagogical preparation that K-12 teachers do. It appears that video cases as a tool for college instruction may support instructors learning to teach. The video case based activities used in this study did not focus on questions. A clear next step is to create some that do.

Future Research

Throughout the research process, I wondered about student perceptions of the questions being asked. Why didn't the students respond to certain questions? What was going through the students' minds when asked a question? How might the instructor have encouraged the students to respond or think about certain aspects of the mathematics being discussed? Though not the focus of this study, I saw that Nick's students had a tendency to pose questions as "why . . .?" and Nick often used the word "why" in posing questions. Socio-mathematical norms for communication in a college mathematics class may be established in the first few hours of instruction (Tsay et al., 2011). Future studies could examine the relationship of the types of questions instructors ask to the types of questions students ask--from the start of a semester until the end of the semester. Interviewing both the students and instructors about the questions asked could provide valuable feedback about student thinking and instructor response to student thinking. This would further build on Speer's (2001) work by investigating not only the instructor

reason for asking questions, but also the students' reasons for asking, answering, and not answering questions as well as student thoughts about questions. Such a study would possibly include video-clip based student focus group interviews--where students watch and discuss a question-driven interaction--at least twice during a semester and a comparison of the students' perception of questions to the instructor's perception of questions. Learning more about how students think about questions could aid in identifying what types of questions can contribute to student learning. This, in turn, could shape the development of new video cases that focus on questioning.

Whether an answer to an instructor question is correct or incorrect is an aspect of the question context, that is, of the discourse neighborhood. The ways instructors of the dissertation study dealt with correctness in response to the questions they asked appeared to be different after video case activities. Each instructor during observed lessons had a set of regular and repeatedly used responses to students giving incorrect answers to questions. In other words, there was a discourse pattern related to dealing with the incorrect responses. For Nick and Disha, how they dealt with incorrectness appeared to be different after video case activities. Future studies could focus attention on how instructors respond to incorrect solutions offered by students. What similarities exist between instructors when incorrect solutions are offered? What is the nature of change during in how instructors respond to incorrect answers to questions as they gain teaching experience?

Gutmann (2009) examined the beliefs novice mathematics TAs held about who could learn mathematics. Specifically, his study focused on whether TAs believed everyone could learn mathematics or if there were certain people more capable or who

had a gift to do mathematics. He interviewed seven TAs. All noted that there was an "upper" and a "lower" level of mathematics. However opinions differed on whether everyone could learn and do mathematics. One participant held fast to the idea that in order to succeed in mathematics, one must work hard. The other TAs seemed to think that in addition to working hard, one must also possess some natural ability or "creativity" to be successful in mathematics. However, they also noted that they had been successful by working hard. Herzig (2002) found similar views among mathematics graduate students and professors. The professors often talked about students having a "gift" that made them more mathematically creative and better able to do well in the field of mathematics. In contrast, the graduate students in Herzig's study expressed that their successes were due to hard work.

The works of Gutmann and Herzig introduce a possible research problem. If novice instructors believe that one must work hard in order to be successful, then how might that change the types of questions and expectations they have for their students? Similarly, if novice instructors believe that one must be "naturally gifted" in order to be successful in mathematics, what types of questions and expectations do they bring to the class? How might their questions differ according to the perceived ability of the students in the room? Similar to Gutmann's (2009) participants, Nick felt that there was more to being successful in mathematics than natural ability. During his first interview he considered,

> . . . is there some natural ability right? I like to believe that that's not true. I like to believe that natural ability can be overcome and you may have a tendency to go a certain level but I think you can overcome those in general . . ., you know if you're tone deaf, you're probably never going to play musical instrument so ignoring those cases. I like to think people can overcome.

Additionally, Nick discussed “limiting factors” he had to deal with in the classroom (including a lack of time to cover the material); he stated “. . . these aren't math kids so at some level they don't care about what I'm saying . . .” (interview 1). Throughout Nick’s instruction I saw him discuss applications of the mathematics being taught. His questions often focused on why something would be useful to the students. His belief that people “can overcome” a natural ability or lack of some natural ability, and the fact the most of his students “aren’t math kids” influenced his instructional focus and the questions he asked. It was not common for Nick simply to tell the students an answer.

Further research could also include examining questions asked in advanced mathematics classes. The instructors in this study regularly communicated that they saw their students as “others” in the sense that the students would not become mathematicians (as the TAs were attempting to do). I wonder how questions play out in classes where the students might be more likely to pursue a career similar to the instructor’s. A new study might include video recording the classes at least six times throughout the semester, video clip interviews (from the classroom being observed), student focus group interviews, and individual instructor interviews. The interviews could focus on particular instances in the class in which questions were asked. Showing the same clip to both the instructor and the student focus group could allow for a comparison of the instructor perception of questions to the students’ perceptions of the questions.

While some changes were apparent with my participants, I question if those changes will persist over time. To examine how questioning practices may evolve, persist, or regress over time, a study of a single novice TA as the instructor goes through the first three years of teaching, would be worthwhile. If questioning strategies revert

back to previous patterns, then how might professional development activities need to be adjusted to not only change questioning strategies, but also sustain changes in questioning strategies? Reciprocally, knowing how questioning strategies may evolve with novice instructors could aid in creating professional development activities. A study of this nature might include observing and video recording the instructor regularly. Video clip interviews after each observation that focus on instructor intent when asking questions, might offer insight into how and why the instructor is making changes (or not).

Future Research to Test Theory

In what follows, I present a summary visualization of the framework, across all five instructors (Figure 27). The purpose of the visualization is to illustrate the potential sites for professional learning that emerged from the analysis of question categories, depths, and neighborhoods in the teaching of the five participants in this study. The model represented in the visual is not generalizable, that is not the purpose of qualitative research. Nor are there hard and fast conclusions to be drawn from the kind of naturalistic inquiry in this study. Rather, as outlined in Chapter II, member checking, peer debriefing, expert checks, progressive subjectivity, and persistent observation support the credibility, authenticity, and transferability of the proposed model. In Figure 6, I offered an initial picture of the hypothesized relationships among aspects of question-driven discourse in the context of novice instructors teaching calculus to bio-science students. In Figure 27, I offer an amended model, a new inductive basis for future work that includes the perspectives and experiences identified in Chapter IV. The enhanced model has additional disks with *in vivo* codes (i.e., the words used by one or more participants to describe an aspect of their experience/perspective). Although each person's

representative mobile was unique (see Chapter IV), some things were similar among some of the instructors. For example, Nick, Omar, Pramod, and Evelyn all mentioned the importance of patience in asking and waiting for answers to questions, in part because their attention had been drawn to patience by working with the *Office Hour* video case (e.g., being patient, waiting, wait time). In Figure 27, this is represented in the existence of the *Patience* disk under “As Teacher” (because one instructor remarked on it) and the three + signs (three other instructors echoed the sentiment). The shading in gray reiterates this qualitative result by drawing the eye to those disks representing views or experiences that were held by several, the darker the gray the more people who mentioned it or gave evidence of it in their teaching. Each disk with *italic* terms emerged from this research as a potential site for accessing and shaping novice instructor perceptions of teaching, learning, and questioning. One revision to the original framework itself is the addition of Univocal above the original “Question Categories” and introduction of “Dialogic Question Categories” as a separate aspect of the model.

The diagram can serve as an illustration for researchers and case facilitators to show how the video case materials might push against current views of novice instructors and (re)shape how they think about teaching. This is an interim diagram. Further research is needed to refine it, but it does illustrate particular things the instructors in this study mentioned in the interviews, weekly logs, and during coordination. When preparing to facilitate the video case activities, it may be useful to note the topics the instructors mentioned as access points and prepare to explore those ideas in more detail during course coordination.

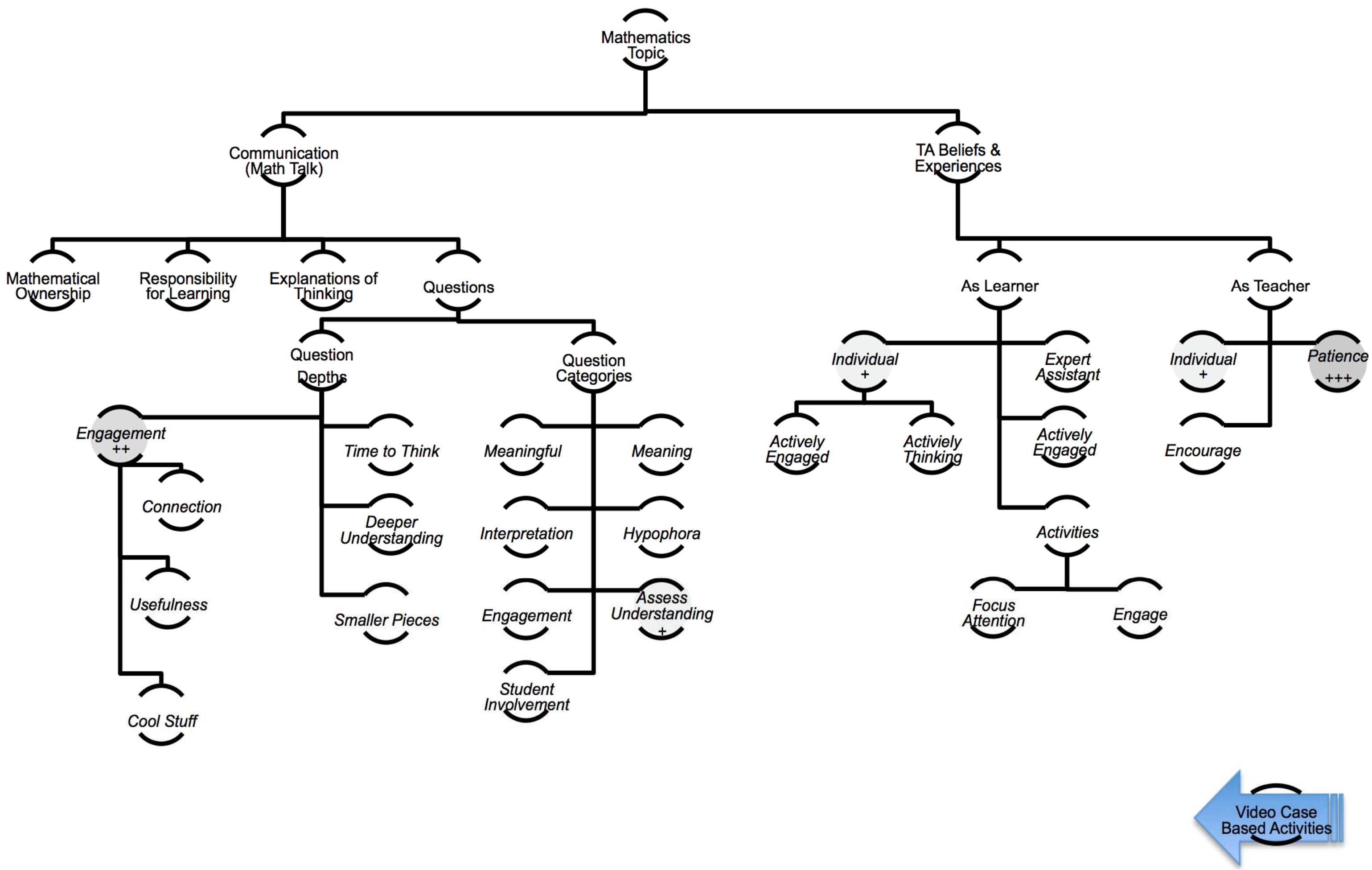

Figure 27. Summary Framework visualization for all five instructors.

Dialogic Question Categories

As noted previously in this chapter, all the instructors had common discourse patterns surrounding the question types *Does that make sense?* and *What is the next step?* These short, shallow, cycles of interaction may have been an indicator of another version of my initial question categories, a dialogic one. Given Skovsmose's (2014) suggestion that dialogic (rather than univocal) interactions are more powerful in contributing to conceptual understanding, I see that in a re-examination of the categories defined for this study, I made a univocal assumption. This was based on my own mathematics learning experiences and of all the hundreds of college mathematics class meetings I have witnessed as student, teacher, research observer, and videographer. I had only rarely seen a dialogic approach to mathematics instruction. What if there is another version of those question categories that assumes a constructing of meaning (rather than a conveying of meaning)? They might look like the descriptions in Table 22. Notice how each description is changed with a dialogic assumption. Comprehension check now requires a classroom norm for public conversation of ideas, right or wrong. A Content Check is different for instructor and student because it involves contrasting cases, such as might arise from comparing multiple student responses (rather than looking at just one student response at a time). In Elicit Student Thinking, the role of instructor in getting a question into the talk in the room is different because of de-centering--the valued questioning is among students rather than always channeled through the instructor. For successful dialogical probing of student thinking, teachers would have to have the skills described in Smith, Hughes, Engle, and Stein (2009) to "both build on and honor student thinking while ensuring that mathematical ideas at the heart of the lesson remain prominent" (p.

550) *and* do it with college age learners (Smith and colleagues' examples are from middle school mathematics teaching).

Table 22

Question Category Definitions—Revised for Dialogic Assumption

Categories	Descriptions
Comprehension Check	To ~~assess~~ *elicit* ~~one~~ *two* or more students' declarative understanding of a topic, procedure or task *in order to make it public and debatable* (e.g., What should we do next?, Does that make sense?)
Content Check	Used to ~~push~~ *discover* the mathematical ~~focus or direction of~~ *foci and directions across* the students' attention (e.g., ~~Should we try the chain rule~~ *Which of these two options for next step is more useful*?)
Elicit Student Thinking	To ~~draw out what the students~~ *pay attention to what students are saying to each other about what they* are thinking, including prompts for students to communicate what they thought to other students or teacher (e.g., *Explain to student X, w*hat do you first notice about this graph?)
Probe Student Thinking	To *orchestrate multiple student contributions to structured conversation about the* ~~investigate~~ reasoning behind or explanation for a given response or procedural work, including prompts to communicate why a person or group thought what they did (e.g., *Students Y and Z, do you agree with X? Why/why not?* ~~That's correct, but why?~~)

Note. Descriptions revised for dialogic assumption are in italics

If the short, shallow exchanges I saw in this study had been richer, it might have been possible to include disks in Figure 27 hanging below "Dialogic Question Categories." Instead, those exchanges are a launching point for a revision to the model that can be tested in future work. In fact, a study of much more experienced instructors might offer plenty of information under the heading Dialogic Question Categories.

Ultimately, the question categories and associated cognitive load analysis criteria of question depth, offer a framework for future development of research and professional learning materials that can aid in transitioning calculus instructors to higher Math Talk level question skills.

Conclusion

At the beginning of the research process, I aimed at doing research at the intersection of the enacted curriculum and the intended curriculum (recall Figure 1). Rigorous quantitative analysis of the final exam scores and comparison of pass/fail rates between semesters was inconclusive. The naturalistic analyses of classroom instruction, participant interviews, and logs offers credible and transferable results--the long and short case reports are likely to pertain to another large research university and the revised framework for examining questions as an aspect of Math Talk (Figure 27) holds promise in future research and development.

The detailed profiles in this study provide examples of novice instructors, their experiences, their perceptions of mathematical teaching and learning, and detailed reporting on their use of questions by type and depth. To my knowledge, this is the first report on novice college calculus instructors to do so. This study built on the qualitative work of Speer (2001), which investigated two mathematics TAs and how their beliefs about learning affected the questions they asked during recitation sessions for calculus classes for engineering and mathematics majors. She found that if a TA believed it possible to have a correct answer but still not understand the problem, the TA would ask the students for explanation, regardless of an answer’s correctness. However, if the TA believed that a student could have a wrong answer but still understand a problem, that TA

was less likely to ask for explanation on correct work, and would often ignore incorrect answers given by students. Similarly, I examined novice mathematics instructors and how they asked questions while teaching. I added to Speer's work by examining closely the types of questions asked by novice instructors and considering question depths. Similar to Speer, I conducted video clip interviews with each of my participants; however, I also included a video case-based intervention during the coordination meetings. I further built on this work by closely monitoring the instructors' questions across multiple classroom visits, interviews, coordination meeting conversations, and logs. This study also extends the work of Hufferd-Ackles et al. (2004), by providing the question depth and question categories enhancements to their Math Talk framework. Both the Math Talk framework and the question depth codes with accompanying attention to discourse neighborhoods can aid in the analysis of classroom questions and the discourse surrounding those questions.

The video case based activities gave instructors a platform to increase their PCK, particularly about student thinking. This can contribute to better teaching, thus addressing the overarching practical problem of how to improve collegiate mathematics teaching and learning. According to participants, the video case conversations and later reflections also resulted in a change in awareness about questioning practices and, according to the coding of classroom interactions, variety in question depth and/or category, particularly for the four most novice instructors. An additional positive result is that the instructors said they enjoyed the activities and saw them as a resource for thinking about teaching. I close with a quote from Pramod's exit interview about his experiences with the case studies:

I think, a conscious investment, if you like, into making this change of, you know, of improving my interactions and stuff, I think I feel more of a, I don't know, I feel better about myself . . . I feel more of a real teacher now [laughs].

REFERENCES

Adler, F. (2012). *Modeling the dynamics of life: Calculus and probability for life scientists* (3rd ed.). Boston, MA: Brooks/Cole.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Arcavi, A., Kessel, C., Meira, L., & Smith, J. (1998). Teaching mathematical problem solving: An analysis of an emergent classroom community. In A. Schoenfeld, J. Kaput, and E. Dubinsky (Eds.), *Research in College Mathematics Education. Vol 3* (pp. 1-70). Providence, RI: AMS.

Austin, A. E. (2002). Preparing the next generation of faculty: Graduate school as socialization to the academic career. *The Journal of Higher Education*, *73*, 94-122.

Ball, D. (1997). What do students know? Facing the challenges of distance, context, and desire in trying to hear children. In B. J. Biddle, T. L. Good, & I. Goodson (Eds.), *International handbook of teachers and teaching, Vol.2* (pp. 769-818). New York, NY: Springer.

Ball, D. L., & Bass, H. (2000). Interweaving content and pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.), *Multiple perspectives on the teaching and learning of mathematics* (pp. 83-104). Westport, CT: Ablex.

Ball, D. L., & Bass, H. (2003). Making mathematics reasonable in school. In J. Kilpatrick, W. G. Martin, & D. Schifter (Eds.), *A research companion to Principles and standards for school mathematics* (pp. 27-44). Reston, VA: NCTM.

Ball, D. & Cohen, D. (1999). Developing practice, developing practicioners: Toward a practice-based theory of professional education. In L. Darling-Hammond, & G. Sykes (Eds.), *Teaching as the Learning Profession.* (pp. 3-31). San Francisco: Jossey-Bass.

Beck, I. L., McKeown, M. G., Hamilton, R. L., & Kucan, L. (1997). *Questioning the author: An approach for enhancing student engagement with text*. Newark, DE: International Reading Association.

Belnap, J. K., & Withers, M. G. (2009). Critical experiences in GMTAs' discussions regarding teaching. In M. Zandieh (Ed.), *Proceedings of the 12th Conference on Research in Undergraduate Mathematics Education*. Retrieved from https://mathed.asu.edu/crume2009/Belnap1_LONG.pdf

Beyer, L., & Liston, D. (1996). *Curriculum in conflict: Social visions, educational agendas, and progressive school reform*. New York, NY: Teachers College.

Blank, R. K., & de las Alas, N. (2009). Effects of teacher professional development on gains in student achievement (Tech. Report). How Meta Analysis Provides Scientific Evidence Useful to Education Leaders. Washington, DC: Council of Chief State School Officers.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3-15.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and teacher education*, *24*(2), 417-436.

Boston, M. D., & Smith, M. S. (2009). Transforming secondary mathematics teaching: Increasing the cognitive demands of instructional tasks used in teachers' classrooms. *Journal for Research in Mathematics Education*, 119-156.

Boud, D., & Feletti, G. (Eds.). (1997). *The challenge of problem based learning* (2nd ed.). London: Kogan Page.

Brophy, J. (Ed.). (2008). *Using video in teacher education* (Advances in research on teaching, Vol. 10). Bingley, United Kingdom: Emerald.

Bressoud, D., Carlson, M., Mesa, V., & Rasmussen, C. (2013). The calculus student: Insights from the MAA national study. *International Journal of Mathematical Education in Science and Technology*. Retrieved from http://www.maa.org/programs/faculty-and-departments/curriculum-development-resources/characteristics-of-successful-programs-in-college-calculus#sthash.AfP50rB1.dpuf

Carlson, M. P. (1998). A cross-sectional investigation of the development of the function concept. In A. H. Schoenfeld, J. Kaput, & E. Dubinsky (Eds.), *Research in collegiate mathematics education. III* (pp. 114-162). Providence, RI: American Mathematical Society.

Carlson, M., Jacobs, S., Coe, E., Larsen, S., & Hsu, E. (2002). Applying covariational reasoning while modeling dynamic events: A framework and a study. *Journal for Research in Mathematics Education*, *33*(5), 353-378.

Carpenter, T. P., & Fennema, E. (1992). Cognitively guided instruction: Building on the knowledge of students and teachers. In W. Secada (Ed.), *Curriculum reform: The case of mathematics education in the United States* (pp. 457-470). Elmsford, NY: Pergamon.

Carpenter, T. P., Fennema, E., & Franke, M. L. (1996). Cognitively guided instruction: A knowledge base for reform in primary mathematics instruction. *Elementary School Journal*, *97*(1), 3.

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C., & Loef, M. (1989). Using knowledge of children's mathematical thinking in classroom teaching: An experimental study. *American Educational Research Journal, 26*, 499–532.

Coles, A. (2013). Using video for professional development: The role of the discussion facilitator. *Journal of Mathematics Teacher Education, 16*(3), 165-184.

Craig, S.D., Sullins, J., Witherspoon, A., & Gholson, B. (2006). The deep-level-reasoning-question effect: The role of dialogue and deep-level-reasoning questions during vicarious learning. *Cognition and Instruction, 24*(4), 565-591.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five designs.* Thousand Oaks, CA: Sage.

Cullinane, J., & Treisman, P. U. (2010). *Improving developmental mathematics education in community colleges: A prospectus and early progress report on the statway initiative*. Paper presented at the NCPR Developmental Education Conference: What Policies and Practices Work for Students?, Teachers College, Columbia University. Retrieved from http://www.utdanacenter.org/ mathematicsways/index.php

DeFranco, T. C., (1996). A perspective on mathematical problem solving based on the performances of Ph.D. mathematicians. In J. Kaput, A. Schoenfeld, & E. Dubinsky (Eds.), *Research in collegiate mathematics education. II* (pp. 195-213). Providence, RI: American Mathematical Association.

Deshler, J., Hauk, S., & Speer, N. (2015). Professional development in teaching for mathematics graduate students. *Notices of the AMS, 62*(6), 638-643.

Dorff, M. (2013, August/September). *CSPCC, URSIP, and CI* (MAA's Project Leadership Conference). *MAA Focus*. Retrieved from the online version 25 August 2013, http://digitaleditions.walsworthprintgroup.com/article/ CSPCC,_URSIP,_and_CI_%28MAA%25E2%2580%2599s_Project_Leadership_ Conference%29/1461362/168519/article.html

Dreyfus, H. L., & Dreyfus, S. E., (2004). The ethical implications of the five-stage skill-acquisition model. *Bulletin of Science, Technology, & Society, 24*, 251-264.

Driscoll, D., Craig, S. D., Gholson, B., Ventura, M., & Graesser, A. (2003). Vicarious learning: Effects of overhearing dialog and monologue-like discourse in a virtual tutoring session. *Journal of Educational Computing Research, 29*(4), 431-450.

Farmaki, V., & Paschos, T. (2007). The interaction between intuitive and formal mathematical thinking: A case study. *International Journal of Mathematical Education in Science and Technology, 38*(3), 353-365.

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education, 27*, 403-434.

Friedberg, S. (2005). Teaching mathematics graduate students how to teach. *Notices of the AMS, 52*(8), 842-847.

Friedberg, S., Ash, A., Brown, E., Hughes-Hallett, D., Kasman, R., & Kenney, M. (2001). *Teaching Mathematics in Colleges and Universities: Case Studies for Today's Classroom: Faculty Edition*. Providence, RI: American Mathematical Society.

Gall, M. D., Gall, J. P., & Borg, W. R. (2006). *Educational research: An introduction* (8th ed.). Boston, MA: Allen & Bacon.

Gee, J. P. (1996). *Social linguistics and literacies: Ideology in discourses*. London, England: Falmer.

Gholson, B., & Craig, S. D. (2006). Promoting constructive activities that support vicarious learning during computer-based instruction. *Educational Psychology Review*, *18*(2), 119-139.

Gray, E. M., & Tall, D. O. (1994). Duality, ambiguity and flexibility: A proceptual view of simple arithmetic. *Journal for Research in Mathematics Education, 25*(2), 115-141.

Gray, E. M., & Tall, D. O. (2001). Relationships between embodied objects and symbolic procepts: An explanatory theory of success and failure in mathematics, *Proceedings of the 25th Conference of PME* 3, 65-72. Utrecht, The Netherlands.

Grosse, C. S., & Renkl, A. (2007). Finding and fixing errors in worked examples: Can this foster learning outcomes? *Learning & Instruction, 17*(6), 617-634.

Groth, R. E. (2013). *Teaching mathematics in grades 6-12: Developing research-based instructional practices.* Thousand Oaks, CA: Sage.

Gutmann, T. (2009). Beginning graduate student teaching assistants talk about mathematics and who can learn mathematics. In L. Border (Ed.), *Studies in graduate and professional student development: Research on graduate students as teachers of undergraduate mathematics* (Vol. 12, pp. 85-96). Stillwater, OK: New Forums Press.

Hastings, N. B., Gordon, F. S., Gordon, S. P., & Narayan, J. (Eds.). (2006). *A fresh start for collegiate mathematics: Rethinking the courses below calculus* (MAA Notes 69). Washington, DC: Mathematical Association of America.

Hatfield, M. M., & Bitter, G. G. (1994). A multimedia approach to the professional development of teachers: A virtual classroom. . In D. B. Aichele (Ed.), *NCTM yearbook: Professional development for teachers of mathematics* (pp. 102-115). Reston, VA: National Council of Teachers of Mathematics.

Hauk, S., Mendoza-Spencer, B., & Toney, A. F. (2009). Teaching this beautiful math. In M. Zandieh (Ed.), *Proceedings of the 12th conference on research in undergraduate mathematics education.* Retrieved from http://sigmaa.maa.org/rume/crume2009/Hauk_SHORT.pdf

Hauk, S., Speer, N. M., Kung, D., & Tsay, J.-J., (2011). *Video cases for development of novice college mathematics instructors*. Retrieved from http://opeweb.ed.gov/fipse/grantshow.cfm?grantNumber=P116B060180

Hauk, S., Speer, N. M., Kung, D. T., & Tsay, J-J. (2010). "Working group report: Video cases for novice college mathematics instructor professional development." Marriott Raleigh City Center, Raleigh, NC. 25 February 2010. Working Group Presentation

Hauk, S., Speer, N. M., Kung, D. T., Tsay, J-J., & Hsu, E. (2011). *Selected field-test materials for case facilitators. Video cases for college mathematics instruction.* Retreived from http://collegemathvideocases.org/cases/index.php

Hauk, S., Speer, N., Kung, D. T., Tsay, J-J., Hsu, E., & Segalla, A. (in press). *Video Cases for College Mathematics Instruction*. Public release of Version 1.5 in Fall 2012 through web portal (currently under development at http://collegemath videocases.org/cases/index.php).

Hauk, S., Toney, A., Jackson, B., Nair, R., & Tsay, J.-J. (2013). Illustrating a theory of pedagogical content knowledge for secondary and post-secondary mathematics instruction. In S. Brown (Ed.), *Proceedings of the 16th Conference on Research in Undergraduate Mathematics Education* (Vol. 1, p. 308). Denver, CO.

Herriott, S. R., & Dunbar, S. R. (2009). Who takes college algebra? *PRIMUS, 19*, 74-87.

Herzig, A. (2002). Where have all the students gone? Participation of doctoral students in authentic mathematical activity as a necessary condition for persistence toward the Ph.D. *Educational Studies in Mathematics, 50,* 177-212.

Herzig, A. (2004). Becoming mathematicians: Women and students of color choosing and leaving doctoral mathematics. *Review of Educational Research, 74,* 171-214.

Hinds, M. D. (2002). *Teaching as a clinical profession: A new challenge for education.* New York, NY: Carnegie Corporation.

Holton, D. (Ed.). (2001). *The teaching and learning of mathematics at university level: An ICMI study* (Vol. 7). Boston, MA: Springer Science & Business Media.

Holton, D., Artigue, M., Kirchgraeber, U., Hillel, J., Niss, M., & Schoenfeld, A. H. (Eds.). (2001). *The teaching and learning of mathematics at university level: An ICMI study*. Boston, MA: Kluwer.

Huck, S. W. (2008). *Reading Statistics and Research* (5th ed.). Boston, MA: Pearson.

Hufferd-Ackles, K., Fuson, K., & Sherin, M. (2004). Describing levels and components of a math-talk learning community. *Journal for Research in Mathematics Education, 35*(2), 81-116.

IBM Corp. (2013). *IBM SPSS Statistics for Windows, Version 22.0*. Armonk, NY: IBM Corp.

Ingram, J., & Elliott, V. (2014). Turn taking and “wait time” in classroom interactions. *Journal of Pragmatics, 62,* 1-12.

Kazemi, E., & Franke, M. L. (2003). Using student work to support professional development in elementary mathematics. *Center for Study of Teaching and Policy: University of Washington*. Retrieved from https://depts.washington.edu/ctpmail/PDFs/Math-EKMLF-04-2003.pdf

Kilpatrick, J., Martin, W. G., & Schifter, D. (Eds.). (2003). *A research companion to principles and standards for school mathematics*. Reston, VA: National Council of Teachers of English.

Kung, D. T. (2010). Teaching assistants learning how students think. In F. Hitt, D. Holton, & P. Thompson (Eds.), *Research in collegiate mathematics education VII* (pp. 143-169). Providence, RI: American Mathematical Society.

Kung, D., & Speer, N. (2009). Teaching assistants learning to teach: Recasting early teaching experiences as rich learning opportunities, *Studies in Graduate and Professional Student Development, 12*, 133-152.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing.

Lester, F. K., & National Council of Teachers of Mathematics. (2007). *Second handbook of research on mathematics teaching and learning: A project of the national council of teachers of mathematics*. Charlotte, NC: Information Age Pub.

Lincoln, Y. S., & Guba, E. G. (2000). Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 163-188). Thousand Oaks, CA: Sage.

Lutzer, D. J., Rodi, S. B., Kirkman, E. E., & Maxwell, J. W. (2007). *Statistical abstract of undergraduate programs in the mathematical sciences in the United States: Fall 2005 CBMS Survey.* Providence, RI: American Mathematical Society.

Mason, J. (2010). Mathematics education: Theories, practice, and memories over fifty years. *For the Learning of Mathematics,* 3-9.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom.* Cambridge, MA: Harvard University Press.

Merriam, S. B. (1998). *Qualitative research and case study applications in education. Revised and expanded from "case study research in education.."* San Francisco, CA: Jossey-Bass Publishers.

Merseth, K. K., & Lacey, C. A. (1993). Weaving stronger fabric: The pedagogical promise of hypermedia and case methods in teacher education. *Teaching and teacher education*, *9*(3), 283-299.

Miller, R. L., Santana-Vega, E., & Terrell, M. S. (2006). Can good questions and peer discussion improve calculus instruction? *Problems, Resources, and Issues in Mathematics Undergraduate Studies*, *16*(3), 193-203.

Nassaji, H., & Wells, G. (2000). What's the use of 'triadic dialogue'? An investigation of teacher-student interaction. *Applied Linguistics*, *21*(3), 376-406.

National Board for Professional Teaching Standards. (2013, March 15). *National board standards*. Retrieved from www.nbts.org/national-board-standards.

National Center for Education Statistics. (2000). *Profile of undergraduates*. Washington, DC: Author.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core standards mathematics.* Washington, DC: Author.

Nickerson, S., & Bowers, J. (2008). Examining interaction patterns in college-level mathematics classes: A case study. In M. Carlson & C. Rasmussen (Eds.), *Making the connection: Research and practice in undergraduate mathematics education* (pp. 179-190). Washington, DC: Mathematical Association of America.

No Child Left Behind Act of 2001: Qualifications for Teachers and Professionals, 20. U.S.C., § 6319 (2008).

Parker, F., Bartell, T. G., & Novak, J. D. (2014). *Developing culturally responsive mathematics teachers: Secondary teachers' evolving conceptions of knowing students.* Manuscript submitted for publication.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage.

Pellegrino, J. W., Chudowsky, N., & Glaser, R. (Eds.). (2001). *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academy Press.

Persellin, D., & Goodrick, T. (2012). Faculty development in higher education: Long-term impact of a summer teaching and learning workshop. *Journal of the Scholarship of Teaching and Learning*, *10*(1), 1-13.

Peterson, P., Fennema, E., & Carpenter, T., (1989). Using knowledge of how students think about mathematics. *Educational Leadership, 46*(4), 42-47.

President's Council of Advisors on Science and Technology (PCAST). (2012), *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Retrieved from http://www.whitehouse.gov/ sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25- 12.pdf.

Reys, R., (2013). Getting evidence-based teaching practices into mathematics departments. *Notices of the AMS*, *60*(7), 906-910

Rittle-Johnson, B. (2006). Promoting transfer: Effects of self-explanation and direct instruction. *Child Development*, *77*(1), 1-29.

Roach, K., Roberson, L., Tsay, J.-J., & Hauk, S. (2010). Mathematics graduate teaching assistants' question strategies. In S. Brown (Ed.), *Proceedings of the 13th conference on Research in Undergraduate Mathematics Education*. Retrieved from http://sigmaa.maa.org/rume/crume2010/Archive/Roach.pdf

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research, 66*, 181-221.

Rowe, M. B. (1986). Wait time: slowing down may be a way of speeding up! *Journal of teacher education*, *37*(1), 43-50.

Ryve, A. (2011). Discourse research in mathematics education: A critical evaluation of 108 journal articles. *Journal for Research in Mathematics Education*, *42*(2), 167-199.

Saha, P. K. (1984). Bengali. In W. S. Chisholm, L. T. Milic, & J. A. C. Greppin (Eds.) ,*Interrogativity: A colloquium on the grammar, typology, and pragmatics of questions in seven diverse languages* (pp. 111-143). Philadelphia, PA: Benjamins.

Saldanha, L., & Thompson, P. W. (1998). Re-thinking co-variation from a quantitative perspective: Simultaneous continuous variation. In S. B. Berensah & W. N. Coulombe (Eds.), *Proceedings of the annual meeting of the psychology of mathematics education-North America.* Retrieved from http://pat-thompson.net/PDFversions/1998SimulConVar.pdf

Saxe, G., Gearhart, M., & Nasir, N. (2001). Enhancing students' understanding of mathematics: A study of three contrasting approaches to professional support. *Journal of Mathematics Teacher Education*, *4*(1), 55-79.

Schifter, D., & Fosnot, C. T. (1993). *Reconstructing mathematics education: Stories of teachers meeting the challenge of reform*. New York, NY: Teachers College Press.

Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 1-27). Orlando, FL: Academic Press.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Bulletin, 84*(1), 1-66.

Schoenfeld, A. H. (1998). Reflections on a course in mathematical problem solving. In J. Kaput, A. H. Schoenfeld, & E. Dubinsky (Eds.), *Research in collegiate mathematics education III* (pp. 81-113). Providence, RI: American Mathematical Society.

Seago, N., Mumme, J., & Branca, N. (2004). *Learning and teaching linear functions: Video cases for mathematics professional development, [grades] 6-10.* Portsmouth, NH: Heinemann.

Seymour, E., Melton, G., Wiese, D. J., & Pedersen-Gallegos, L. (2005). *Partners in innovation: Teaching assistants in college science courses.* Boulder, CO: Rowman & Littlefield.

Sherin. M. (2007). New perspectives on the role of video in teacher education. In J. Brophy (Ed.), *Advances in research on teaching: Vol. 10. Using video in teacher education* (pp. 1-27). Boston, MA: Elsevier.

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

Schunk, D. (2004). *Learning theories: An educational perspective* (4th ed.). Columbus, OH: Pearson.

Siegler, R. S., & Chen, Z. (2008). Differentiation and integration: Guiding principles for analyzing cognitive change. *Developmental Science, 11*(4), 433-448.

Simon, M. A., & Tzur, R. (2004). Explicating the role of mathematical tasks in conceptual learning: An elaboration of the hypothetical learning trajectory. *Mathematical Thinking and Learning*, *6*(2), 91-104.

Skovsmose, O. (2014). Dialogic teaching and learning in mathematics education. In *Encyclopedia of Mathematics Education* (pp. 152-153). Netherlands: Springer.

Sofronas, K. S., & DeFranco, T. C. (2008). An examination of the knowledge base for teaching among mathematics faculty teaching calculus in higher education. In F. Hitt, D. Holton, & P. Thompson (Eds.), *Research in collegiate mathematics education VII* (pp. 147-179). Providence, RI: American Mathematical Society.

Sorto, M., Mccabe, T., Warshauer, M., & Warshauer, H. (2009). Understanding the value of a question: An analysis of a lesson. *Journal of Mathematical Sciences and Mathematics Education*, *4*(1), 50-60.

Smith, M. S., Hughes, E. K., Engle, R. A., & Stein, M. K. (2009). Orchestrating discussions. *Mathematics Teaching in the Middle School*, *14*(9), 549-556.

Speer, N. (2001). Connecting beliefs and teaching practices: A study of teaching assistants in reform-oriented calculus courses. (Doctoral Dissertation: University of California, Berkeley, 2001).

Speer, N. M., & Hald, O. (2008). How do mathematicians learn to teach? Implications from research on teachers and teaching for graduate student professional development. In M. Carlson & C. Rasmussen (Eds.), *Making the connection: Research and practice in undergraduate mathematics education* (pp. 303-317). Washington, DC: Mathematical Association of America.

Speer, N. M., & King, K. (2009). Examining mathematical knowledge for teaching in secondary and post-secondary contexts. In S. Brown (Ed.). *Proceedings of the annual meeting of the special interest group of the Mathematical Association of America on research in undergraduate mathematics education (SIGMAA on RUME),* San Diego, CA.

Speer, N., Murphy, T., & Gutmann, T. (2009). Educational research on mathematics graduate student teaching assistants: A decade of substantial progress. *Studies in Graduate and Professional Student Development*, *12*, 1-10.

Speer, N. M., Smith, J. P., III, & Horvath, A. (2010). Collegiate mathematics teaching: An unexamined practice. *The Journal of Mathematical Behavior*, *29*(2), 99-114.

Speer, N. M., & Wagner, J. F. (2009). Knowledge needed by a teacher to provide analytic scaffolding during undergraduate mathematics classroom discussions. *Journal for Research in Mathematics Education,* 530-562.

Stein, M. K., & Smith, M. (1998). Mathematical tasks as a framework for reflection: From research to practice. *Mathematics Teaching in the Middle School, 3,* 268-275.

Stein, M. K., Smith, M. S., Henningsen, M., & Silver, E. A. (2000). *Implementing standards based mathematics instruction: A casebook for professional development.* New York, NY: Teachers College Press.

Stigler, J. W., & Hiebert, J. (2004). Improving mathematics teaching. *Educational Leadership*, *61*(5), 12-17.

Stigler, J. W., & Stevenson, H. W. (1992). *The learning gap: Why our schools are failing and what we can learn from Japanese and Chinese education.* New York, NY: Summit Books.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Procedures and techniques for developing grounded theory.* Thousand Oaks, CA: Sage

Tabachnick, B. G., & Fidell, L. S. (2013). *Using Multivariate Statistics* (6th ed.): Boston, MA: Allyn and Bacon.

Tall, D. O., & Vinner S. (1981). Concept image and concept definition in mathematics, with special reference to limits and continuity. *Educational Studies in Mathematics, 12* 151-169.

Truxaw, M. P., & Defranco, T. C. (2008). Mapping mathematics classroom discourse and its implications for models of teaching. *Journal for Research in Mathematics Education*, *39*(5), 489-525.

Tsay, J. J., Judd, A. B., Hauk, S., & Davis, M. K. (2011). Case study of a college mathematics instructor: patterns of classroom discourse. *Educational Studies in Mathematics*, *78*(2), 205-229.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education*, *24*, 244-276.

van Zee, E., & Minstrell, J. (1997). Using questioning to guide student thinking. *The Journal of the Learning Sciences, 6*(2), 227-269.

Weber, E. G. (1993). *Varieties of questions in English conversation* (Vol. 3). Philadelphia, PA: John Benjamins Publishing.

Wells, G. (1993). Reevaluating the IRF sequence: A proposal for the articulation of theories of activity and discourse for the analysis of teaching and learning in the classroom. *Linguistics in Education, 5*(1), 1-37.

Wertsch, J. V. (1998). *Mind as action*. New York, NY: Oxford University Press.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of research in education, Vol. 24* (pp. 173-210). Washington, DC: American Educational Research Association.

Wilson, M., & Bertenthal, M. (2005). Systems for state science assessment. Board on Testing and Assessment, Center for Education, National Research Council of the National Academies. Washington, DC: National Academies Press.

Wisher, R. A., & Graesser, A. C. (2007). Question asking in advanced distributed learning environments. In S. M. Fiore & E. Salas (Eds.), *Toward a science of distributed learning and training* (pp. 209-234). Washington, DC: American Psychological Association.

Wood, T. (1994). Patterns of interaction and the culture of mathematics classrooms. In S. Lerman (Ed.), *The culture of the mathematics classroom* (pp. 149-168). Dordrecht, The Netherlands: Kluwer.

APPENDIX A

LETTER OF COMMITMENT FROM COURSE COORDINATOR

Department of Mathematics

December 5, 2012

Kitty Roach
School of Mathematical Sciences
University of Northern Colorado

Greeley, CO 80639

Dear Kitty,

Thank you for inviting me to be a part of the proposed research project on college mathematics instructor professional development. I think this is an important and valuable area of work in postsecondary education that will have a significant impact on undergraduate student mathematical learning.

I am the course coordinator for Math, Calculus for Biological Scientists, with a Ph.D. in Mathematics. I have been the course coordinator for Math since Fall 2009. In the 2010-2011 academic year, I was supported by a grant from The Institute for Learning and Teaching at University to redesign this course by incorporation modules that link mathematics and biology. As director of The Laboratory for Mathematics in the Sciences at , I am currently involved in developing other applied mathematics courses and outreach programs to K-12 schools as well as training graduate students to teach such courses.

I commit to working with you to offer video case based professional development to mathematics instructors at during course coordination. I understand that at least 3 and as many as 5 video cases will be offered and may be central to as many as 6 meetings of the group.

Again, thank you for the invitation. I look forward to working with you.

Sincerely,

Assistant Professor
Department of Mathematics

APPENDIX B

WEEKLY INSTRUCTOR ONLINE LOG

WEEKLY INSTRUCTOR ONLINE LOG

The following logs are should be completed each week. The questions ask about how you might be incorporating ideas from course coordination, specifically coordination that includes video vignettes.

1. How I used ideas from course coordination this week (Check all that apply)

[_] individually with a student
[_] in the classroom
[_] with a group of students
[_] with 1 or more colleagues
[_] Does not apply

1a) Briefly describe the idea used and how it was used (if none used, please enter N/A):
[TEXT BOX – REQUIRED]

1b) How do you think your use of this idea influenced student learning? (if none used, please enter N/A)
[TEXT BOX – REQUIRED]

2. My use of the ideas presented in course coordination has helped increase student confidence in math.

[_] Never [_] Rarely [_] Sometimes [_] Often

3. In my use of the ideas presented in course coordination I have seen students gain deeper mathematical knowledge.

[_] Never [_] Rarely [_] Sometimes [_] Often

4. Use of the ideas presented in course coordination has helped increase student interest in math.

[_] Never [_] Rarely [_] Sometimes [_] Often

5. Please estimate how much time, outside of coordination, you spent this week:

a. talking with other people about teaching, [Drop down menu of time intervals]
b. grading student work, [Drop down menu of time intervals]
c. preparing materials for student use (e.g., worksheets, quizzes, etc.) and/or planning for class, [Drop down menu of time intervals]
d. other teaching related activities (please describe briefly), if none used, please enter N/A).

[TEXT BOX – REQUIRED]

6. Comments about your teaching this week that you'd like to share? Please use the textbox below. If none, enter N/A.

[TEXT BOX – Required]

Note that we review these entries weekly. Please email kitty.roach@unco.edu for a timely response to any question or concern. Remember to click "submit" below.

APPENDIX C

INTERVIEW PROTOCOLS

INTERVIEW PROTOCOLS

Interview 1 (Intake Interview)

To be conducted prior to the instructor viewing any of the video case materials. These are semi-structured interviews (Patton, 2002). The interviews will have these basic questions with possible follow-up questions.

Introduce myself: I am Kitty Roach and I am a graduate student at UNC (University of Northern Colorado). I am working on my Ph.D. in Mathematics Education. I really appreciate you helping me with my research.

Question 1: Could you tell me a little bit about your background? For example, what degree(s) do you have? Have you ever taught before? If so, what classes, and how many classes?

Question 2: What degree are you working on here at BRU? What are your plans after you get your degree? {Or if speaking with an adjunct: How did you come to be at BRU? What are your plans for the future, both short term and long term?} What are your long-term plans? In other words, where do you ultimately see yourself, say in 10-15 years?

Question 3: How do you think students learn? How do you know learning when you see it?

Question 4: What teaching strategies do you plan on using this semester? Why those strategies?

Question 5: Do you have any questions for me?

End the interview by thanking the participant. Explain that I will be coming to their class within the next week to video their class. I will also see them in Coordination. If you have any other questions or concerns, please don’t hesitate to email me. Thank you!

Interview 2

To be conducted after at least 2 of the video case materials have been shown at coordination.

Begin by saying thank you for allowing me to interview you a second time. In this interview we will be looking at short clips of your teaching. I would like you to focus on the questions that you ask. We will look at (1 to 3) video clips. Are you ready?

Question 1: [Show the video clip and remind them to focus on the questions that they ask] Do you remember this day? Here is a transcript of the clip I just showed you. So what questions did you see yourself ask during the video clip. Please mark them on the

transcript. [Depending on the questions asked by the instructors in the video clips viewed, I will ask follow-up questions. Examples are given below.]

Follow- up questions:

- What question(s) did you ask? Please mark them on the transcript.
- Why did you ask that question? (If coordination is mentioned, probe how coordination may have influenced the questions asked.)
- How did you expect the students to respond?
- Did the students respond the way you expected? If yes, how did they respond? If no, what was different about their response?
- Do you think you accomplished your goal by asking that question? Why or why not?

Final Question: Do you have any questions for me?

Thank you for letting me interview you. We have just one more interview left at the end of the semester. Let me know if you need anything.

Interview 3 (Final Interview)

To be done in the last two weeks of the semester.
The final interview will be based on classroom observations and responses to weekly logs. This interview may includes follow-up questions to weekly log responses and may also include video clips from the instructors' classes as in interview 2.

Example questions may be:

1. I noticed in the weekly logs you mentioned that you used [an idea that they used]. Could you expand on that idea and how you used it? What was the goal of using that idea? Did you achieve your goal? How? Or why not?
2. Would you use this idea again? Why or why not?
3. Have you noticed a change in your teaching over the course of this semester? Could you describe that change?
4. [To be asked after viewing a video clip of the instructor's teaching, as in Interview 2.] Why did you ask this question? How did you expect the students to respond? Did they respond the way you expected? If yes, how did they respond? If no, what was different about their response? Do you think you accomplished your goal by asking the question? Why or Why not?

APPENDIX D

CONSENT FORMS FOR HUMAN PARTICIPANTS IN RESEARCH

CONSENT FORM FOR INSTRUCTOR PARTICIPANTS

Project Title: A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions

Lead Researcher: Kitty L. Roach, Graduate Research Assistant, kitty.roach@unco.edu
Research Advisor: Robert A. Powers, Ed.D., Associate Professor, School of Mathematical Sciences, (970) 351-1157

I am requesting your permission to audio and video record your classroom practice. The audio/video I will be collecting will be used to examine classroom discourse surrounding questions. Unless additional liability release is completed, any audio or video data records will be destroyed no later than five years after the end of completing my dissertation. Please contact *Kitty Roach* at the email address given above if you have any questions or concerns about this research.

Thank you for assisting us with the project. Prior to the observations, I will contact you to schedule a time to be observed. While being observed in your teaching, you may be asked to carry a digital recorder. I may also be in the room to take field notes. Information collected during your educational practice may involve a few minutes before class setting up the recorder, but observations will not take any more of your time than teaching your course. No names will be used in the reporting of the data. Each person will be identified by a pseudonym. Student work and classroom video may be used for reporting purposes only. By signing below, you agree to the confidential gathering of audio and video data for research.

The risks and discomforts inherent in this study are no greater than those typically encountered during regular class participation, regular classroom teaching, and regular coordination meetings. As with any learning opportunity instructors may experience some discomfort as they encounter their own ignorance in discussing teaching.

It is possible that both the students and instructors could benefit by participating. The instructors will be paid $100 for full participation. The instructors could benefit by gaining knowledge of student thinking. This could result in more productive classroom interactions and better performance, by the students, on midterm and final exams.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form

will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

Sincerely,

Researcher’s Signature — Date

Participant’s Full Name (please print) — Participant’s Signature

CONSENT FORM FOR STUDENT PARTICIPANTS

Project Title:	A Study of Novice Instructors' Questioning Techniques and Classroom Discourse Surrounding Those Questions
Lead Researcher:	Kitty L. Roach, Graduate Research Assistant, kitty.roach@unco.edu
Research Advisor:	Robert A. Powers, Ed.D., Associate Professor, School of Mathematical Sciences, (970) 351-1157

Your instructor has agreed to participate in my research study and I am requesting your permission to audio and video record your classroom. The audio/video I will be collecting will be used to examine classroom discourse surrounding questions. Unless additional liability release is completed, any audio or video data records will be destroyed no later than five years after the end of completing my dissertation. Please contact *Kitty Roach* at the email address given above if you have any questions or concerns about this research. Thank you for assisting us with the project. While audio/video recording your class, I may also be in the room to take field notes. No names will be used in the reporting of the data. Each person will be identified by a pseudonym. Student work and classroom video may be used for reporting purposes only. By signing below, you agree to the confidential gathering of audio and video data for research.

Participation will not take any more of your time than attending class. After the first few minutes, you probably won't even notice the video recording. If you are okay with the video recording but want to stay out of frame, feel free to move to the seats indicated as being out of view. By signing below, you agree to be video-recorded for the purpose of research. Thank you, in advance, for your help.

The risks and discomforts inherent in this study are no greater than those typically encountered during regular class participation. It is possible that both the students and instructors could benefit by participating. The instructors could benefit by gaining knowledge of student thinking. This could result in more productive classroom interactions and better performance, by students, on midterm and final exams.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your

selection or treatment as a research participant, please contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

Sincerely,

Researcher's Signature	Date
Participant's Full Name (please print)	Participant's Signature

APPENDIX E

RESEARCHER CLASSROOM OBSERVATION PROTOCOL

RESEARCHER CLASSROOM OBSERVATION PROTOCOL

The following is an example excel worksheet that the researcher will use for classroom observations. The researcher will focus on questions asked by the instructor during class. The questions in class will be transcribed in the “Question” column. The context of the question will be briefly described in the “Context” column. A code will then be assigned to each question based on the perceived intent of the instructor. This form was created by Roach et al., 2010.

Time	Question	Comp check			invest thinking			elicit thinking			Class manage ment			no code	Context	Memo
		I	G	C	I	G	C	I	G	C	I	G	C			
11:54	So how did you figure out this one?	2													student asked a question about how to work a problem the worksheet.	
12:01	So How did you use the power rule? How did that help you?								2							as she asks the question she scans the group, however only appears to be getting response from an individual
12:35	What's the derivative of 5x?		1													group begins to respond
12:46	log of what?								2						responding to the girl suggesting that they take a log	
16:02	So take the derivative, does it work?		2												The instructor is asking the students if the derivative of the their "antiderivative" works.	
16:32	Can you come with an even more general way of writing it?		3												Student found the correct antideriviative and the instructor seemed to be trying to get the student to generalize his method	
25:08	So how do we know that that's right or not?						3									brief pause

APPENDIX F

INSTITUTIONAL REVIEW BOARD APPROVA

UNIVERSITY *of*
NORTHERN COLORADO

Institutional Review Board

DATE:	August 28, 2013
TO:	Kitty Roach, B.S., M.S.
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[411855-2] Questions and College Calculus Classroom Discourse
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	August 27, 2013
EXPIRATION DATE:	August 27, 2014
REVIEW TYPE:	Expedited Review

Thank you for your submission of Amendment/Modification materials for this project. The University of Northern Colorado (UNCO) IRB has APPROVED your submission. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on applicable federal regulations.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require that each participant receives a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of August 27, 2014.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Northern Colorado (UNCO) IRB's records.

APPENDIX G

TOTAL QUESTION COUNTS PER INSTRUCTOR

TOTAL QUESTION COUNTS PER INSTRUCTOR

Summary of coding for observations of Nick

			Nick			
Focus	**Code**	**Depth**	1	4	5	6
Question	**ClassMgmt**	0	7	5	6	14
	CompCheck	0	22	16	24	27
		1	3	7	7	9
		2	0	0	0	0
		3	0	0	0	0
	ContentChk	0	0	6	5	1
		1	0	1	0	0
		2	0	3	0	0
		3	0	0	0	0
	ElicitThinking	0	0	0	0	2
		1	2	14	5	0
		2	5	1	5	1
		3	0	0	0	0
	Hypophora	0	9	1	3	4
	ProbeThinking	0	0	0	0	0
		1	0	0	0	0
		2	0	2	0	0
		3	0	0	0	0
Neighborhood	**DayTopic**		0	4	0	2
	LargerTopic		0	0	0	0
	NextStep		12	23	34	28
	NoMath		4	3	6	13
	Problem		32	26	15	15
Grand Total			48	56	55	58

Summary of coding for observations of Disha

			Disha			
Focus	**Code**	**Depth**	1	2	5	6
Question	**ClassMgmt**	0	0	18	2	6
	CompCheck	0	58	74	100	62
		1	9	28	15	24
		2	0	10	2	0
		3	0	0	0	0
	ContentChk	0	3	0	2	7
		1	0	0	2	0
		2	0	0	0	0
		3	0	0	0	0
	ElicitThinking	0	1	0	0	0
		1	1	1	5	0
		2	3	1	6	0
		3	0	0	0	0
	Hypophora	0	25	17	18	12
	ProbeThinking	0	0	0	0	0
		1	0	0	1	0
		2	0	0	1	0
		3	0	0	0	0
Neighborhood	**DayTopic**		6	2	2	3
	LargerTopic		0	0	0	0
	NextStep		58	76	86	52
	NoMath		2	11	1	6
	Problem		34	60	65	50
Grand Total			100	149	154	111

Summary of coding for observations of Omar

			Omar			
Focus	**Code**	**Depth**	1	2	5	6
Question	**ClassMgmt**	0	0	0	1	0
	CompCheck	0	26	19	16	25
		1	16	68	48	21
		2	2	1	1	2
		3	0	0	0	0
	ContentChk	0	2	0	6	4
		1	0	0	3	1
		2	0	0	0	0
		3	0	0	0	0
	ElicitThinking	0	1	0	0	0
		1	8	3	6	0
		2	2	0	1	3
		3	0	0	0	0
	Hypophora	0	6	5	6	7
	ProbeThinking	0	0	0	0	0
		1	0	0	0	0
		2	0	1	0	4
		3	0	0	0	0
Neighborhood	**DayTopic**		0	7	3	3
	LargerTopic		0	0	0	0
	NextStep		33	23	33	25
	NoMath		0	0	1	0
	Problem		30	67	51	39
Grand Total			63	97	88	67

Summary of coding for observations of Pramod

			Pramod			
Focus	**Code**	**Depth**	1	2	5	6
Question	**ClassMgmt**	0	9	0	1	8
	CompCheck	0	41	13	10	17
		1	11	13	9	12
		2	4	1	0	1
		3	0	0	0	0
	ContentChk	0	0	0	2	0
		1	0	0	0	0
		2	0	0	0	0
		3	0	0	0	0
	ElicitThinking	0	1	0	0	0
		1	4	0	1	4
		2	8	0	7	1
		3	0	0	0	0
	Hypophora	0	4	0	2	1
	ProbeThinking	0	0	0	0	0
		1	0	0	0	0
		2	0	0	0	0
		3	0	0	0	0
Neighborhood	**DayTopic**		6	7	0	1
	LargerTopic		0	0	0	0
	NextStep		28	4	9	19
	NoMath		9	0	1	8
	Problem		39	16	22	16
Grand Total			82	27	32	44

Summary of coding for observations of Evelyn.

			Evelyn			
Focus	**Code**	**Depth**	1	3	5	6
Question	**ClassMgmt**	0	1	9	6	2
	CompCheck	0	19	29	31	17
		1	11	19	26	6
		2	0	1	0	0
		3	0	0	0	0
	ContentChk	0	2	6	9	1
		1	0	1	0	0
		2	0	1	0	0
		3	0	0	0	0
	ElicitThinking	0	0	0	0	0
		1	0	1	0	1
		2	0	1	0	0
		3	0	0	0	0
	Hypophora	0	9	4	3	2
	ProbeThinking	0	0	0	0	0
		1	0	0	0	0
		2	0	0	0	0
		3	0	0	0	0
Neighborhood	**DayTopic**		2	12	3	4
	LargerTopic		0	0	0	0
	NextStep		24	21	32	2
	NoMath		0	10	6	2
	Problem		16	29	34	21
Grand Total			42	72	75	29