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A QUALITATIVE STUDY OF SECONDARY MATHEMATICS TEACHERS' QUESTIONING, RESPONSES, AND PERCEIVED INFLUENCES

by

Melissa Joan McAninch

A thesis submitted in partial fulfillment of the requirements
for Doctor of Philosophy degree in Teaching and Learning
(Mathematics Education) in the Graduate College of the
University of Iowa

May 2015

Thesis Supervisors: Assistant Professor Kyong Mi Choi
Associate Professor Soonhye Park

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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Melissa Joan McAninch

has been approved by the examining committee for the thesis requirement for the Doctor of Philosophy degree in Teaching and Learning (Mathematics Education) at the May 2015 graduation.

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ABSTRACT

The purpose of this study was to examine secondary mathematics teachers' questioning, responses, and perceived influences upon their instructional decisions regarding questioning and response to students' ideas. This study also compared the questioning practices, responses, and influences of beginning teachers to more experienced teachers. Previous studies on teacher quality in mathematics education have focused on general characteristics of mathematics teachers' instructional practice including a broad range of instructional strategies. Little is known about mathematics teachers' questioning practices and responses to students' ideas that research has repeatedly reported are critical to student mathematics learning in secondary classrooms. Furthermore, it is not clear how different novice teachers are in questioning and responding to students from experienced teachers. This understanding can provide insights into teacher education programs for mathematics teachers. With those issues in mind, this study was designed to examine the following questions: (1) What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion? (2) What similarities and differences exist in responses to students during pivotal teaching moments between novice and experienced teachers when guiding a classroom mathematical discussion? (3) What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers?

This study employed a multiple case study research design to compare the questioning practices and responses of three beginning teachers and three experienced teachers. Multiple sources of data were collected, including two interviews (i.e., initial interview and follow-up interview) for each teacher, five days of classroom video footage for each teacher, and field

notes by the researcher for each interview and observation. The researcher conducted initial interviews with each teacher to gain a general sense of the teacher's philosophy and use of questions in guiding classroom discussion. Five instructional days of observation followed the initial interview, and then the researcher conducted a follow-up interview by use of video-stimulated response. All interviews were transcribed verbatim for analysis. The data was analyzed mainly using the constant comparative method to identify regularities and patterns emerging from the data. Results showed differences among the beginning and experienced teacher participants in the frequency and variety of questions asked. Although all six teachers used the largest number of questions in the Socratic questioning category, differences were more prominent in the semantic tapestry and framing categories. Results regarding teacher responses to pivotal teaching moments showed that four teachers favored a procedural emphasis in their responses to students, and two teachers used responses to direct students to make clear connections within or outside of mathematics. Perceived influences identified for these teachers include: (1) reflection on experience and mathematical knowledge for teaching, (2) time, and (3) relationship with students, teachers, and parents, and knowledge of student background.

The results found through this qualitative study suggest benefits for practicing teachers to expand the types of questions they use in the classroom, making particular efforts to include those areas that teachers from this study showed to be most lacking: semantic tapestry questions that help students build a coherent mental framework related to a mathematical concept, and framing questions that help frame a problem and structure the discussion that follows. The comparison between beginning and experienced teachers also shed light on important practices for teacher education. The beginning teacher participants from this study had no trouble noticing pivotal teaching moments in their lessons but were less developed in their responses to them.

These findings are suggestive, but not generalizable to all secondary mathematics teachers. Future quantitative studies could take some of these limited findings to a broader sample of teachers and test for statistical significance. For example, a larger quantitative study could be designed to categorize the types of questions asked by a larger sample of teachers and compare the variety of question asking to student achievement results from state assessment data. This comparison could produce more generalizable results in terms of teacher effectiveness in questioning for student learning.

PUBLIC ABSTRACT

The purpose of this study was to describe the types of questions secondary mathematics teachers' asked and what they perceived as influences for their decision making in responses to students. This study compared the questioning practices and influences of beginning teachers to more experienced teachers and explored the following questions: (1) What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion? (2) What similarities and differences exist in responses to students during pivotal teaching moments between novice and experienced teachers when guiding a classroom mathematical discussion? (3) What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers?

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Results showed differences between the beginning and experienced teachers in the frequency and variety of questions asked, with the most prominent differences in the semantic tapestry and framing categories. Four teachers favored a procedural emphasis in their responses to students, and two teachers used responses to direct students to make clear connections within or outside of mathematics. Perceived influences identified include: (1) reflection on experience and mathematical knowledge for teaching, (2) time, and (3) relationship with students, teachers, and parents, and knowledge of student background.

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CHAPTER ONE

INTRODUCTION

Researchers have been making efforts for years with describing qualities of effective teaching (Borko & Livingston, 1989; Chin, 2007; Hill, Rowan, & Ball, 2005; Hill, Schilling, & Ball, 2004; Leinhardt & Greeno, 1986). The recent adoption of the Common Core State Standards for Mathematics (CCSSM) and design of related assessments, implementation of new Race to the Top (RTTT) legislation that includes a piece for teacher accountability, as well as the growing availability of student achievement data and new methods for analysis have provided motivation and a call for new methods to re-examine this problem (CCSSI, 2012; USDOE, 2013). Goe and Stickler (2008) address the inconsistencies of past research, saying that many past studies showed a difference between teachers in contributions to their students' academic growth, but research has not been able to consistently identify specific teacher qualifications, characteristics, and classroom practices that positively influence student learning, and "unfortunately, this is just the information that educational policymakers need most" (p. 1).

Broad definitions of teacher quality such as definitions focusing on general teacher training factors (e.g., certification and college degrees) or factors related to teacher practice, are partly to blame for the lack of consistent findings in this area (Goe, 2007). Careful research is needed to help better pinpoint indicators of teacher quality (Goe & Stickler, 2008), so that studies can provide important implications, such as being able to identify the knowledge and skills required for pre-service teachers to become successful classroom teachers, recruiting and retaining effective teachers, designing and implementing teacher professional development programs, and designing valid and reliable teacher evaluations (Stronge, Ward, & Grant, 2011). Comparison studies of novice and expert teachers are especially needed to better understand indicators of teacher quality and address the question of whether novice teachers can learn and develop the skills that expert teachers possess through a teacher training program (Hogan, Rabinowitz, & Craven III, 2003).

Teacher questioning, a part of teacher quality related to classroom practice, has received researchers' attention as being a salient difference between teacher-centered and student-centered environments (Almeida & de Souza, 2010; Harris, 2000; Hoffman, Steinberg, & Wolfe, 2012). Teachers go from being a direct lecturer, or giver of information, to more of a facilitator of student learning through discussion (Hoffman et al., 2012). Where discourse in a traditional classroom takes on an initiation-response-feedback (IRF) chain that is framed by the teacher and ends with the teacher evaluating the response and providing affirmation or corrective feedback, an adjustment to the last piece of the sequence could open up the discourse to allow students to become "co-constructors of meaning" (Chin, 2006). Chin outlines a framework for questioning that will provide such productive discussion that is beneficial for use in a student-centered science classroom (Chin, 2006, 2007).

Because a teacher says much less in a student-centered classroom, the content of each teacher's utterance is valuable in framing the discussion. In this age of increasing teacher accountability due to NCLB and RTTT requirements (USDOE, 2013), teachers are under pressure to perform well and need to be able to improvise during any teacher-student interaction (Ruiz-Primo & Furtak, 2007). After hearing a student's response, question, or misconception a teacher must immediately assess student understanding and make a carefully worded response that will help to advance the student toward developing a concept appropriately. A student's question or incorrect response may be enough to trigger an informal assessment episode for the teacher, which prompts a spontaneous response such as a follow-up question, a call for other students to share their views, or an explanation or demonstration (Ruiz-Primo & Furtak, 2007). Additionally, this student's question or incorrect response may disrupt the flow of discussion and give the teacher an opportunity to respond in a way that enhances or extends student thinking (Stockero & Van Zoest, 2013). These instances are referred to as pivotal teaching moments (PTMs), and can be very important opportunities for students to make connections, reflect on current knowledge, and build new understandings. The types of questions a teacher asks and the method for asking them, as well as the pattern of teacher responses to students during classroom discussion and the noticing and appropriate reaction to PTMs will impact the ways students think about and develop concepts (Chin, 2007; Stockero & Van Zoest, 2013). In a student-centered classroom, students play an active role in constructing knowledge of concepts through this classroom discussion, so it is particularly important to examine the types of questioning and responses that prompt students to take a more active cognitive role in helping to develop each concept (Chin, 2007).

The current literature provides information about teacher questioning in science (Chin, 2006, 2007) and examines teacher-student interactions in elementary school mathematics (Hill et al., 2008; Hill et al., 2005), as well as examination of beginning mathematics teacher noticing of PTMs (Stockero & Van Zoest, 2013). Studies have also looked at teacher improvisation and ability to predict misconceptions (Hogan et al., 2003;

Leinhardt & Greeno, 1986). There is a clear need for studies of teacher questioning in mathematics, especially at the secondary level, as well as more specific study of teacher improvisation in terms of spontaneous responses to students during PTMs within a classroom discussion.

Most studies in the areas mentioned in paragraphs above were comparison studies of expert and novice teachers. Comparisons of samples from both teacher populations were important to identify the characteristics that help identify and disseminate exemplary teaching practice (Hogan et al., 2003; Leinhardt & Greeno, 1986). Borko and Livingston (1989) found that the expert teachers they studied possessed a talent for improvisation and could simultaneously improvise and achieve planned learning goals. Hogan and colleagues (2003) showed that expert teachers presented mathematical content more conceptually and better predicted students' attained comprehension and misconceptions.

While many studies have observed differences in instructional practices of expert and novice teachers, few have looked into explanations for why these differences occur. Of the studies that seek to find these explanations, one reason is that expert and novice teachers make different instructional decisions is that expert teachers have more complex knowledge schemata (Jacobs, Lamb, & Philipp, 2010). These schemata for teachers are based on three main components – scripts that give direction for common teaching activities, scenes that represent teachers' knowledge of people and objects in common classroom events, and propositional skills that represent teachers' knowledge of the different parts of the teaching-learning situation such as the nature of students in their classrooms and pedagogical knowledge for how to teach them – which have been developed over years of teaching. Another explanation provided by Hill et al. (2005) relates to their findings that teacher's mathematical knowledge for teaching (MKT) is positively correlated with student achievement. They conclude that teachers with greater MKT are making better instructional decisions than teachers with less MKT.

The qualities of exemplary teaching of mathematics in past studies—related to knowledge schemata and MKT—could be explained by a teacher's finesse with questioning in leading classroom discussion. Chin (2007) found that science teachers who utilized questions from certain categories - Socratic questioning, verbal jigsaw, semantic tapestry, and framing - helped students to work together to construct ideas and climb a "cognitive ladder," where each question the teacher asked served as a rung on the ladder. Hill and colleagues (2008) found that the elementary teachers they studied with greater MKT led mathematical discussions more effectively. Further research is needed to compare the practices of novice and experienced teachers in this area to illuminate more specific qualities of exemplary instruction that lead to effective discussion. In mathematics education few studies have directly analyzed teachers as facilitators of classroom mathematical dialogue at the secondary level other than what was described above (Hill et al., 2008; Stockero & Van Zoest, 2013).

This study uses response patterns of novice and experienced teachers to provide detailed information that will form a foundation for further quantitative study. This information may be helpful in creating teacher observation protocols or survey instruments used in future studies that could identify ways in which other in-service teachers and prospective teachers can improve their skill with leading classroom discussions and ultimately improve student learning. Specifically, the examination of potentially teachable factors of influence for instructional decision-making informs future studies in teacher education that could aid in creating a stronger curriculum for professional development and pre-service mathematics teacher education programs. Teachers less adept at questioning may be taught these factors or be provided with scaffolded practice to enhance their instructional decision making skill to a level on par with more adept teachers.

Purpose of the Study

The purpose for this study is to understand the teachers' patterns of in-class questioning and responses as they facilitate mathematical discussion. In particular, I aim to compare beginning teachers to more experienced teachers with regard to their patterns in questioning and responses. In this study, mathematical discussion is defined as a classroom interaction among the teacher and students, where the teacher guides the direction of the mathematical conversation and facilitates development of a mathematical concept or problem solving procedure. Additionally, I describe teacher-perceived factors of influence for questioning and responses as they facilitated mathematical discussion. My research questions that guided this study were:

1. What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion?
2. What similarities and differences exist in responses to students during pivotal teaching moments between novice and experienced teachers when guiding a classroom mathematical discussion?
3. What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers?

Significance of the Study

Research of teachers' instructional practice in mathematics provides understanding of teacher decision making, examines teacher quality, and disseminates results to the field of teacher education. Past studies in mathematics education have compared novice and experienced teachers with regard to broad definitions of instructional practice and have examined beginning mathematics teacher noticing, but little work has been done with secondary mathematics teachers and none with the intent to use teacher noticing in conjunction with understanding of questioning patterns. Results from each of my research questions will be useful for researchers who do further study to improve questioning in the context of classroom mathematical discussion. These results provide insights into several questions critical to mathematics teacher education: How do novice secondary mathematics teachers exhibit differences in terms of questioning and responses during PTMs than experienced teachers? How can patterns in questioning and response to PTMs inform the creation of a measure for effective instructional practice? Can novice teachers learn and develop the skills that expert teachers possess? If so, what supports do they need? How can teachers' perceived factors of influence for decision making relate to their level of cognitive development? The significance for this study is explained with more detail in the paragraphs to follow, organized according to the three research questions in the previous section.

First, the descriptions of usage of questions from Chin's categories of questioning for each of the sampled teachers can suggest areas where beginning teachers lack. Chin (2007) reports that questions in each of these categories are important for promoting critical thinking among students in various ways. Practitioners could find Chin's (2007) categorical framework useful in structuring lessons and use this study's findings as an example illustration for how these questions are used. Instructional coaches and educators in teacher preparation programs will be able to use Chin's (2007) categories for questioning along with the examples from this study to gain topic ideas for professional development workshop or in pre-service teacher education courses. The areas shown to be deficient by the beginning teacher participants in this study may provide a starting point for comprehensive coverage of questioning in the teacher education. More research can also be conducted for teacher effectiveness as related to student achievement or productive mathematical discourse when using questioning from various categories of Chin's (2007) framework.

Second, this study will provide a better understanding of mathematics teachers' noticing and actions during PTMs. The explanations given by teachers sampled within this study can serve to depict some potential differences between novice and experienced teachers when guiding a mathematical discussion. These differences can illuminate avenues for further research in teacher education to examine pre-service teachers' developing ability to notice and respond to PTMs. It also suggests practical implications for practitioners, instructional coaches, and educators in teacher preparation programs, giving ideas for curriculum design and workshops to enhance the skills of pre-service and in-service teachers.

Third, this study can provide more information about patterns in teachers' perceived influences for decision making regarding questioning. Understanding in particular the similarities and differences between the beginning and experienced teachers will provide avenues for more in-depth research examining teacher education curriculum and teachers' cognitive development. In addition, the stimulated-response interviews used for a data collection tool for this study can also serve as a reflective tool for teachers to examine their instructional practices.

This study can refine mathematics educators' and researchers' broad understanding of instructional quality in mathematics as general characteristics of instructional practice, providing instead a narrower focus on teacher questioning. Examination of teacher questioning and teacher noticing, combined with the additional benefit of comparing novice and experienced teachers, will provide information helpful for designing teacher quality observation protocols, defining professional development needs, and giving direction to curriculum studies in teacher education.

Summary

This introduction provides a history of research on teacher quality, explaining the work that has been done in mathematics education and highlighting a need for more clearly articulated definition of teacher quality. Summaries of the research comparing novice and expert teachers in mathematics and of the studies in science education focusing on teacher questioning provide background and illustrate the gap in research of studies in mathematics education on teacher questioning, particularly in secondary mathematics education.

The purpose for research and rationale for studying novice and experienced teacher questioning patterns and their responses during pivotal teaching moments was also addressed. The research questions were listed and significance for the study was also given.

Chapter two discusses the previous research comparing novice and expert teachers, and then describes the discrepancies in research findings of studies on teacher quality. A discussion of the methodological framework, Chin's framework for teacher questioning followed by a summary of research on teacher noticing and pivotal teaching moments provides background to guide the methodology for data collection and analysis. A discussion of potential factors of influence for teacher decision-making concludes the chapter.

Chapter three discusses my methodological framework of teachers' cognitive development that guides the data collection, analysis, and interpretation of results. A multiple case study using a qualitative research approach is then described. A constant comparative approach to data analysis was also described.

Chapter four consists of four sections, discussing the findings from each of the three research questions. First, the researcher examines the similarities and differences among teachers in the number of questions asked and the variety of questions asked from different categories as compared to the questioning framework of Chin (2007). Second is an examination of the patterns of teacher responses during pivotal teaching moments, where the flow is disrupted and the teacher has an opportunity to modify instruction to improve students' mathematical understanding. Two contrasting trends exhibited by participants were to emphasize procedures and to emphasize the importance of making connections or providing motivation to learn new strategies. Additionally, the researcher examined the question asking by students and how it relates to the frequency and variety of questions the teacher asked. The third section includes a discussion of three perceived influences for teacher responses: (1) Reflection on experience and MKT, (2) time, and (3) relationship with students, teachers, and parents and knowledge of student background.

Finally, chapter five discusses the findings of this study from these perspectives: (1) types of teacher questioning in classroom discourse, (2) perspectives on questioning, and (3) factors of influence for teacher decision-making. Contributions to research and pedagogical practice are discussed, as well as limitations of the study and directions for further research.

CHAPTER TWO

LITERATURE REVIEW

This chapter first provides a description for the broad theoretical perspective of cognition and then provides a narrower lens of focus, the theoretical framework of social constructivism used to inform all aspects of my study. My views of learning, both learning of students and the developmental learning of teachers as they gain understanding of the different facets of their careers, heavily influenced my choice for research questions, my methodology, and my analysis and interpretation of the different data sources.

Next, the researcher provides a review of literature in several areas. The review starts broadly with an overview of past work by researchers who have studied teachers' instructional practice and compared novice and experienced teachers. Then a more focused review of studies examining varied aspects of teacher quality highlight a need for a more clearly defined topic of study in secondary mathematics education, namely to provide a deeper understanding of teachers' questioning as well as teacher noticing and pivotal teaching moments.

The last section of the chapter provides a needed review of research for potential influential factors for teacher decision making. This review contributed some starting codes for analysis and provides necessary background myself as a starting qualitative researcher and for readers.

Theoretical Perspective: Cognition

Cognition refers to the way we think and undergo processes to solve problems, make decisions, and understand new information and experiences. Cognitive views of learning refer to the happenings in a person's mind before, during, and after learning takes place (Weinstein & Acee, 2008). The essence of this theory is that the most important part of learning takes place in a person's mind. Educational psychology focuses on studying these processes and promoting cognitive development in children and adults.

Jean Piaget defined the development of knowledge as a constructive process, one with an "active exchange between the individual and his or her environment" (Bond, 2008). Although Piaget is most well-known for his stages of development for children, the focus here will be on his more general terms that are central in describing the process of cognitive development: *schema*, *assimilation*, and *accommodation*. A *schema* is the mental process we use to remember an object, idea, or event (Sullivan; 2009). Our knowledge becomes richer as we gain more information, more experiences, and a better way to organize the experiences we have. *Assimilation* is how a person organizes objects, ideas, or events into an already developed pattern or schema, integrating this knowledge into a pre-existing structure to give it meaning (Bond, 2008). *Accommodation* refers to a person's ability to differentiate among experiences as he or she organizes knowledge structures or schema. Assimilation and accommodation are connected and describe the process of adapting to the world as knowledge is acquired (Bond, 2008).

Research on individual differences brought about models that focus on different types of cognitive processes, using goal-directed learning with intentional use of cognitive, metacognitive, motivational, emotional, and self-management strategies to achieve learning goals (Weinstein & Acee, 2008). Additionally, both novice and experienced teachers in today's classrooms must possess critical thinking and reflective skills, and as successful 21st-century adults must be able to "gather and process rapidly evolving information, cope with ambiguity and complexity, manage diverse perspectives in a global society, and make informed judgments in the face of competing arguments" (Magolda, 2004). Developing teachers go through a continual cycle of practice, reflection, and improvement as they use all of the above strategies and skills to set and meet goals for teaching and learning.

Consider the following examples to illustrate teacher development in terms of cognition. Teachers will consider different methods or instructional strategies before teaching a particular topic or group of students. They will make choices for instruction and then implement it, continuing the mental process of analysis and instantaneous decision making even as they teach the lesson. After finishing the lesson and assessing student learning, teachers will reflect upon the instructional decisions they have made and on how satisfied they are with the results. They will then use assessment and reflection to improve instruction the next time they teach the topic.

Cognitive development theory, particularly the ideas that govern teachers' mental processes in instructional decision making, provides a useful frame for the methods used in data collection and analysis. A critical component of cognitive development of a more complex nature, such as that of working professionals, is the awareness that people actively interpret their experiences, analyze information, choose what to believe, and then make decisions for action based upon those beliefs (Magolda, 2004). This study's research questions are meant to provide a clearer picture of how teachers' use a combination of content knowledge, pedagogical skill, and preferences or beliefs about teaching and learning to guide their planning of questioning before a lesson, improvisational questioning and response during observed lesson's pivotal teaching moments (PTMs), and after reflection upon the lessons' events through a video-stimulated response interview. Although the prior knowledge and experience base is different for novice and experienced teachers, this study attempts to richly describe the instructional practice of questioning and the influences behind instructional decision making regarding questioning for studied teachers.

Theoretical Framework: Social Constructivism

When examining interaction between teachers and students in a classroom, the ideas of cognition alone cannot fully explain the learning that occurs through this social phenomenon. The theoretical framework of social constructivism will provide clear perspective on the higher cognitive processes that can develop through social interaction. The ideas of Vygotsky, a situated cognition theorist, as well as those by Mead and Bruner, provide an important backbone for all aspects of this study and are explained below.

Although scholars in science and mathematics education generally support a constructivist view of learning, there are differing perspectives about the components involved in the learning construction process. This study employed a theoretical framework of social constructivism, which emphasizes the idea that knowledge of a particular phenomenon is “generated and maintained through collective human action, thought, discourse, or other social practices” (Collin, 2013). To extend this idea further with the words of George Herbert Mead, these ideas become important once meaning is attached to them through social interaction (Shapiro, 2006). Social constructivism can be traced back further to Bruner (1986), taking the position that learning occurs through “communal activity, a sharing of the culture”. Going even further to the ideas of Vygotsky (1978), a situated cognition theorist, higher cognitive processes develop from social interaction. In this study, the researcher was particularly interested in the interaction between teachers and students as they constructed knowledge of mathematical phenomena throughout classroom discussions.

Social Constructivism in Science

The questioning categories developed by Chin (2007) for use in science education uses social constructivism as a theoretical framework, and the following paragraphs serve as a detailed description of this learning theory and explanation for how the theory informs the categories Chin developed.

Cognitive development, as defined by Piaget aligns with constructivist theory, and can be compared to social constructivism. Piaget acknowledged that social interaction was a factor in cognitive development but considered an individual’s equilibration to be more essential. Teaching approaches that are based on this perspective are usually structured around practical activities with supporting discussions that bring about cognitive conflict to encourage new knowledge schemes based from these experiences. In these classrooms the teacher’s role is to provide the physical experiences and encourage reflection. What this theory lacks is interaction with symbolic reality in addition to an external physical reality. Scientific understandings come about through conversation among individuals about problems or tasks, where these individuals are introduced to the symbolic tools or culture of science, by more skilled members of the community. A teacher's role in this process is essential, both to provide the physical experiences for students and to make the conventions and tools of the scientific community accessible for students as they enter into the concepts, symbols, and practices of the community (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

An important way for teachers to introduce students to this community of concepts, symbols, and practices is through discourse. Intervention and negotiation with an authority in science, usually the teacher, is critical for this transition to enter the scientific community to occur (Driver, et al, 1994). Through this process, teachers are also learners as they guide students and serve as mediator between students' everyday conceptions and the world of science. The kinds of questions teachers ask and the way they ask them can influence the processes their students engage in as they navigate the everyday and science worlds to construct scientific knowledge (Chin, 2007).

Social Constructivism in Mathematics

Students engage in similar processes of cognitive development as they solve mathematics problems or tasks and construct mathematical knowledge, so Chin's questioning categories and associated theoretical framework transfer appropriately to the field of mathematics. Works by Bauersfeld (1992) and Cobb, et al. (1992) show parallels in social constructivist theory between the fields of science and mathematics.

When studying cognitive development of students in the field of mathematics, it is helpful to think in terms of cognitive representations as well as external representations of mathematical ideas. As a student creates mathematical meanings, he or she undergoes some kind of interpretive activity. Cobb, et al. (1992) outline three features for the representational view of mind:

> 1) The goal of instruction is to help students construct mental representations that correctly or accurately mirror mathematical relationships located outside the mind in instructional representations.
>
> 2) The method for achieving this goal is to develop transparent instructional representations that make it possible for students to construct correct internal representations.
>
> 3) External instructional materials presented to students are the primary basis from which they build mathematical knowledge. (p. 4)

When considering this representational view, there is an obvious piece missing: guidance from the teacher in helping students make a connection between materials and an internal construction of conceptual understandings. One method for teachers to help students bridge this gap is to explicitly show the relationship, but this leads to "excessive algorithmatization of mathematics and disappearance of conceptual meaning" (Cobb, et al., 1992). Hence, social interaction plays an important role in students' mathematical learning.

> "[Teachers] might then consider the various ways that students actively interpret the materials as they engage in genuine mathematical communication in the social context of the classroom. The materials would then no longer be used as a means of presenting readily apprehensible mathematical relationships but would instead be aspects of a setting in which the teacher and students explicitly negotiate their differing interpretations as they engage in mathematical activity. " (Cobb, et al., 1992, pp. 5-6).

Bauersfeld (1992) also states the critical need for children to develop constructive competence through social interaction with their teacher and classmates. He recommends negotiation of mathematical meaning between teacher and students through discussion of solved tasks, learning by contrasting with negative instances, and discussion of underdetermined tasks.

This process of negotiation in a mathematics classroom is similar to that in a science classroom in the fact that students transition into the formal culture of mathematics with guidance from their teacher. Students "progressively mathematize their experiences with the teacher's initiation and guidance" (Cobb, et al., 1992, p. 13). Teachers in mathematics classrooms serve a similar navigator's role as in science classrooms, helping students navigate between everyday understandings and the world of mathematics as they transition to the concepts, symbols, and practices of the mathematics community.

Research of Instructional Practice

Research examining the work of teachers has been done in multiple contexts and under a variety of lenses. Past studies comparing novice and expert teachers have been completed in several subject domains, for example, science (Clermont, Borko, & Krajcik, 1994), mathematics (Borko & Livingston, 1989; Leinhardt & Greeno, 1986), and physical education (Housner & Griffey, 1985). A meta-analysis by Ericsson and Lehmann (1996) reported results from studies that used qualitative lenses of talent, experience, and teacher knowledge for examining expert teaching skill. Results from studies in mathematics (Borko & Livingston, 1989; Leinhardt & Greeno, 1986) showed the schemata exhibited by teachers who have a well-developed pedagogical content knowledge prepared these teachers to "perceive and recall more subtle classroom events, focus on individual student learning occurring in the classroom, and adjust instructional strategies accordingly" (Hogan et al., 2003). Hogan and colleagues (2003) reviewed studies that compared expert and novice teachers and provided insight into a generalized understanding of teacher cognition, which shows the importance of extensive content knowledge, and explains differences between novice and expert teachers in terms of teacher-focus or student-focus during reflection. Additionally, the authors argue that further research is needed to determine whether novice teachers can be taught the representational skills of experts. Research comparing the questioning patterns of novice and experienced mathematics teachers has not been done and would contribute a more specialized understanding of teacher cognition.

The following sections outline previous research in four areas of importance for my study, ranging from general studies of teacher quality, teacher-centered versus learner-centered instruction, and influences for teaching practice to more specific topics of teachers' questioning and spontaneous responses to students. Background information on pivotal teaching moments (PTMs) is also included as delineated in past studies.

Teacher Quality

In 2000, the National Council of Teachers of Mathematics (NCTM) asserted a vision that outlined six principles for school mathematics, with one of these principles being teaching. This principle highlights the need for effective teachers who will "understand what students know and need to learn and then challenge and support them to do it well (NCTM, 2000). Authors state that mathematics teachers must possess a "deep and flexible knowledge" of their content, curriculum, and central ideas for their grade level, as well as knowledge of the challenges their students may face, ideas for how to represent these ideas effectively, and ideas for how to assess students' understandings. This knowledge is what helps teachers to make decisions about curriculum, responses to students' questions, and future planning, and is a knowledge that surpasses what most teachers experience in standard pre-service mathematics courses (NCTM, 2000). Previously, NCTM had outlined six standards for the teaching of mathematics: (1) worthwhile mathematical tasks, (2) the teacher's role in discourse, (3) the student's role in discourse, (4) tools for enhancing discourse, (5) the learning environment, and (6) the analysis of teaching and learning (NCTM, 1991). This study relates to mathematics teaching standards (2), (3), and (4).

Teacher quality can be examined in a variety of ways and can produce varying results. Goe and Stickler (2008) describe four lenses for examining teacher quality: *Teacher qualifications*-credentials, knowledge, and experience that teachers bring with them to the classroom; *Teacher characteristics*-attitude and other attributes such as expectations for students, collegiality, race, and gender; *teacher practices*-the ways teachers interact with students and the teaching strategies they use; and *teacher effectiveness*-a "value-added" assessment that looks at the degree to which a teacher contributes to student learning (as measured by student achievement scores). Although teacher quality can be broadly defined in these ways, "…research has not been very successful at identifying the specific teacher qualifications, characteristics, and classroom practices that are most likely to improve student learning. Unfortunately, this is just the information that policymakers need most" (p.1). Findings in the area of teacher quality are difficult to interpret because of multiple ways to identify and measure teacher qualifications, characteristics, and practices that contribute toward effective teaching. To effectively examine this issue, researchers must be more precise in defining and measuring such attributes.

This study focused on one specific feature of teachers' classroom practices, specifically on teacher questioning and responses to students during mathematical discourse. This definition fits with Goe and Stickler's (2008) recommendation for research studies, falling under their *teacher practices* category, where studies should focus on "the ways in which teachers interact with students and the teaching strategies they use to accomplish specific teaching tasks" (Goe & Stickler, 2008). This finer grained lens for explaining teacher practices was intended to illuminate potential characteristics of teacher questioning that could improve student learning. However, other teacher qualifications and characteristics were not ignored as the researcher explored questions about teacher questioning, planned methodology for data collection and analysis, and found emerging patterns in teacher responses possible sources of influence for teacher decision-making.

There have been studies in mathematics education with a focus on more specific teacher qualifications, characteristics, and practices that served as valuable background information for the researcher. Past studies in mathematics education have suggested the influence of specific teacher qualifications such as teacher experience and knowledge on classroom practice (Borko & Livingston, 1989; Ericsson & Lehmann, 1996; Hill et al., 2008; Hogan et al., 2003; Leinhardt & Greeno, 1986; López, 2007). Past research has also described teacher characteristics such as teacher beliefs and preferences to impact classroom instructional practice (Begeny, Eckert, Montarello, & Storie, 2008; Changsri, Inprasitha, Pattanajak, & Changtong, 2012; Mahmud, Warchal, Masuchi, Ahmed, & Schoelmerich, 2009). Additionally, there have been studies with a focus on more specific features of mathematics teachers' classroom practice, such as teacher noticing (Jacobs et al., 2010; Russ & Luna, 2013; Stockero & Van Zoest, 2013; van Es & Sherin, 2002), teacher-centered versus student-centered instruction (Ackerman, 2003; Lesh, Doerr, Carmona, & Hjalmarson, 2003; Lesh & Lehrer, 2003; Polly, Margerison, & Piel, 2014) and broader characterizations of teachers' questioning (Herbal-Eisenmann & Breyfogle, 2005; Wood, 1998). The following sections outline the findings from past research studies in more detail.

Experienced vs. Novice Teachers

NCTM asserts that the level of knowledge a mathematics teacher must possess is beyond that experienced in most pre-service education experiences, and that teachers must continually seek to learn about pedagogy and mathematics, engaging in reflection and professional development (NCTM, 2000). It is not a surprise that the past and current bodies of research reveal a distinct difference between the instructional practices of novice teachers and experienced teachers.

A few differences illuminated in the literature are differences in knowledge schemata (Borko & Livingston, 1989; Jacobs, Lamb, & Philipp, 2010), mathematical knowledge for teaching (MKT) (Hill et al., 2005), and stability of belief structures (Belo, van Driel, van Veen, & Verloop, 2014; Simmons et al., 1999). Differences between novice and experienced teachers with regard to instructional decision making are of particular interest in this study. While many studies have observed differences in instructional practices of expert and novice teachers, few have looked into explanations for why these differences occur.

One reason that expert and novice teachers make different instructional decisions is that expert teachers have more complex knowledge schemata (Borko & Livingston, 1989; Jacobs, et al., 2010). Borko and Livingston (1989) explain three components to this schemata – *scripts* that direct common teaching activities, *scenes* that represent a teacher's knowledge of people and objects in common classroom events, and *propositional skills* that represent knowledge of the different parts of the teaching-learning situation, such as understanding the students they are teaching and pedagogical knowledge for how to teach them. Jacobs, et al. (2010) look at the differences in teacher noticing, which is the improvisational part of teaching that requires a teacher to attend to, interpret, and decide how to respond in a given classroom situation. Novice teachers are less experienced and thus have less skill with noticing.

Another explanation provided by Hill et al. (2005) for the differences in instructional practice between novice and experienced teachers relates to their findings that teacher's mathematical knowledge for teaching (MKT) is positively correlated with student achievement. They conclude that teachers with greater MKT are making better instructional decisions than teachers with less MKT. Novice teachers have much less MKT and as a result make less wise instructional decisions.

Belo et al. (2014) explain that teacher beliefs play a critical role in almost every aspect of instructional decision making, and they describe the belief structure for teachers as made up of overall general beliefs about teaching, learning, and assessment, and also domain-specific curricular beliefs pertaining to the content and students that they teach.

Results from this study as well as prior literature from Simmons et al. (1999) and Seung, Park, and Narayan (2011) suggest that teachers could hold a mixed belief structure, and that the belief structure of pre-service and novice teachers is less stable than that of experienced teachers.

Although these studies provide important background information about the differences in instructional practice between novice and experienced teachers, none of the previously mentioned literature compare these two teacher populations with regard to teacher questioning or teacher responses during pivotal teaching moments.

Teachers' Questioning during Classroom Discussion

Classroom instruction has changed over the years from a traditional lecture-dependent approach to a more student-centered approach. Teachers who ascribe to a teacher-centered approach will teach in a very direct and time-efficient manner, providing information for a given topic through lecture, guidance or demonstration (Ackerman, 2003; Polly et al., 2014; Wu & Huang, 2007). A teacher in this traditional type of environment sees himself as the deliverer of knowledge, seeking little input from students in the teaching process (Belo et al., 2014). In contrast, teachers who use a student-centered model for instruction believe students are active participants in constructing knowledge as opposed to passively receiving this knowledge from a teacher (Lesh et al., 2003; Seung, Park, & Narayan, 2011). Student-centered instruction allows teachers to provide opportunities for students to construct this knowledge through carefully crafted experiences (Lesh et al., 2003; Polly et al., 2014). Classroom interaction is an essential component of teaching and learning in a student-centered environment, and questioning is an important phenomenon to consider within the context of interaction. A teacher's questions are useful to guide instruction in appropriate directions to meet lesson objectives, as well as to extend and solidify students' understanding of a particular topic (Chin, 2007).

A recent change to the guiding standards for teachers of mathematics, the Standards for Mathematical Practice, found within the Common Core State Standards for Mathematics (CCSSM), describe practices for learning mathematics that have held longstanding importance in mathematics (CCSSI, 2012). Two of these standards, (1) Construct viable arguments and critique the reasoning of others, and (2) Make sense of problems and persevere in solving them, require students to be able to reason, explain, experience a productive struggle, and communicate using the language of mathematics. Teachers are expected to develop these practices in their students partly through purposeful questioning in mathematical discourse (NCTM, 2014).

Effective teachers of mathematics use purposeful questioning to assess student understanding, prompt critical thinking, reasoning, and sense making of mathematical ideas (NCTM, 2014). The questions teachers ask should encourage students to reflect and explain their thinking as meaningful contributors to a classroom mathematical discussion. Teachers should also be able to ask questions that assess various levels of student understanding and support students in asking their own questions. NCTM (2014) suggests that asking questions alone is not enough to ensure that students can make sense of mathematics and improve their understanding. The type of questions asked and pattern in asking them are also important factors to consider.

Wood (1998) described two types of questioning by the terms *funneling* and *focusing*, where *funneling* refers to the tightly guided set of questions a teacher might ask to lead students toward a particular solution or conclusion, and *focusing* refers to a more open style of questioning that necessitates attention by the teacher to what the students are thinking, prompting them to explain their thinking and remaining open to a task being explored in many ways. This work was further elaborated by studies that examined teachers who used these types of questions and the patterns exhibited in asking them (Breyfogle & Herbel-Eisenmann, 2004; Herbal-Eisenmann & Breyfogle, 2005). Results described the questioning patterns for observed teachers and gave ideas for how to turn *funneling* into *focusing* to help promote a more open mathematical discussion.

The existing frameworks in mathematics education provided useful insight into teacher questioning but still provided more general information than that from research in science education on the topic of teacher questioning (Chin, 2006, 2007; Oliveira, 2010). Chin (2006, 2007) studied teacher questioning during class discussions of science concepts and developed a teacher questioning framework consisting of four major categories -- Socratic questioning, verbal jigsaw, semantic tapestry, and framing. Part of her model, the reflective toss (the teacher evaluation part of an IRF dialogue interchange), was based from work by van Zee and colleagues that analyzed student and teacher questioning during conversations about science. Oliveira (2010) took the information gained from previous studies to see what growth in teacher questioning skills could occur after participation by teachers in a summer institute on questioning in science inquiry discussions. Studies in science education have addressed this issue of questioning, but studies that transfer this knowledge and questioning framework to mathematics have yet to be done.

The framework set forth by Chin that includes categories *Socratic questioning*, *verbal jigsaw*, *semantic tapestry*, and *framing* will serve as a useful framework for studying teacher questioning in mathematics. These categories are described below in more detail.

Socratic questioning is a category including questions that help to prompt and guide student thinking. Subcategories for Socratic questioning are pumping, reflective toss, and constructive challenge. Verbal jigsaw is a technique used to focus on key words and phrases using content-specific terminology to piece together "integrated propositional statements" (Chin, 2007). Subcategories for verbal jigsaw are association of key words and phrases and verbal cloze. Semantic tapestry is a questioning technique that helps students to put together a conceptual framework. Subcategories are multi-pronged questioning, stimulating multi-modal thinking, and focusing and zooming. The last category, framing, is used to frame a problem or discussion topic and to frame the discussion that ensues. Subcategories are prelude, outline, and summary. For further descriptions of the framework developed by Chin, as well as my additions to include categories of productive statements, see table 3-1.

Although few studies have been done in mathematics regarding teacher questioning (Breyfogle & Herbel-Eisenmann, 2004; Franke et al., 2009; Herbal-Eisenmann & Breyfogle, 2005; Wood, 1998), various studies on classroom interactions have focused on different aspects of classroom practices. For example, Martin, McCrone, Bower, and Dindyal (2005) examined the classroom interactions in a secondary geometry class over a four-month period. They used a social interactionism lens to examine the relationship between teacher actions and student actions in the context of geometric proof development and concluded that understanding the interactions between teacher and students is not only dependent on each student's willingness to learn but on the teacher's pedagogical choices. Amit and Fried (2005) focused on authority relations during mathematical discussion in eighth-grade classrooms, showing that different amounts of authority or perceived authority by teachers promote different classroom environments in terms of collaboration, cooperative learning, and constructivist pedagogy.

Pivotal Teaching Moments and Teacher Noticing

Recent work in the fields of mathematics and science education on teacher noticing allows researchers to critically examine teacher attention, studying a range of activities in the classroom that teachers do and do not notice, such as classroom talk and student behaviors (Jacobs et al., 2010; Russ & Luna, 2013; van Es & Sherin, 2002). A salient distinction between the research in this area in mathematics education and science education is the focus of study, however. Mathematics education researchers generally focus singly on teacher noticing, and researchers in science education instead focus on teacher noticing in conjunction with understanding some other aspect of teaching and learning (Russ & Luna, 2013).

The focus in mathematics education for analysis of teacher noticing has been in recognizing patterns of teacher behavior. The method typically used by researchers has been to categorize teacher comments about noticing into different coding categories (Russ & Luna, 2013). Video footage has been particularly helpful for researchers who examined teacher noticing. For example, in one study teachers were asked to view classroom video clips before and after a video-based professional development and their comments about the things they noticed could then be categorized to identify patterns in noticing behavior (e.g. van Es & Sherin, 2002).

A recent study by Stockero and Van Zoest (2013) examined teacher noticing of pivotal teaching moments (PTMs) for beginning mathematics teachers. Results from this study showed an importance of a deep understanding of the mathematics students are learning to be ready to notice students' high-level thinking and to be able to productively act on that thinking. Results from this study combined with ideas previously examined in the area of teacher questioning allow an opportunity for new studies to look at the pattern of teacher questioning in classroom discourse and teacher questions and responses during PTMs when the flow of discourse is interrupted.

A precursor to the study by Stockero and Van Zoest (2013), Scherrer and Stein (2013) developed a coding scheme meant to help teachers notice student and teacher interactions during episodes involving higher cognitive levels of thought. Results were successful in changing what teachers notice during classroom discussion, but they were less effective at helping teachers see how different interactions cause different opportunities for learning.

Combining the insights gained from previous research, more studies of teachers are needed in mathematics education where protocols can be used to determine teacher noticing patterns during PTMs. Additionally, research in mathematics education is needed that uses teacher noticing in conjunction with understanding teacher questioning and factors of influence on teacher practice .

Potentially Influential Factors on Teachers' Responses

Every teacher decision is based upon at least one source of influence. These influences could come from memories or schema from prior experiences, teachers' pedagogical or content-specific knowledge, or teachers' beliefs and preferences. Sources of influence are important to consider within this study as the researcher examines a specific example of teacher decision-making, teacher questioning and responses, as well as teacher decision making during pivotal teaching moments. This section examines previous research of these influences on instructional decision-making. Examination of these factors provides a basis for describing teachers' perceived influences on decision making and reactions during PTMs.

Teaching Experience

Leinhardt and Greeno (1986) explained complex cognitive skills associated with teaching. They described the intricate knowledge structure containing various interrelated sets of conceptual frameworks, or schemata, and concluded that the schemata of experienced teachers are more organized and developed than the schemata of novices. A similar study conducted by Borko and Livingston (1989) characterized teaching as a complex cognitive skill in accordance with Leinhardt and Greeno (1986) but further described it as an improvisation performance. Findings showed that experienced teachers were better able to pull from their schemata during classroom instruction and showed greater improvisational skills (Borko & Livingston, 1989). Additionally, they noted that expert teachers were better able to successfully return to fulfill a lesson objective after improvising and deviating from their lesson plan than novice teachers. Borko and Livingston (1989) attributed the development of these complex schemata to years of experience and concluded that novice teachers will nearly always be less efficient at planning and executing a lesson than their experienced colleagues.

Torff (2003) conducted a similar comparison study of novice, experienced, and expert history teachers, looking at the use of higher order thinking skills and content knowledge in the classroom. He found that a developmental continuum existed, and novice teachers emphasized content knowledge more while giving much less focus to higher order thinking skills. As a teacher gained experience and neared the category of expert, he or she emphasized higher order thinking skills more and content knowledge less. These results combined with that of the two previously mentioned studies show that experience should be a salient factor in a teacher's questioning ability and ease with noticing and reacting to PTMs in a way that will drive conceptual understanding forward within students' mathematical discourse.

Teachers' Knowledge

The knowledge an effective teacher possesses has been and is still an important focus for educational research; however, the distinctions between different bodies of knowledge and the vocabulary used to describe them vary significantly. For example, Shulman (1986) breaks teacher knowledge into three categories: content knowledge, advanced pedagogical content knowledge, and curriculum knowledge. Others have divided teachers' knowledge into four domains including subject-matter knowledge, general pedagogical knowledge, pedagogical content knowledge, and knowledge of context (Grossman, 1990). For the sake of this review, I will consider one broad categorization of knowledge identified by Hill, et al. (2004) simply as *mathematical knowledge for teaching (MKT)*. Mathematical knowledge for teaching can be described simply as the “mathematical knowledge that is demanded by the work teachers do.” (Ball, Thames, & Phelps, 2008). Use of the MKT construct is becoming more popular, and it is important to note that the storage and application of knowledge are complex and multifaceted (Shechtman, Roschelle, Haertel, & Knudsen, 2010). I choose to consider MKT as a potential influential factor on teacher responses because of the simplicity of the terminology and the elegance of the MKT model. The pieces of MKT as outlined by Ball, et al. (2008), common content knowledge (or knowledge that is also used outside of teaching), specialized content knowledge (or knowledge used uniquely by teachers), knowledge of content and students (a combination of knowing about mathematics and about how students learn), and knowledge of content and teaching (a combination of knowledge of mathematics and designing instruction for that content), are useful constructs in analyzing a teacher’s perceived motives for asking specific questions or providing specific responses to students.

Some studies show a relationship between MKT and student achievement (Hill et al., 2005; Tchoshanov, 2010), and Hill et al. (2004) suggests it is logical to consider exactly how teachers with rich mathematics knowledge for teaching apply that knowledge to their instruction. To this end, Shechtman and colleagues (2010) analyzed the effect of MKT on the instructional decisions of teachers. The study considered three areas of instructional decision making, namely, topic coverage, choice of teaching goals, and use of technology. They found no relationship between instructional decision making and MKT. To the contrary, Tchoshanov (2010) showed that teachers with greater mathematical knowledge presented information more conceptually than those with less mathematical knowledge who tended to present information more procedurally. In addition, he found that the classroom environment of teachers with greater mathematics knowledge tended to be more active, respectful, and positive than those with less mathematics knowledge. Lastly, Hill et al. (2008) considered several case studies of elementary mathematics teachers and demonstrated that elementary teachers with greater MKT were able to lead richer and more engaging mathematical discussions. Showing similar results, Cengiz, Kline, and Grant (2011) found that their sampled beginning elementary mathematics teachers had difficulty extending students' thinking. These authors also found a relationship between this challenge in extending thinking and the teacher's MKT.

In general, most research has shown that MKT is positively correlated with student achievement. Hill et al. (2004) proposed that it is logical to assume if teachers who possess a high level of MKT produce students with higher academic achievement, they must be doing something different in their classrooms. However, the link between MKT and the instructional decisions of teachers is an underdeveloped area of research with some contradictory findings, and no research has yet been conducted in secondary mathematics classrooms.

Teachers' Beliefs and Preferences

Another potentially influential factor of teachers' response patterns is the teachers' beliefs and preferences. Teachers' instructional decision making certainly cannot be predicted entirely by their MKT and their teaching experience. Much of what happens in a teacher's classroom is governed by her own beliefs and preferences. General beliefs about teaching and learning as well as domain-specific beliefs play a significant role in shaping a teacher's instruction. Decisions teachers make regarding objectives, assessment, and which instructional strategies are more effective are influenced by teachers' beliefs about overall goals for education, learning, and how to regulate students' learning processes (Belo et al., 2014). In particular, teacher beliefs play a critical role in cognitive monitoring and in knowledge interpretation (Belo et al, 2014). Generally a person's beliefs are relatively stable and resistant to change, but research has found pre-service and novice teachers' beliefs about teaching and learning to be less resistant to change than more experienced teachers' beliefs (Belo et al., 2014). Results from a study by Seung et al. (2011) of pre-service teachers in science education also showed a change in beliefs after experiencing a science methods course. Most of these students entered the methods class with traditional views of science instruction and left the course with a mix of traditional and constructivist beliefs, keeping their original beliefs while adding some constructivist perspectives to them (Seung et al., 2011).

Additionally, researchers have discovered that teachers' beliefs are related to prior experience and actual teaching practice (Belo et al., 2014) and beliefs about their students' academic achievement and potential are regularly used to inform instructional decisions (Begeny et al., 2008). In a study conducted with a group of Korean teachers, Changsri et al. (2012) found that teachers were able to, in many cases, identify their beliefs and preferences that were negatively affecting their instructional decisions. Another study analyzing student and teacher instructional preferences in four countries, Bangladesh, Japan, The United States, and Germany, found that student and teacher values and preferences differ in each country likely due to historical, cultural, social economic, and other differences, and these differences were demonstrated in instructional choices made in schools (Mahmud et al., 2009). It can therefore easily be hypothesized that differences in values, beliefs, and preferences among individual teachers may affect instructional decisions and the ways in which they respond to students during classroom discussion.

Summary

This chapter presented the gap in existing research comparing novice and experienced teachers with specific characteristics of teacher practice, a component of teacher quality. Previous studies have examined elementary teachers' facilitation of discourse and noticing of PTMs, but no such studies have been completed with secondary mathematics teachers. To effectively examine teacher questioning patterns, the researcher chose to utilize a questioning framework from the literature in science education, and this framework is described in the chapter. Further description of PTMs and teacher noticing, and discussion of potential factors of influence for teacher decision-making in the context of prior research are also included in the chapter.

CHAPTER THREE

DESIGN AND METHODS

This chapter provides a detailed description of my research design and methods. First, a statement of subjectivity outlines all sources of potential bias based on the researchers' past experience, knowledge, beliefs and values related to teaching and teacher education. Then follows a detailed description of the research design, multiple case study, and a thick description of the research context in terms of settings and participants. Next, the researcher outlines the methods for data collection, including the sources used and the process for data collection. Then methods for analysis of the three research questions are outlined, following a progression of phases. Finally, a discussion of issues relating to trustworthiness for the study concludes the chapter.

Statement of Subjectivity

I realize my personal and professional experiences as well as my philosophy of teaching have an impact on the entire process of research design, data collection, and analysis. The following paragraphs are my disclosure of these education and personal experiences and beliefs.

I have worked as a middle school and secondary mathematics teacher, so my initial impression of what makes "good teaching" is biased by my own experience with instruction and the instruction I observed from my colleagues and through my teacher education program. I taught four years before I left K-12 education to pursue my doctorate degree, so I was in the transitional stage between that of a novice teacher and an experienced teacher. As I am in the field I have theoretical knowledge and limited schematic knowledge to use as a basis for pinpointing the best segments of discussion for analysis. I examine the classroom video clips with a lens that is somewhat limited by my few years of K-12 teaching experience but biased as a result of the experience I have had.

My experiences in working with pre-service teachers as a student teaching supervisor have also impacted my impression of quality teacher practices. As I watch student teachers present lessons devoid of creativity or lessons that are more mechanical in terms of mathematical discussion I build preconceptions about the quality of teaching to expect from beginning teachers and the types of knowledge that influence the decisions they make in the classroom. I must keep in mind that all beginning teachers are not created equal and look for aspects of their instructional practices that are similar to that of the more experienced teachers I observe as well as those practices that are not as well developed.

My knowledge of teacher education, teacher knowledge, and findings from previous research studies affects the findings for this study because I came into the field with presumptions about possible patterns for teacher responses and influences for those responses. I may be more tuned to those teacher responses that are influenced by a complex mathematical knowledge for teaching or characteristics of teaching by novices and experts that have been disclosed in the literature.

My teaching philosophy will also significantly affect the lens through which I examine these teachers' practices and will affect my decisions for which lesson segments to follow-up for further analysis. I tend to lean toward a more constructivist approach to instruction and will be more interested in studying a teacher who uses student-centered mathematical discussion techniques to develop concepts and problem-solving skills. I must be careful not to totally ignore discussion that is outside of this realm but satisfies my definition for productive discussion. I also need to be careful not to create my own meaning for occurrences, events, and concepts that are different from what the teacher intended. I will use peer debriefing and teacher stimulated-recall interviews to guard against this particular bias.

A few personal values must be carefully monitored as I am in the field and going through the process of analysis. I am an impatient person by nature and must be careful not to rush through my data collection, interviews, and analysis to keep within my timeline for the project. I will keep in mind that I am not limited to only five days for data collection and can expand to further days in the field as needed. I also will take advantage of asking follow-up questions to be sure I get answers to all of the questions that come up through my data analysis and as I write the findings. During interviews I will be careful to listen completely to my participants without interruption and will not jump to conclusions about their instructional philosophies or the reasons for the decisions they made throughout the time they are teaching.

Research Design: Multiple Case Study

This study employed a multiple case study design with six in-service mathematics teachers to include three novice teachers and three experienced teachers. A case study is a type of qualitative research that utilizes in-depth analysis of a bounded entity: a person, place, or event (Stacks, 2005). Examination of this entity is usually as related to some relevant issue, and researchers reveal information about some phenomena through the process of this detailed study and its cultural and social contexts (Putney, 2010). This type of research is common in the social sciences, public relations, and in the business world, and it is commonly used for applied purposes. Although results from a case study are not generalizable, they are used to offer insights for practices and tactics and provide great detail about the particular person, place, or event being studied.

Case study can be difficult to define, as it can be looked at as a research method, design, approach or outcome. I define case study as a research design, where it defines the structure or logic for setting up my study. The particular study I have designed is an *instrumental case study* because I am interested in developing an understanding of the phenomena of teacher questioning and spontaneous classroom response outside of the cases I study. My study is also considered to be a *multiple case study* or *comparative case study* because I examined six individual cases and compare them to develop a general understanding of the phenomena in which I am interested (Putney, 2010). In selecting cases, I selected a sample with maximum variation, containing three novice teachers and three experienced teachers with various instructional practices and situated within various school districts. This wide variety in my cases adds to a more complete understanding of teacher questioning and responses. Findings from these cases will serve as "individual portraits" that each contribute individually to my understanding of the phenomena I study as well as contributing collectively (Putney, 2010).

Research Context

Setting

Four high schools and two middle schools within five different school districts were the setting for this study. All of the schools were located within a 150-mile radius of each other in a Midwestern state. Three schools were situated within larger cities of population, with one school in a city with population 68,000 and the other with population around 25,000. The other three schools were smaller, in cities of populations

10,500, 7000, and 1500. Three of the schools were located in cities that contained a university or college. All of the schools were public institutions. See Table 3.1 for an overview of participants.

Table 3.1

Overview of Participants

Teacher	School	Gender	Years of Experience	Grade Level	Subject
Tom	A	M	17	High School	Geometry
Dana	B	F	8	High School	Algebra I
Amy	C	F	4	Middle School	Algebra I
Samantha	D	F	1	High School	Algebra II
Noah	E	M	1	Middle School	Algebra I
Kathleen	F	F	1	Middle School	Algebra I

School A.

School A had a population of about 2000 students in grades 9-12 and had 15 teachers in the mathematics department. Mathematics courses were available in college preparatory and remedial tracks, ranging from pre-algebra to calculus. This school had 22 % of students receiving free and reduced lunch and 30% minority enrollment. ACT scores for students in mathematics averaged 26.2 in 2013, and state test scores for 11th graders in mathematics were 91%. The state average for 11th graders in mathematics was 81%, showing this schools scores well above this average. The geometry classroom I observed in this school contained 29 students, with 10% minority population.

School B.

School B had a population of about 550 students in grades 9-12 with 4 teachers in the mathematics department. Mathematics courses were available in college preparatory and remedial tracks, ranging from pre-algebra to calculus. Three percent of students in this school were of minority population, and 20% of students were eligible for free or reduced lunch. State test score averages were at 79% in mathematics for 11^{th} graders in this school, slightly lower than the state average of 81%. This school recently adopted a one-to-one technology program, where every student was assigned a laptop. The remedial algebra classroom I observed contained 16% minority with 18 total students.

School C.

School C had a population of about 345 students in grades 7-8 with 5 teachers in the mathematics department. Mathematics courses were available in advanced and remedial tracks, ranging from seventh-grade mathematics to Algebra 2. Four percent of students in this school were of minority population, and 21% of students were eligible for reduced lunch. State test score averages for eighth-graders were at 93% in mathematics, much higher than the state average of 73%. The algebra classroom I observed contained 1% minority with 25 students in total.

School D.

School D had a population of about 1400 students in grades 9-12 with 9 teachers in the mathematics department. Mathematics courses were available in college preparatory and remedial tracks, ranging from pre-algebra to calculus. Twenty-three percent of students in this school were of minority population, and 32% of students were eligible for free or reduced lunch. State test score averages were at 72% in mathematics for 11th graders in this school, lower than the state average of 81%. The Algebra 2 classroom I observed contained 17% minority with 23 students in total.

School E.

School E had a population of about 1000 students in grades 9-12 with 5 teachers in the mathematics department. Mathematics courses were available for remedial as well as advanced students, ranging from sixth-grade mathematics to algebra. Twenty-seven percent of students in this school were of minority population, and 52% of students were eligible for free or reduced lunch. ITBS averages in mathematics were at 63% in this school, lower than the state average of 81%. The pre-algebra classroom I observed contained 16% minority with 25 students in total.

School F.

School F had a population of about 200 students in grades 7-12 with 3 teachers in the mathematics department. Mathematics courses were available in college preparatory and remedial tracks, ranging from seventh-grade mathematics to pre-calculus. Three percent of students in this school were of minority population, and 24% of students were eligible for free or reduced lunch. State test score averages were at 81% in mathematics for 8th graders and 89% for 11th graders in this school, higher than the state averages of 73% and 81% respectively. The algebra classroom I observed contained 0.05% minority with a total of 20 students.

Participants

The teachers who participated for this study were selected based on convenience and purposive sampling. The three novice teachers were selected to participate because of their relationship as alumni to the institution I work for. Other teachers were contacted through email and then by phone to ask for their participation. The email they received told basic information about the purpose of my study and the required commitments from them if they chose to participate. I then followed up by contacting teachers during their planning time to talk further with them about the study. The following are summaries of each participant who agreed to participate. All names are pseudonyms, and some genders have been changed to protect confidentiality of the participants.

Case 1: Tom.

Tom has 17 years of teaching experience and 13 years in his current school. He has a traditional teacher-centered instructional style but uses questioning as his primary teaching tool. Tom explained that questioning is his way for students to relay information and for him to receive feedback. He strongly believes in teaching the interplay between different representations in mathematics, such as analytical, graphical, and verbal representations. Tom likes his students to be engaged in the learning process and to take ownership of what they are learning, and he uses his questioning to keep students active and to help them build knowledge. He believes teaching is secondary to his relationships with students and perceives his personality as having broad appeal.

Case 2: Dana.

Dana has 8 years of teaching experience, with 6 years in her current school. She thrives on structure and provides routines, explicit expectations, and clear boundaries for her students. Over half of her instructional time is with remedial students, so Dana believes her structured environment along with more specific one-on-one interventions help give her students an optimal opportunity to learn. Her philosophy regarding the role of a teacher is that the teacher comes to teach and students should learn from the teacher, but she admits there is “gray area” in that she’ll do whatever it takes to help her students learn. Dana follows a gradual release model of instruction where she models examples, and then she works through some examples together with students before releasing them to practice with a partner and individually. She believes both a richer conceptual knowledge and her experiences in teaching have changed the way she teaches, allowing her to ask questions that will lead to connections or fix misconceptions with students.

Case 3: Amy.

Amy is in her fourth year of teaching and her second year in her current school. She believes in providing a sort of controlled chaos, where students are engaged and talking in groups about mathematics. Amy tries to limit her time with direct lecture to no longer than ten minutes, and then circulates around her classroom as students discuss and work through problems in groups. Amy’s questioning style typically is in the form of framing questions to lead students to the discovery of a concept or to the usefulness of a particular strategy, and she likes to emphasize “the why and how” as well as helping students make connections within and outside of mathematics. Although she plans a few of her questions in advance, most of the things she asks during a discussion come in the moment as the students talk through them. She believes her skill in questioning has grown because of observations and peer observations during her first few years of teaching, as well as the support of her mentor teacher and reflection from watching videos of her teaching. She acknowledges that the more times she goes through a lesson she knows where students make mistakes and can approach instruction differently to incorporate a way to avoid those mistakes.

Case 4: Samantha.

Samantha is in her first year of teaching and is experiencing much more diversity in her classroom than what she saw in her teacher education program or her student teaching. This new exposure to ELL students has challenged her to try to learn to communicate better with these students and to rely on an interpreter whenever possible. She describes her questioning in class as a sort of prompt for students to help her solve problems about what steps come next in the solution. She likes to give hints to students in the form of another question to force the students to go back to previous problems. Samantha also uses a gradual release model for instruction and finds the consistent structure easy to manage in her first year of teaching.

Case 5: Noah.

Noah is also a first-year teacher, who was asked to continue on in a full-time position after he completed his student teaching. He enjoys teaching lessons with high engagement and is not a fan of direct lecture, although he follows a gradual release method of instruction similarly to Cases 2 and 3. As students are working, questions he typically asks are, “Why did you do that?” or “What did you discover?” Noah likes to stretch students to think at a higher level and has noticed in particular that the class observed has been receptive to the idea of asking questions of him as much as he asks of them. Although he writes a few questions out ahead of teaching a lesson, a few things come up in the moment as he is teaching. When he wants them to build a concept themselves, Noah pre-plans his questions to help build that understanding. He believes in good connectivity between teacher and students and in providing positive feedback to his students as they work to understand mathematics concepts.

Case 6: Kathleen.

Kathleen is a first-year teacher who also thrives on running an active, hands-on, less structured classroom. She likes for students to be able to work together in groups to understand the concepts and see why it matters. Kathleen believes in a student-centered classroom, where her students are responsible for learning and in charge of what they learn. Her questions often appeal to prior knowledge or ask “why?” and “how?” She passes her authority to students occasionally and lets them be the teacher. She has learned the questioning strategies she uses through observing different classes and physically writing down her questions in a lesson plan, and she sees the value in helping students to form their own connections between past and current mathematics topics.

Data Collection Procedure

Three types of qualitative data were collected for this study; video recordings of classroom observations, audio recordings of initial and semi-structured interviews, and field notes.

Five consecutive lessons within a unit were videotaped and transcribed for each teacher. Video clips, audio recordings, and transcripts provided direct pictures of instruction that showed the kinds of questions and statements teachers used and gave an idea for triangulation purposes about which factors influenced their responses to students. When I recorded lessons, the main focus was the teachers but this data also included recorded sounds of students’ voices in order to explore factors in the teachers’ questioning and to pinpoint the responses that directly followed students’ comments.

I took field notes during the classroom observations that provided sensitive information about the classroom was missed from examination of audiotapes and transcripts. For example, field notes contained information about the students, the classroom environment, overall atmosphere in the school that may affect the teacher's decision-making, and information about students' behaviors as well as notes about what the teacher presented that was not recorded, such as written or projected examples on the chalk board or interactive white board. Table 3.2 shows each data type, source, and the purpose for using each.

Two sessions of semi-structured interviews were conducted for each teacher. Semi-structured interviews are a type of interview for qualitative research where the questions are pre-determined but open-ended in format so that the researcher has control over the topics for the interview but there is no specific range of responses for each question (Ayres, 2008). The initial interview contained questions on the topics of the teacher's philosophy for teaching, philosophy for questioning, classroom environment, perceived roles of teacher and student during classroom discussion (See Appendix A). The stimulated-recall interview contained questions regarding the teacher's decision-making during in-class instruction. I determined two or three episodes of instruction that I interpreted to be critical instances for concept development or containing teacher responses deviant from his or her typical classroom style. During the stimulated-recall interview the teacher watched a clip from the instruction videos then answered questions that helped me understand the teacher's motivations behind responding in that manner. See Appendix A for the list of questions for the stimulated-recall interview.

Table 3.2

Data Types, Sources, and Purposes

Data Type	Data Source	Research Question	Items Collected
Non-participant Observation	Whole class	1, 2	30 lessons from the 6 participating teachers over the course of the study
Video	Video of the lessons (focus on the teacher)	1,2, & 3	30 lessons from the 6 participating teachers over the course of the study
Semi-structured interview	With the teacher before the series of lesson observations	3	Six 30-minute interviews, one initial interview for each of 6 participating teachers
Stimulated-recall interview	With the teacher after the series of lesson interviews	2, 3	Six 30-minute video stimulated-recall interviews, one for each of 6 participating teachers
Field Notes	Journal from classroom observations and interviews	2, 3	Thirty-six entries from reflections during and after each interview and lesson for each of the 6 participating teachers

Analysis of Data

The method I used for data analysis was a general qualitative approach using constant comparative analysis to uncover patterns and themes within my data (Strauss & Corbin, 1998). I examined excerpts of classroom data to discover categories and subcategories of teacher responses in terms of their properties and dimensions. Here, properties are the "general or specific characteristics or attributes of a category" and dimensions refer where a property sits along a continuum (Strauss & Corbin, 1998). For example, one property that helps distinguish "novice" teachers from "experienced" teachers is "presence of schemata" which is memories of teaching episodes that have been previously experienced by the teacher and impact future performance (Borko & Livingston, 1989). I developed open codes as the basis of my conceptualization of the phenomenon of teacher as the facilitator of classroom discourse and my in-depth classification of teacher questioning patterns and responses to students as well as exploration of the factors of influence for these specific teacher actions.

This study used constant comparative methods for analysis. I had a starting list of codes, Chin's (2007) questioning framework for research question 1, and a starting list based from review of literature for questions 2 and 3. Further codes emerged throughout my comparison. I compared data for all teachers among the different days of lesson observation, looking for consistency in questioning patterns and the presence of PTMs. I compared each teacher against the others for my first two research questions, looking for similarities and differences in the questioning patterns and response types that emerged for each teacher. To explore my third research question I compared the themes across teachers in terms of perceived influences for responses. Although the participating teachers were teaching different courses and different topics, their general questioning techniques and responses to students were still comparable regardless of the topic.

Data from the observations was analyzed by using a general qualitative analysis approach (Corbin & Strauss, 2008; Strauss & Corbin, 1998) to find patterns in teachers' responses during classroom discourse and discover possible influences for these teachers' chosen responses. Transcripts of video clips from the lessons, as well as transcripts from audio recordings of an initial and post-observation interview were the main data sources for analysis. Field notes taken by the observer were secondary documents that provided additional and multi-dimensional points of view on teachers' instructional decision making in the mathematics classroom. I followed a three-phase process for analysis pertaining to the first two research questions, and omitted the first phase for analysis pertaining to the third research question. I outline the phases in Tables 3.3, 3.4, and 3.5 and describe them in detail in the following paragraphs: (1) identify teacher questions and responses from each instructional lesson for analysis, (2) analyze transcripts of observations and interviews to determine initial codes, (3) create axial codes and selective codes to determine themes and use constant comparison to find similarities and differences among the participants. Following this three-phase process I triangulated among my data sources to check how the field notes, observation transcripts, and interview transcripts supported the themes I found.

Table 3.3

Three Phases of Analysis for Research Question 1

Type of Comparison	Procedure	Expected Outcomes	Questions
Phase 1 Select clips that meet the criteria for investigation (questioning in mathematical discourse)	Identify questions for analysis and video clips to be used during the stimulated-recall interview Develop a starting list of codes from previous research	To identify instances where the participant is using questioning to engage students in classroom mathematical discussion	What was the activity level of students during discussion? What concepts were being developed and to what extent?
Phase 2 Identify and compare overall question types in each selected clip	Complete initial coding of observation transcripts	To categorize the types of questioning observed	How do these question types match the criteria on my start list of codes?
Phase 3 Identify and compare question patterns	Create axial and selective codes to determine common themes in questioning Compare similarities and differences among participating teachers	To identify forms of questioning To understand the forms of questioning among teachers with various experience levels	What were the similarities and differences of questioning types across days for each teacher? What similarities and differences in questioning patterns were demonstrated among teacher participants?

Table 3.4

Three Phases of Analysis for Research Question 2

Type of Comparison	Procedure	Expected Outcomes	Questions
Phase 1 Select clips that meet the criteria for investigation (spontaneous response to students during mathematical discourse)	*Phase 1* Identify spontaneous responses for analysis and video clips to be used during the stimulated-recall interview	To identify instances where the teacher is using spontaneous response effectively to enhance student learning during mathematical discussion	Which instances show student questions or misunderstandings where the teacher has to react on the fly?
Phase 2 Identify and compare overall spontaneous response types in each selected clip	*Phase 2* Create initial codes of observation transcript using an open coding process	To categorize the types of spontaneous responses observed	What is the form of the response (question, elicit other points of view, demonstration or explanation)? What is the result of the response?
Phase 3 Identify and compare response codes	*Phase 3* Create axial and selective codes to determine common themes in spontaneous responses Compare similarities and differences among participating teachers	To identify forms of spontaneous response To understand the forms of spontaneous response among teachers with various experience levels	What were the similarities and differences of response types across days for each teacher? What similarities and differences in spontaneous responses were demonstrated among experienced teachers and novices?

Table 3.5

Two Phases of Analysis for Research Question 3

Type of Comparison	Procedure	Expected Outcomes	Questions
For Research Question 3 *Phase 1* Identify and compare overall influences through the initial and stimulated-recall interviews for each participant	*Phase 1* Create initial codes of the interview transcripts using an open coding process	To categorize the influences for teacher decisions to make a response to students	What perceived influences affect this response? Did the teacher mention any factors as a source of influence for decision-making?
Phase 2 Identify and compare the influence codes	*Phase 2* Create axial and selective codes to determine common themes in factors of influence Compare similarities and differences among participating teachers	To identify common factors of influence for teacher responses to students To understand the importance of different factors for various teachers	What were the similarities and differences among the responses made and the teachers' perceived influences for them? What major themes of influence emerge among teachers of varying levels of experience?

Research Questions One and Two – Phase One

For the initial phase of analysis pertaining to questions (1) and (2) I watched the videos from each lesson observation and chose segments of instruction from each day to analyze. For question (1) I looked for segments of instruction where the teacher used guiding questions during mathematical discussion. To be considered mathematical discussion, the teacher and students must be interchanging dialogue about some mathematical concept, problem, or procedure. I looked for segments that were long enough to show the development of at least one idea or solution to a full problem. I then transcribed the video segments, making note of pauses and teacher gestures used intentionally during instruction. I then analyzed all teacher questions within each chosen segment that were preceded and followed by either a student utterance or an intentional pause using Chin's (2007) questioning framework as a guide. I looked on a question-by-question basis to help categorize each type of question that was shown as well as examining the content of discussion more holistically to ensure the development of mathematical concepts.

For question (2) I watched the videos and made note of any response to a student utterance that seemed spontaneous – where the student asks a question or makes a statement that shows a lack of understanding and the teacher immediately addresses the misunderstanding with a response of another question, a request for other viewpoints, or a demonstration or explanation. I checked my transcription made for research question (1) and added any segments of spontaneous response that weren't already transcribed. The transcripts for each lesson segment were included for analysis as a whole, with specific segments to be analyzed for research questions one and two flagged respectively.

For the study pertaining to research question (1), I used what I have found through reading previous research, a questioning framework developed by (Chin, 2007), for a starting code list. Table 3-4 shows this list, along with a description and inclusion criteria.

Table 3.6

Teacher Responses that Stimulate Productive Thinking (from Chin, 2007)

Approach and Strategies Used	Features	When Used
Socratic Questioning	Use a series of questions to prompt and guide student thinking	To encourage student to generate new ideas based on reasoning and prior knowledge
• Pumping	Encourage students to provide more information via explicit requests	To foster student talk
• Reflective Toss	Pose a question in response to a prior utterance made by the student	To throw responsibility of thinking back to the student
• Constructive Challenge	Pose a question that stimulates student thinking instead of giving direct corrective feedback	To encourage student to reflect on and reconsider his answer if he gives an inappropriate response
Verbal Jigsaw Questioning	Focus on use of mathematics terminology, key words and phrases to form integrated propositional statements	For topics with several technical terms; for students weak in language skills

Table 3.6 Continued

• Association of key words and phrases	Guide students to form a series of propositional statements to form a coherent mental framework	To introduce factual or descriptive information and to reinforce mathematics vocabulary
• Verbal cloze	Pause in mid-sentence to allow students to verbally "fill-in-the-blanks" to complete the sentence	To elicit or emphasize keywords and phrases; for students who are not articulate or verbally expressive
Semantic Tapestry Questioning	Help students weave disparate ideas together into a conceptual framework	To focus on ideas and abstract concepts; for concepts not associated with an abundance of technical terms
• Multi-pronged questioning	Pose questions from different angles that address multiple aspects of a problem	to help students view a problem from different angles and perspectives
• Stimulating multi-modal thinking	Pose questions that involve the use of a range of thinking (e.g., verbal, visual, symbolic, logical-mathematical) using talk, diagrams, visual images, symbols, formulas, and calculations	To encourage students to think in a variety of modes and understand the concept from multiple perspectives
• Focusing and Zooming	Guide students to think at both the visible, macro level and at the micro or molecular level; or use questions that zoom "in and out," alternating between a big broad question and more specific focused questions	To help students understand a concept at both the macro, overarching level and the micro, in-depth level
Framing Questioning	Use questions to frame a problem, issue, or topic and to structure the discussion that ensues	To help students understand the relationship between the question and the information that it addresses
• Question-based prelude	Use question-answer propositions; questions act as an advance organizer and lead in to information presented subsequently	For expository talk to preface declarative statements and to focus student thinking
• Question-based outline	Present a big, broad question and subordinate or related questions visually (e.g., on slides)	Used to visually focus students' thinking and help students see the links between the big question and subordinate questions
• Question-based summary	Give an overall summary in a question-and-answer format to consolidate key points	At end of a lesson to recapitulate key concepts succinctly

Additional codes emerged through my analysis and are described similarly to those above in Chin's (2007) framework. These emergent categories are classroom management, feedback, and clarification. They are not as integral to classroom discussion but provide a richer description of sampled teachers' questioning and responses.

Table 3.7

Additional Codes for Teacher Questions and Responses

Approach and Strategies Used	Features	When Used
Classroom Management	Use statements in response to students.	Used to maintain a learning environment suited to meeting the learning objectives
• Redirect/Activity Management	Teacher responds to a student comment or acts with the goal of keeping students engaged with the learning task	
• Relationships	Teacher responds to students in order to relate to them and build relationships outside of the content area	
Feedback	Use statements or questions in response to students	Used to provide students with feedback based on their responses or questions
• Repetition	Teacher repeats the students answer and expresses agreement either implicitly or explicitly.	
• Rephrasing	Teacher rephrases the students answer and infers agreement either implicitly or explicitly	
• Corrective	Teacher responds to a student’s misconception by giving a correction	
Clarification	Use statements or questions in response to students.	Used to clarify a previous statement or question

Research Questions One and Two – Phase Two

After choosing segments of dialogue, where each segment is a series of related student-teacher interchanges, I considered each teacher question and surrounding student utterances separately as a unit of analysis. I examined each teacher question with regard to a starting code list from the framework of questioning developed by Chin (2007) and created a category to label every question presented in the transcript. Chin’s categories for questioning appeared to be trans disciplinary and were applicable to mathematical discourse. They encompassed a majority of questions a mathematics teacher would ask during classroom discussion, but I kept an open mind to create new categories of questioning for the items that did not fit this framework. New categories that developed from my analysis were classroom management, and feedback categories. I checked inter-rater reliability by having 4 colleagues' code transcripts from one teacher using my initial code list after 20 minutes of training on the definitions and inclusion criteria from the list. Inter-rater reliability averaged 60% for the five reviewers over the five lessons for that teacher. This percentage is not high, so after this review we sat as a group to discuss the ratings. The biggest discrepancies came when reviewers coded a question using multiple codes instead of choosing the best code for each. Otherwise, the most discrepancies came from the Socratic questioning and semantic tapestry categories. We decided multiple codes were allowed, especially for multi-part questions and responses. We then discussed the definitions and examples for each subcategory within Socratic questioning and semantic tapestry as a group and then worked in pairs to come to a final agreement on the codes for this teacher. I used the amended code descriptions as I analyzed the data for the remaining teachers.

To address research question (2) I used an open coding process for qualitative research to distinguish among types of spontaneous response observed in each. Open coding was appropriate in this case as used from traditional grounded theory (Glaser & Strauss, 1967). Generic categories of spontaneous responses emerged as I analyzed the transcripts to help label the actions of the teachers as they responded to students. . After creating codes for these types of responses I debriefed with my committee chairs and checked against previous research on informal assessment and spontaneous response for credibility of my codes. I incorporated some pre-planned questions in the stimulated-response interview that allowed me to member check for a response being spontaneous instead of planned. The stimulated-response interview was a semi-structured interview where a short list of pre-planned questions were asked to the teacher after I showed a researcher-chosen video clip of the teacher's instruction. See Appendix A.

Research Questions One and Two – Phase Three

Once I split each instructional segment into pieces containing one question or response and categorized them, I began the process of re-assembling the data to find emergent patterns in questioning and spontaneous responses for each teacher using NVivo software. I used constant comparison to compare the questioning and spontaneous response types among different days for the same teacher and among different teachers, looking for similarities and differences in patterns of questioning and response. I expected to find similarities in the types of questions asked and in the ways teachers responded to students and looked in particular for examples of exemplary practice by finding contrasting patterns between experienced and novice teachers.

I refined the categories of teachers' questioning and spontaneous response by adding to, deleting from or modifying the tentative codes lists and clustering related codes together. I started with four categories taken from Chin (2007): Socratic questioning, verbal jigsaw, semantic tapestry, and framing. Using the three dimensions of questioning suggested by Carlsen (1991)– context of questions, content of questions, and responses and reactions to questions– I analyzed my codes further to interpret more deeply and make decisions about revising my categories and subcategories of questioning and spontaneous response.

Research Question Three – Phase One

To analyze the sources of influence for each teacher's in-class responses to students I first needed to understand each teacher's instructional philosophy and philosophy of questioning. I reviewed the initial interview transcript and corresponding field notes, creating open codes to categorize the key instructional features and characteristics for each teacher. I had ideas for potential sources of influence from reading previous research, and through open coding of the initial interview transcript and stimulated-recall interview transcript I created initial codes based on the factors identified through previous research (mathematical knowledge for teaching (MKT), experience, beliefs, and preferences) as well as any additional emergent factors that surfaced, such as time, content knowledge, and reflection. I debriefed with my advisor and compared codes from the initial and post interviews to verify consistency with my findings.

Research Question Three – Phase Two

After I created my initial codes, I used axial and selective coding to cluster categories and find emerging themes of perceived influence for each teacher. I used constant comparison among experienced teachers, among novice teachers, and between novice and experienced teachers to explore similarities and differences among the participating teachers. I looked for common themes in factors of influence among the novice teachers and experienced teachers and also examined the deviant patterns of influence to look for factors that might indicate exemplary practice. I used member checking and debriefing with my committee chairs to verify credibility of the themes of influence I found.

Table 3.8

Understanding my Research Questions

(Research Questions)	What do I need to know?	Why do I want to know this? (Rationale)	How can I know this? (What data will help answer this?)	Interview questions
What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion?	What are the questioning patterns of novice teachers? What are the questioning patterns of experienced teachers?	Shift to student-centered learning necessitates high-quality teacher responses (Chin, 2006; Hoffman, et al., 2012) CCSSM and RTTT result in renewed focus on teacher quality (Goe, & Stickler, 2008)	Classroom observations Field Notes Initial Interview	How would you describe your teaching philosophy? How would you describe your philosophy of questioning in the classroom? Do you have any sort of classification of questions in your mind? Explain.
What similarities and differences exist in spontaneous responses to student-initiated discussion between novice and experienced teachers when guiding a classroom mathematical discussion?	What are some types of spontaneous response shown by teachers? What differences in spontaneous responses exist among novice and experienced teachers?	Informal formative assessment is done through spontaneous response (Ruiz-Primo, & Furtak, 2007) Teachers need to be able to improvise to facilitate discussion and learning (Ruiz-Primo, & Furtak, 2007)	Classroom observations Field Notes Initial Interview Stimulated-Recall Interview	What are your criteria for judging whether or not your questioning is eliciting desired outcomes? Do you think about your question asking outside of class? When and in what ways? How do you respond to student answers? What types of feedback do you give? How do students expand upon correct answers? How do students interact with one another and initiate questions? Can you recall any of your thoughts when you asked that question? Did anything that occurred in class influence your decision to ask that question? Explain.

Table 3.8 Continued

What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers?	What possible factors influence teacher responses? What are teacher-perceived factors that impact responses? How do the factors of influence differ for novices and experienced teachers?	MKT (Hill, Schilling, & Ball, 2008) Experience (Borko, & Livingston, 1989) Beliefs & Preferences (Begeny, et al., 2008) Link between these factors and student achievement (Borko & Livingston, 1989; Hill et al., 2004)	Initial Interview Stimulated-Recall Interview Field Notes	What experiences have influenced how you ask questions in the classroom? What information were your choices [in a particular episode] based on? Did anything that occurred in class influence your decision to ask that question? Explain. What information did you base that decision on [decision to respond in a particular way]? Was there anything else you thought of doing at that point but decided against? What influenced this decision?

Issues of Trustworthiness

Studies of a qualitative nature do not follow the same rules for design as experimental or quasi-experimental studies. This difference does not allow for a relaxation of the rules of rigor, however. Instead it requires a different way for explaining this rigor. Trustworthiness is a way for qualitative researchers to control potential sources of bias in a study's design, implementation, analysis, and interpretation that parallels the notions of internal validity, external validity, reliability, and objectivity from more conventional, scientific studies (Lincoln and Guba, 1986). The four criteria considered in the design of this study and implementation of this study, credibility, transferability, dependability, and confirmability, are explained below.

Credibility (Internal Validity)

Credibility, a key criterion for trustworthiness, is a way for qualitative investigators to ensure that their study measures or tests what is intended (Shenton, 2004). Several strategies for ensuring credibility are explained by Lincoln and Guba (1986) and Shenton (2004) and are used in this study.

One key way to address credibility is “the adoption of research methods well established both in qualitative investigation in general and information science in particular” (Shenton, 2004). Specific procedures used throughout the data collection, analysis, and interpretation in this study have been selected from those already well established. The interview questions for both initial interviews and stimulated-recall interviews were only slightly modified from questions that had been used in other studies. General qualitative approach and constant comparative analysis was used to ensure credibility as well.

Another strategy used to ensure credibility is triangulation, “cross-checking of data by use of different sources, methods, and at times, different investigators” (Lincoln and Guba, 1986). The researcher used interview transcripts, lesson observation video footage and transcripts, as well as observer field notes to triangulate and verify the findings of this study. Another form of triangulation uses a wide range of participants (Shenton, 2004). Viewpoints of individuals can be compared and verified against others, and a richer description of the phenomena studied can be developed. In this study, the researcher used teachers from 6 different schools and compared novice teachers to expert teachers to gain a richer view of questioning and responses to students.

Peer debriefing, "meeting with a disinterested professional peer to keep the inquirer honest," is another strategy used in this study to ensure credibility. The researcher met with her advisers to consult about emerging design and themes. The researcher also discussed one case thoroughly with peer researchers, who also helped verify inter-rater reliability of the initial code list.

Another strategy used in this study was member checks. Lincoln and Guba (1986) consider this "the single most important provision that can be made to bolster a study's credibility." The researcher used verbatim transcriptions from video and audio recordings and also sent an abridged version of the results chapter, individualized to contain all results and context pertinent to each participant for the participants to verify the accuracy of the data. Each participant was also given the opportunity to request to preview the results in their entirety.

Transferability (External Validity)

Transferability represents the applicability of a study's findings to other situations. In particular, researchers are concerned with the extent to which the "results of the work at hand can be applied to a wider population" (Shenton, 2004). This case study describes results for a small number of participants that are specific to those individuals and environmental contexts. Lincoln and Guba (1986) suggest that it is the researcher's responsibility to provide "sufficient contextual information about the fieldwork sites" to let the reader determine the transferability.

A strategy suggested by Shenton (2004) to help ensure transferability is a thick description of the phenomenon being studied. Lincoln and Guba (1986) also recommend a narrative to be developed about the context so readers can judge whether or not to apply all or part of the findings to other contexts. The researcher used both of these strategy suggestions in this study.

Dependability

The issue of dependability refers to the idea of another researcher being able to repeat the same work, in the same context, with the same methods and participants, and get similar results. Shenton (2004) suggests the researcher to report the processes within the study in detail so that future researchers would be able to repeat the work. For this study, the researcher documented all processes in detail, and then shared with advisors to help evaluate the processes to confirm dependability.

Confirmability

In qualitative research, confirmability refers to the researchers concern with objectivity. This ensures that the ideas expressed in terms of findings result from the experiences and ideas of the participants rather than being biased by the researcher's (Shenton, 2004). Triangulation was used as a strategy to reduce the effect of researcher bias. The researcher also included a subjectivity statement with this study, clearly explaining all possible sources of bias and planned strategies to account for them. Debriefing with advisors also helped the researcher to maintain objectivity throughout the analysis of data and in developing resulting themes. Another additional strategy used by the researcher to maintain awareness of and reduce bias was to take field notes and spend time in written reflection after every experience in the field.

Summary

This study explored the types of questions asked by three novice and three experienced teachers and the spontaneous responses they gave to students during pivotal teaching moments (PTMs). In addition, the researcher attempted to understand the perceived influences upon questions asked and responses to students for these teachers. Guided by a framework of cognitive development, as described in the beginning of this chapter, the study used a multiple case study design. Three types of data sources, including semi-structured and stimulated-recall interviews, classroom observations, and field notes, were used in this study. A general qualitative approach with constant comparative analysis was used to explore the research questions. Various strategies, such as triangulation, using multiple sources of data and established methods, peer debriefing, member checks, and detailed descriptions of setting and methods were used to ensure credibility, transferability, dependability, and confirmability of the study. The following chapter will report findings as related to the three research questions, including three findings and ten themes.

CHAPTER FOUR

RESULTS

The purpose of this study was to understand the quality of teachers' in-class response patterns in terms of questioning and statements as they facilitated mathematical discussion as well as to explore potential factors that influenced each teacher's responses. The following research questions were addressed: (1) What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion? (2) What similarities and differences exist in responses to students during pivotal teaching moments (PTMs) between novice and experienced teachers when guiding a classroom mathematical discussion? (3) What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers?

The researcher used multiple sources of data, observations, interviews, and field notes, to explore the above questions and triangulate the findings. Table 4.1 shows the findings of this study as well as the sources where each finding was drawn. These findings will be explained in depth in the following paragraphs. Each finding was corroborated by multiple data sources, providing a more comprehensive understanding of the questions asked by teachers, their reactions to PTMs, and the perceived influences behind their response patterns in class.

This chapter consists of four sections, discussing the findings from each of the above mentioned research questions. First, the researcher examines the similarities and differences among teachers in the number of questions asked. Additionally, the questions asked were categorized according to the questioning framework of Chin (2007), and additional categories – classroom management, feedback, and clarification, emerged through the process. Second is an examination of the patterns of teacher responses during pivotal teaching moments, where the flow is disrupted and the teacher has an opportunity to modify instruction to improve students' mathematical understanding. Two contrasting trends exhibited by participants were to emphasize procedures and to emphasize the importance of making connections or providing motivation to learn new strategies. Additionally, the researcher examined the questions asked by students and how it relates to the frequency and variety of questions the teacher asked. The third section includes a discussion of three perceived influences for teacher responses: (1) Reflection on experience and MKT, (2) time, and (3) relationship with students, teachers, and parents and knowledge of student background.

Table 4.1

Matrix of Findings and Sources for Data Triangulation

Major Findings	Source of Data		
	O	I	F
Question 1: What similarities and differences exist in questioning patterns between the novice and experienced teachers when guiding a classroom mathematical discussion?			
Finding 1: Differences in frequency of questions asked and in variety of question types used.			
Theme 1.a. The three experienced teachers asked more questions each lesson than two of three novice teachers.	X		X
Theme 1.b. The experienced teachers had a greater variety of question types and offered more feedback to students than novice teachers.	X		X

Table 4.1 Continued

Question 2: What similarities and differences exist in responses to students during pivotal teaching moments between the novice and experienced teachers when guiding a classroom mathematical discussion?			
Finding 2: The experienced and novice teachers responded in various ways to pivotal teaching moments, with emphasis on proper procedures, making connections, and motivating new strategies.			
Theme 2.a. Both novice and experienced teachers emphasized the importance of proper procedures but reflected this emphasis differently through classroom instruction and questioning.	X		X
Theme 2.b. Two teachers, one experienced and one novice, chose questions to ask and responses to give based on emphasis on connections within and outside of mathematics.	X	X	X
Theme 2.c. One experienced teacher placed special emphasis on motivation to learn new strategies.	X		X
Theme 2.d a. Classrooms where teachers emphasized connections and motivation for learning new strategies showed the highest frequency of student asked questions.	X		X
Question 3: What perceived factors impact the responses the teachers give to students' ideas, and how are these factors of influence different among the novice and experienced teachers?			
Finding 3: There were multiple perceived influences for the teachers' question asking and responses to students.			
Theme 3. a. The novice teachers demonstrated a perceived knowledge of mathematics, but believed years of experience would improve their skills with question asking.	X	X	X
Theme 3.b. The experienced teachers had perceived knowledge of mathematics and MKT, but could not extricate experience when explaining the factors of influence for their question asking and responses.		X	X
Theme 3.c. All six teachers expressed concern with a lack of instructional time.		X	X
Theme 3.d. Three teachers, one experienced and two novice, described their students' backgrounds and the relationship they had with their students as an influence on their questioning.		X	X

Note: In this table, O=observations, I=interviews, F=field notes.

Similarities and Differences in Questioning Patterns between Novice and Experienced Teachers

After analysis of lesson observation transcripts from novice and experienced teachers, the researcher found differences and similarities among the teacher participants. These comparisons are described in terms of frequency and variety of questions asked in the sections to follow. Table 4.2 shows the frequencies and percentages in each category of questioning for teacher participants.

Table 4.2

Frequencies and Percentages of Questions in each Category of Questioning

	Frequency (Percentage of Total ≥1%)					
Category	Tom	Dana	Amy	Samantha	Noah	Kathleen
Verbal Jigsaw	17 (5)	10 (5)	33 (14)	0	3 (3)	17 (7)
Semantic Tapestry	21 (7)	7 (3)	5 (2)	0	0	0
Framing	13 (4)	3 (1)	3 (1)	1 (1)	1 (1)	0
Classroom Management	2	4 (2)	8(3)	25 (32)	14 (12)	29 (12)
Feedback	105 (33)	68 (31)	88 (36)	15 (19)	28 (25)	59 (25)
Clarification	23 (7)	21 (6)	2 (1)	7 (9)	8 (7)	36 (15)
Total	318	216	244	78	114	236

Note: Some questions were assigned multiple codes.

Theme 1.a: Frequency of Questions

The researcher first examined the number of questions asked by each teacher in each lesson. After comparing to ensure similarity of frequencies among the five lessons for each teacher, an average number of questions per lesson for each teacher were calculated. Table 4.3 displays these average per-lesson frequencies for each teacher. Notice the disparity in frequency of questions asked between novice and experienced teachers five of six cases. Tom, who asked the most questions of his students, explains his reasoning for doing so.

> I would say that I'm still traditional, and it's interesting that this is focused on questioning because that is my primary teaching tool as being a primarily a lecturer or traditional teacher. It's my primary way of relaying information, engaging students, and also giving feedback on how well these students are processing the information (Tom's initial interview, April 2013).

Dana and Amy cited similar reasons for asking more questions during instruction, explaining the need to engage the students and check frequently for understanding.

Table 4.3

Average Frequency of Questions per Lesson for Five Observed Lessons

Teacher	Average frequency
Tom	59
Dana	33
Amy	42
Samantha	14
Noah	18
Kathleen	43

Kathleen, a first-year teacher who asked an average of 43 questions per lesson, had a higher average than the other novice teacher participants. She explained her philosophy for questioning in addition to the expectations she placed on her students.

> [Students] are responsible for their own learning. I obviously set them up for success in my planning and how I conduct my planning, but they are kind of in charge of what they learn. I give them some kind of leading questions, but we also talk about why this is and how this works and how did you get this answer. (Kathleen's initial interview, October, 2013)

Kathleen's explanation of her questioning practices, as well as her discussion at other points during the interview about student engagement and understanding, help to distinguish her among the other two novice teachers. Both the frequency of questions asked and the explanation she gave during the interviews align more with that of the experienced teachers. The other two novice teachers asked fewer questions and gave different explanations of their questioning practices during interviews. Samantha described the questions she asked as "What comes next?" questions and stated that she had forgotten some of what she learned in her pre-service education courses about questioning (Samantha's initial interview, October 2013). Noah gave an explanation in his interview that he used questioning to engage students, prompt students for "What is our next step?", and to ask questions such as "Why do we do this?" (Noah's initial interview, October 2013). His explanations and reasoning appear to be similar to that of Kathleen's, but examination beyond basic frequencies of questions was necessary to gain a more complete picture of the differences between these teachers' questioning practices.

Theme 1.b: Variety of Question Types and Feedback

Initial examination of frequencies alone cannot create a complete picture of these teachers' questioning practices, so research continued with an analysis of the categories of questioning used according to Chin's questioning framework Chin (2007). Table 4.2, found at the beginning of this section, displays the relative frequencies within each category of questioning as given by each teacher. Note that this table displays the frequencies with regard to general categories but does not break the occurrences into subcategories of questioning. Tables 4.5, 4.7, 4.8, and 4.9 show each major category of questioning broken into subcomponents for each teacher.

Table 4.2 shows a distinction between the novice and experienced teacher participants in all categories. These differences will be outlined in the following paragraphs and shown in more detail within subcategories for each.

Previous research describing the priority for instructional decision making in terms of classroom management over student learning is confirmed by these study participants, evidenced by the higher number of classroom management questions for the observed novice teachers than for the experienced teachers (Borko & Livingston, 1989; Hogan et al., 2003). The following is sample dialogue taken from Noah's day one lesson.

Table 4.4

Noah's Classroom Dialogue Represents Novice Teacher Questions

	Classroom Dialogue	Coding	Sub-coding
Teacher	What we do to set these up is separating looking at 6x and 15 so I want you to figure out what number goes into both of those. [S1]?	Socratic Questioning	Pumping
Student 1	3		
Teacher	3. …And when you multiply you get 6x+15.	Feedback	Repetition
Student 2	But then how do we solve it?		
Teacher	There's nothing to solve because there is no equal sign. …How did you guys do on that one?	Classroom Management	Redirect/ Activity Management
Student 3	I got it right.		
Teacher	Simplify; simplify these two monomials multiplied together so since everything is multiplied we're able to use the commutative property and the associative property. …		
Student 4	S4: Woohoo, I got it right!		
Student 5	Yes!		
Teacher	So since this is still simplify, you can still use that term because if you handed this to somebody and told them ok y is going to equal -2, they only have to stick y in after the 32 here, and their answer would be as simple as possible. … Does that help [S6] with your question?	Classroom Management	Redirect/ Activity Management
Student 6	Yeah.		
Teacher	Last one. Simplify this algebraic expression. …First step that I do is try and simplify the fraction part of it. 10 over 35.		
Student 7	Oh.		
Teacher	So I know, 10 and 35, what number can go into both of them?	Socratic Questioning	Pumping
Students	5		

Questions such as Noah's were more prominent in the dialogue of novice teachers than that of the experienced teachers. Questions to check for understanding of classroom procedures, to build or maintain relationships with students, and to manage the lesson activities fell into this category.

In a related vein, the researcher was not surprised to see more feedback given by experienced teachers than by novice teachers in this study. Past research has described novice teachers as more prone to monitoring their own actions and verbalizations than that of their students and giving first priority to controlling the classroom environment rather than thinking about how to enhance learning opportunities (Borko & Livingston, 1989). The dialogue in Table 4.4 above does show instances of feedback, but feedback given by the novice teachers in this study was 59% repetition, 41% rephrasing of a student response. A subcategory of Socratic questioning, constructive challenge, is a more productive type of feedback that challenged students to further their thinking (constructive challenges). Of the 29 constructive challenge questions given by novice teachers, 25 of them came from Kathleen's lessons, as shown in Table 4.5. Experienced teachers had 53% of feedback being repetition and 47% rephrasing with total frequency of feedback being more than 3 times the number of novice teachers. Experienced teachers in this study had a total frequency of 40 constructive challenge questions (about three-fourths as many as novice teachers), with 22 of these coming from Dana's lessons.

Examining Table 4.5 further, the variation in proportion of reflective toss and constructive challenge questions seemed to have no clear pattern or distinction. Samantha did not utilize either of these two subcategories, and Dana used only constructive challenges in addition to pumping questions. The other four teachers used all three subcategories of questioning, with 75% of questions on average being pumping questions and 25% being the other two subcategories. The proportion of reflective toss and constructive challenge varied depending on the teacher. Teacher questioning that elicits further student thinking and promotes classroom dialogue is important for formative assessment (Chin, 2006). The researcher found through analysis of these transcripts that those questions in the reflective toss and constructive challenge categories were more likely to promote this further dialogue among multiple students than questions in the pumping category.

Table 4.5

Frequencies of Socratic Questioning Subcategories of Questioning

	Frequency (Percentage of Total ≥1%)					
Subcategory	Tom	Dana	Amy	Samantha	Noah	Kathleen
Pumping	103 (32)	81 (38)	87 (36)	30 (38)	42 (36)	69 (29)
Reflective Toss	23 (7)	0	7 (3)	0	14 (12)	1
Constructive Challenge	11 (3)	22 (10)	11 (5)	0	4 (4)	25 (11)

The most varying results found through examination of Table 4.2 were the bands of questions in the middle of each column: framing, semantic tapestry, and verbal jigsaw. Novice teacher participants used only some or none of these categories for questioning, but experienced teachers asked questions from all three in differing proportions. Table 4.6 illustrates the use of questions in these categories by an experienced teacher, Tom.

Table 4.6

Tom's Questions Represent Various Questioning Types

	Classroom Dialogue	Coding	Sub-coding
Teacher	… I think most of you were ok with the setup in number 2 to find the measure of angle B, but then solving it can be a little tricky. Alright, so we're going to use the	Framing	Question-Based Prelude

Table 4.6 Continued

	Law of Sines, so there's the Law of Sines. Uh, [Student 6] can you tell us your initial set-up?		
Student 6	49.69		
Teacher	49.69? Ok, so we will approximate that to 49.7 degrees, to the nearest tenth. …You might remember when we talked about triangle congruence, uh, many many months ago, we had an ambiguous case. So we had ASA, we had SAS, we had SSS. Which one	Feedback	Repetition and Rephrasing
	was the ambiguous case? *[pause for 4 seconds]* Do you remember which one was the	Verbal Jigsaw	Key Words and Phrases
Teacher	ambiguous case? No, not quite? [Student 7], how about you? No? What's that? SSA.	Socratic Questioning/ Classroom	Pump/ Redirect/Activity Management
Student 8	SSA, thank you [Student 8]. Yes, SSA was	Management	
Teacher	the ambiguous case. [Student 9], what set-up do we have here? Um, SSA.	Feedback	Repetition Pump
Student 9	*[nods]* We have SSA. So notice in this case,	Socratic	
Teacher	that we have the set-up of SSA. [Student 10], what did it mean for it to be the ambiguous case? What was implication on that? What does ambiguous mean? Uh, ambiguous means not clear, it can go	Questioning Feedback	Rephrase Key Words and Phrases
Student 10	one of many ways [*gestures back and forth*	Verbal Jigsaw	
Teacher	*with his arm horizontally]* Oh, because the angle wasn't like fixed. Like it has two, uh, more than one angle.		
Student 10	Ok, how many different types of angles did we have?		
Teacher	Two Two, yeah. So with the ambiguous case we		Pump
Student 10	could have two possible triangles. You guys	Socratic	
Teacher	might remember it was the swinging gate idea. *[draws a diagram to represent the swinging gate idea on the board and continues to explain verbally and visually with a diagram on the chalkboard]*. … So you've got two different possibilities. Alright? So, what that insinuates is that there's potentially two different triangles to solve. So B can not only be 49.7 degrees, but it can also take on what other value? *[3 second pause*] What other angle measure can B take on such that the sine of B takes on this value? [Student 11]? Um, one hundred and thirty-one, thirty point three.	Questioning Feedback Classroom Management Semantic Tapestry	Repetition Activity Management Stimulating Multi-modal Thinking Reflective Toss
Student 11	One hundred thirty point three. [Student 12], do you agree with him?	Socratic Questioning	Repetition Reflective Toss
Student 12	No		

Kathleen utilized verbal jigsaw (7% of questions asked), Noah used only 3% of verbal jigsaw questions and one framing question, and Samantha only asked one question from the framing category. Of the experienced teachers, Tom had the most equal proportion of use among the three categories (4% framing, 7% semantic tapestry, and 5% verbal jigsaw questions). Dana showed the most limited use of the experienced teachers from these categories (1% framing, 3% semantic tapestry, and 5% verbal jigsaw). Amy showed a similar overall usage of questions from these categories but had a disproportionately large amount of verbal jigsaw questions (14%) compared to semantic tapestry and framing. Questioning that uses a variety of the above categories is more likely to scaffold and extend student thinking, and teachers who use questions from these categories are very purposeful in asking them, following up on a previous student response in a productive way (Chin, 2007).

Table 4.7 shows the distribution of verbal jigsaw questions, where verbal cloze represents a "fill-in-the-blank" type of questioning, and the other category relates to vocabulary associated with specific mathematical concepts. Emphasis on the proper vocabulary is critical for success in promoting productive mathematical discourse among students in the classroom (NCTM, 2014). As this figure shows, experienced teacher participants were using questions from the key words and phrases category, but novice teacher participants were not.

Table 4.7

Frequencies of Verbal Jigsaw Subcategories of Questioning

	Frequency (Percentage of Total ≥1%)					
Subcategory	Tom	Dana	Amy	Samantha	Noah	Kathleen
Key Words & Phrases	8 (3)	7 (3)	3 (1)	0	0	0
Verbal Cloze	9 (3)	3 (1)	30 (12)	0	3 (3)	17 (7)

In the clip of instruction in Table 4.6 above, Tom asks a question about the meaning of “ambiguous case.” In the stimulated-recall interview, he explains that he had assumed this definition would be “prerequisite information” (Tom’s stimulated-recall interview, April, 2013). As he watched the video clip, Tom reflected upon his experience and admits he was taken aback by the fact that some of his students were unfamiliar with the term. He might never have discovered the issue had he not asked the question, however.

Other experienced teachers had similar explanations for the need to be sure students were able to understand and communicate effectively using key words and phrases from mathematics. Amy used a connection to English grammar as she taught the idea of substitution in her algebra class.

> Substitution works and we do it all the time in English. So to drop the analogy of using a thesaurus to substitute words. It’s the same thing. The most common mistake kids will make is they’ll leave in if they’re substituting 2y+3 for x they’ll leave in the 2x (2y+3) so if you say it in a sentence where you’re substituting the word and you leave the other word in it sounds absurd but then they do the same thing in math.” (Amy’s stimulated-recall interview, November 2013).

Novice teacher participants were more likely to assume the vocabulary and key phrases were clear for students. Pacing was an issue for two of the three novice teachers observed, and discussion that centered on conceptual understanding or vocabulary were often cut short in the interest of time (field notes for Noah and Samantha, October 2013).

Table 4.8 depicts the variation among experienced teachers within the semantic tapestry category of questioning. Semantic tapestry questions emphasize conceptual understanding as well as providing emphasis to multiple modes of thinking within a mathematical topic. The novice teachers studied did not use questions from this category, but all experienced teacher participants used at least five questions from this category during the time they were observed.

Table 4.8

Frequencies of Semantic Tapestry Subcategories of Questioning

	Frequency (Percentage of Total ≥1%)					
Category	Tom	Dana	Amy	Samantha	Noah	Kathleen
Multi-Pronged Questioning	5 (2)	3 (1)	1	0	0	0
Stimulating Multimodal Thinking	8 (3)	4 (2)	3 (1)	0	0	0
Focusing and Zooming	8 (3)	0	1	0	0	0

Tom used almost equal proportions of each of the subcategories within semantic tapestry (38% focus and zoom, 38% Stimulating multi-modal thinking, and 24% multi-pronged questioning), which relates to the emphasis he expressed for students being able to understand detail within a problem as well as being able to generalize and represent the mathematics they learned in different ways. In his interviews, Tom expressed a firm belief that students be able to “handle mathematics” in what he refers to as “the three modes of mathematics, and that’s analytical, graphical, and verbal approach" (Tom's initial interview, April 2013). He expressed particular interest in the relation between these three.

Dana paid careful attention to potential misconceptions and addressed them directly as she taught (field notes, October 2013). She used her classroom questioning to be sure students were aware of the conceptual issues related to common misconceptions related to the topics she taught.

Amy showed through her interviews and posters adorning her classroom walls her beliefs that representing mathematics and solving problems using different methods are important to achieve success in mathematics (Amy's initial interview, October 2013, Amy's stimulated-recall interview, November 2013, field notes, November 2013). These convictions correspond to her use of questions from all three subtopics within semantic tapestry as well.

Of the novice teacher participants, Samantha expressed her surprise that students were unable to pick up on the connections between similar topics in different lessons during the week and frustration that she ran out of time in class to emphasize the conceptual ideas more.

> I guess I was hoping someone would notice it and then we can quickly discuss the fact that they're both parabola shapes and I don't know if I told this class, but I said that x was where it went through the x-axis. … We barely got through it in the other section this morning so I knew we wouldn't really get through all of it there. So I figured actually preparing them for what was going to be on the test versus fun conceptual things. Time wise it was less important (Samantha's stimulated-recall interview, November 2013).

Table 4.9 shows the relative frequencies of questions found within the subcategories of framing. Framing questions are meant to introduce lessons, place emphasis on essential ideas within the lesson, and provide a way to summarize the lesson. Tom was the only experienced teacher to use all three subcategories within framing. An important distinction to be noted from initial interviews is that Tom noted his primary instructional technique to be questioning (Tom's initial interview, April 2013). As Tom planned his lessons around the questions he would ask. The other teachers explained in interviews that they may plan a few questions in advance, but they do not build their lessons around the questions they ask.

Table 4.9

Frequencies of Framing Subcategories of Questioning

	Frequency (Percentage of Total ≥1%)					
Category	Tom	Dana	Amy	Samantha	Noah	Kathleen
Question-Based Prelude	10 (3)	0	3 (1)	1 (1)	1 (1)	0
Question-Based Outline	1	0	0	0	0	0
Question-Based Summary	2	3 (1)	0	0	0	0

In summary, there were distinct differences between the experienced and novice teachers observed, both in terms of quantity of questions asked and in the diversity of question types used. Particularly interesting in light of previous research about classroom questioning and discourse (Chin, 2006, 2007; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001) are the findings within the categories of semantic tapestry, framing, and verbal jigsaw. Every teacher showed a different pattern of usage with regard to these categories and their respective subcategories. Novice teachers in this study showed little or no use of questions from these categories, which suggests a deficiency between novice and experienced teachers with regard to effective classroom questioning practices (Chin, 2007; NCTM, 2014). See Table 4.10 for the complete set of data for questioning types.

Table 4.10

Frequency of Questions within each Category and Subcategory

	Frequency (Percentage of Total ≥1%)					
	Tom	Dana	Amy	Samantha	Noah	Kathleen
Socratic Questioning	137 (43)	103 (48)	105 (43)	30 (38)	60 (53)	85 (36)
Pumping	103 (32)	81 (38)	87 (36)	30 (38)	42 (36)	69 (29)
Reflective Toss	23 (7)	0	7 (3)	0	14 (12)	1
Constructive Challenge	11 (3)	22 (10)	11 (5)	0	4 (4)	25 (11)
Verbal Jigsaw	17 (5)	10 (5)	33 (14)	0	3 (3)	17 (7)
Key Words & Phrases	8 (3)	7 (3)	3 (1)	0	0	0
Verbal Cloze	9 (3)	3 (1)	30 (12)	0	3 (3)	17 (7)
Semantic Tapestry	21 (7)	7 (3)	5 (2)	0	0	0
Multi-Pronged Questioning	5 (2)	3 (1)	1	0	0	0
Stimulating Multimodal Thinking	8 (3)	4 (2)	3 (1)	0	0	0
Focusing and Zooming	8 (3)	0	1	0	0	0
Framing	13 (4)	3 (1)	3 (1)	1 (1)	1 (1)	0
Question-Based Prelude	10 (3)	0	3 (1)	1 (1)	1 (1)	0
Question-Based Outline	1	0	0	0	0	0
Question-Based Summary	2	3 (1)	0	0	0	0

Table 4.10 Continued

Classroom Management	2	4 (2)	8(3)	25 (32)	14 (12)	29 (12)
Redirect/Activity Management	1	2 (1)	5 (2)	17 (22)	8 (7)	17 (7)
Relationships	1	2 (1)	3 (1)	8 (10)	6 (5)	12 (5)
Feedback	105 (33)	68 (31)	88 (36)	15 (19)	28 (25)	59 (25)
Repetition	64 (20)	24 (11)	45 (18)	10 (13)	12 (11)	20 (8)
Rephrase	30 (9)	31 (14)	40 (16)	0	12 (11)	10 (4)
Corrective	11 (3)	13 (6)	3 (1)	5 (6)	4 (4)	29 (12)
Clarification	23 (7)	21 (6)	2 (1)	7 (9)	8 (7)	36 (15)
Total	318	216	244	78	114	236

Note. Some questions were assigned multiple codes.

Similarities and Differences in Responding to Students During Pivotal Teaching Moments between Novice and Experienced Teachers

Transcripts and field notes from the stimulated-recall interviews for each teacher were analyzed and coded using constant comparison and open coding to examine recurring themes in teachers' responses to PTMs. The PTMs were the primary focus for the stimulated-recall interviews. Note that some teachers noticed and responded to more than two PTMs, but only two were chosen for each teacher to provide focus for the interviews and later analysis of interview transcripts.

Two salient themes emerged through the analysis of teacher responses. In the sections to follow, the researcher will describe a similarity among four teachers in responding with an emphasis on appropriate procedures as well as two different emphases on connections within and outside of mathematics and motivation for learning new strategies. Another theme of note is the occurrence of more student questions that had influence on two teachers' responses, which will be discussed in finding 2.d.

Theme 2.a: Emphasis of Proper Procedures through Classroom Questioning

Analysis of the stimulated-recall interview transcripts revealed an emphasis on appropriate procedures from all of the observed teachers. Four of these teachers had a unique focus for questioning and response during a PTM that related to appropriate procedures. The procedural focus for Tom was coupled with a focus on conceptual understanding. Dana steered her students tightly toward correct procedures to avoid misconceptions. Samantha emphasized procedures and explained that lack of time prevented additional emphasis on conceptual connections. Noah emphasized procedures and made responses based on knowledge of the curriculum. The cases for these four teachers are explained in more detail in the following paragraphs.

Tom.

As he reflected on his reaction to a PTM during his stimulated-recall interview, Tom stated his goals in terms of proper procedures to follow in solving for all side lengths and angles of a triangle, but he also emphasized the importance of checking students' understanding of conceptual knowledge.

> My overall objective I think was to have them recognize, recall the ambiguous case of SSA and then move into the state where we're also recalling that with the ambiguous case there are, or there exist the possibility that two triangles, two distinct triangles, exist based on the given criteria. And then due to the fact that two triangles exist, one with an acute angle and the other one with an obtuse angle, moving them or transitioning them into the idea that we can solve both triangles and we need to solve both triangles since two triangles exist. (Tom's stimulated-recall interview, April 2013).

One episode that merited further conversation was when a lack of vocabulary knowledge surfaced. Table 4.11 shows the dialogue that occurred during this particular PTM. The deviation from Tom's planned lesson, a question pertaining to vocabulary (highlighted in bold in Table 4.11), is what triggered this PTM.

Table 4.11

Tom's Classroom Dialogue during a PTM

Speaker	Classroom Dialogue
Teacher	SSA, thank you [Student 7]. Yes, SSA was the ambiguous case. [Student 8], what set-up do we have here?
Student 8	Um, SSA.
Teacher	*[nods]* We have SSA. So notice in this case, that we have the set-up of SSA. [Student 10], what did it mean for it to be the ambiguous case? What was implication on that?
Student 9	**What does ambiguous mean?**
Teacher	Uh, ambiguous means not clear, it can go one of many ways [*gestures back and forth with his arm horizontally]*
Student 10	Oh, because the angle wasn't like fixed. Like it has two, uh, more than one angle.
Teacher	Ok, how many different types of angles did we have?
Student 10	Two
Teacher	Two, yeah. So with the ambiguous case we could have two possible triangles. You guys might remember it was the swinging gate idea. *[draws a diagram to represent the swinging gate idea on the board and continues to explain verbally and visually with a diagram on the chalkboard]*. … So you've got two different possibilities. Alright? So, what that insinuates is that there's potentially two different triangles to solve. So B can not only be 49.7 degrees, but it can also take on what other value?

As Tom responded to student 9, he made use of gesture and verbal definition. The researcher noted during the lesson, "[Student 10] seemed to pick up on the arm motion to remember the meaning of the ambiguous case." (Observation notes, April 2013). Tom went on from there to give a more complete explanation of this ambiguous case with a diagram on the chalkboard. He explained in his stimulated-recall interview that he was surprised to hear the question asked in class.

> It might have been because we've already had this and maybe I didn't define it for you, and odds are that I didn't but the fact that the question never came up "What's it mean to be ambiguous?" and so I was a little taken back by the fact that they weren't able to come up with it. (Tom's stimulated recall interview).

He then explained his choices in the minutes that followed this question and Student 10's response to his definition. "So I think that was pretty much the prompt was that she was describing it verbally to me and I wanted to give a visual demonstration of that because from my perspective the visual is the most pertinent, the most powerful demonstration of that idea." (Tom's stimulated-recall interview, April 2013).

This interchange of events and interviews that followed demonstrates Tom's desire to help his students understand why they are completing this two-option process in solving the triangle for the case of SSA. He reiterates on numerous occasions a student's need to understand mathematics from "multiple modalities," and his actions in terms of questioning and response to PTMs aligns well with his philosophy (Tom's initial interview and stimulated-recall interview, April 2013).

Dana.

Dana emphasized the proper process in doing mathematics but had a slightly different focus. She explained that she reviews her own process in solving problems to know which questions to ask to steer her students toward a solution (Dana's stimulated-recall interview, November 2013). One PTM that the researcher chose to investigate further took place during a group activity, where students were solving an area application problem in groups. Table 4.12 shows the dialogue that occurred. Some student responses were inaudible and are marked as such.

Table 4.12

Dana Discusses an Area Application Problem with a Small Group

Speaker	Classroom Dialogue
Student 6	That's a square. So wouldn't you divide by both?
Teacher	So if you have a square with side r, how do you find area of the square?
Student 7	(inaudible)
Teacher	So let me draw you a picture. The area is the inside of this square. Now how do you find the area?
Student 6	length times width
Teacher	Ok, but what do you know about the length and width of a square?
Student 6	The same?
Teacher	They're the same. So instead of saying s times s, what could you say?

During her stimulated-recall interview, Dana explained, “I suppose I have knowledge of how to do the problem and by experience I knew this was an application problem and they would get stuck.” (Dana’s stimulated-recall interview, November 2013). Similarly, in her initial interview, Dana mentioned her ability to anticipate misconceptions and steer her students away from them. “I know where students fall into traps and I know where they struggle so it’s easier for me to ask questions that would lead to “why would you do it this way rather than that way?” (Dana’s initial interview, October 2013). This awareness of misconceptions allowed Dana to target them and steer students away from the common mistakes as they solved this application problem and during other times throughout the week of observation. The researcher’s field notes confirm these findings: “[Dana] must be steering the procedures tightly to avoid confusion among her students.” (Field notes, October 2013).

Samantha.

Samantha’s use of questioning aligned with district policy to use a gradual release model of instruction, and most questions she asked were procedural. The researcher noted in field notes the presence of PTMs and an assumption that Samantha noticed these moments (Samantha’s field notes, November 2013), but observation results show that Samantha chose not to act on all of them. The literature in the area of PTMs separate the skills of noticing and response and explain the noticing and appropriate reaction to PTMs will impact the ways students think about and develop concepts (Chin, 2007; Stockero, & Van Zoest, 2013). These results show that Samantha already exhibits the skill of noticing but is still developing the ability to react to them in a way that improves student understanding.

One PTM occurred as Samantha showed her students the expression that represents the discriminant and asked students what it reminded them of. In her stimulated-recall interview, Samantha said she hoped they would be reminded of the quadratic formula (Samantha's stimulated-recall interview, November 2013). When students failed to make this connection, Samantha chose to move on. She explains her reasoning:

> Timing. That's a bad answer, but timing. Because we barely got through it in the other section this morning so I knew we wouldn't really get through all of it there. So I figured actually preparing them for what was going to be on the test versus fun conceptual things. Time wise it was less important" (Samantha's stimulated-recall interview, November 2013).

Samantha expressed a desire to find time to explore more about the discriminant and its connection to the quadratic formula (Samantha's stimulated-recall interview, November 2013), but resigned herself to sticking with procedural questions and short responses to PTMs that did not deviate far from the path she led her students on toward the solutions.

Noah.

Noah, another beginning teacher who maintained emphasis on procedures, followed his textbook curriculum closely and made all responses to PTMs with upcoming lessons and units in mind. Noah also recognized PTMs as they occurred in his classroom (Field Notes, November 2013), and made a conscious choice based on curriculum and knowledge of his students' abilities whether or not to respond in a way that deviated from his pre-planned lesson.

Table 4.13 displays classroom dialogue where a student discovers a pattern, and Noah decides to cut the student off in case he would extend the pattern too quickly. Throughout this dialogue, the teacher emphasizes appropriate procedures related to simplifying expressions with negative exponents, but he takes some time to demonstrate why the rule works. Noah also used unique phrases throughout his instruction, such as "everyone's best friend" and "pineapple upside down cake" to help students remember traditional concepts and procedures in terms of metaphors and non-traditional rules.

Table 4.13

Noah's Classroom Dialogue during a PTM

Speaker	Classroom Dialogue
Teacher	It is dividing by 2 every time that we go down.
Student 11	Or it's multiplying by 2 every time you go up.
Teacher	Or it's multiplying as we go up. So here's my question then. What's half of 2?
Multiple Students	One!
Teacher	One, so hopefully this makes more sense then, of why we're going down in powers and 2^0 is 1. Noticing that we have a pattern going on here. Each time that we go down in power, for our 2's we are dividing by 2 or cutting it in half.
Student 12	.5
Teacher	Ok, so thank you, half of 1 is ½ or 0.5.
Student 13	¼, 1/8
Teacher	[Student 13], that's enough. Ok, so for ½ we're to cut 1 in half so continuing the power, ½ can become 2^-1. Notice I'm just going down with each of my exponents and developing this. Again, if I take ½ and then divide that by 2, we are down to ¼. Or 2^-2. So notice with our negative exponents we start to create fractions with these. So I'm going to come back to that table here in a minute. But we'll go ahead and start taking your notes on 4.7 Negative exponents. [writes on board] So another way that we can get to our negative exponents comes from what we learned in 4.6 so if I had x^4 divided by x^7. So I can use my quotient of powers to solve it or I can expand or factor the exponents as well like we did in section 4.5 . Using the quotient of powers through subtractions we have dividing powers so 4-7 gives us x^-3. This is why we spent so much time on integers earlier, so you could quickly see that 4-7 is -3. Or my other way is to factor it. So what does x^4 really mean? Use x*x*x*x over x*x*x*x*x*x*x. Got it. So expanding everything out, canceling what is in common, so what I'm left with on top is everyone's best imaginary friend ever!
Multiple Students	One
Teacher	One on top, then x*x*x or x^3 then is left on bottom. So I can simplify this problem two different ways. I now have that x^-3 equals 1 over x^3.
Student	Can you have [inaudible]
Teacher	Yes, so let me go back over here to our table and use this idea as well. So I had 2^-1 and rewriting it I can write 1 over 2^1. And 2^-2 is 1 over 2^2. And we could do it one more. [Student 13] what is ¼ cut in half?

In his stimulated-recall interview, Noah explained his reasoning for cutting his student's thinking off and then returning to him in the end to give him some credit for recognizing the pattern.

> I just wanted to acknowledge that he knew where the answer was coming. He knew it either subconsciously or consciously he did know it, but I needed to explain where the answer was coming from not just his guess where he knew it subconsciously or consciously. And that's why it pertained, 'hey [student] was correct when he was talking about it and so I'll go back to him and give him the glory in that time frame but it just wasn't time yet. (Noah's stimulated-recall interview, November 2013).

Theme 2.b: Emphasis on Connections

A teacher's ability to enable students to make connections within and outside of mathematics is an important quality of effective teaching of mathematics, because students' understanding of mathematics is enriched and longer lasting as they are able to make these connections (NCTM, 2000). Two teachers observed in this study were able to provide experiences for students that helped make these enriching connections, and actions during PTMs enhanced this connective understanding. These teachers' cases will be described in the paragraphs below.

Amy.

In three of the five class periods observed, Amy made explicit connections to other disciplines or pop culture with the purpose of making mathematics accessible to her students. She explained during her stimulated-recall interview that her goal in making these connections is to "put them all on a level playing field with something they can relate to" (Amy's stimulated-recall interview, December 2013). Table 4.14 shows classroom dialogue during one of these instances, which turned into a PTM as a student makes a common error to disrupt the progress in solving a system of equations.

Table 4.14

Amy's Classroom Dialogue during a PTM and Connections to English

Speaker	Classroom Dialogue
Teacher	March Madness... my favorite sporting event all year. Love March Madness. So I found somebody else that has March Madness... and I guess "the" was underlined too. There we go. So there's my sentence. That was underlined. I find somebody else whose words would fit perfectly into my sentence and I'm going to re-write my sentence using those words. … The NCAA basketball championships are my favorite time of the year. I wouldn't say "The NCAA basketball championships March Madness is..." right? I would … when I substitute something I would take out what I started with and I put in the new word. … So, just like in English class, you substitute words in your sentences we have the same thing that we can do with our math sentences. Alright? And this works basically the same way, so for instance ... right here ... She points to the white board. Two examples. Easy ones to begin with. I have x= 3 and y=2x+7. A system of equations. If I know that x=3, what can I do with that to figure out what y equals? [Student]?
Student 12	Multiply the 3 by the 2x and then get 6 and then you get 6x and then you...
Teacher	Close. There's one thing I didn't like about it. This is what [student] basically said. She said do y= and then 2 times 3x plus 7. When I replace a word in my sentence do I keep my original word in there?
Multiple Students	No
Teacher	No I take it out, right? So do I keep this x in there?
Multiple Students	No
Teacher	No, I take it out and I put the 3 in place of it. So it's just y is going to be 2 times 3 plus 7. 2 times 3 is 6, plus 7 ... y is going to be 13. And if I want to write … I need to have my x and y … I'm going to write it as a point for my solution. So what's my x?
Multiple Students	3
Teacher	3. My y is...?
Multiple Students	13

Amy chose during this PTM to respond to her student's misconception with a connection back to the example she had given from English grammar.

> Substitution works and we do it all the time in English. So to drop the analogy of using a thesaurus to substitute words. It's the same thing. The most common mistake kids will make is they'll leave in if they're substituting 2y+3 for x they'll leave in the 2x (2y+3) so if you say it in a sentence where you're substituting the word and you leave the other word in it sounds absurd but then they do the same thing in math. (Amy's stimulated-recall interview, December 2013).

Amy indicated that she was not surprised by this kind of misconception during class and was ready to act on it. "I don't hope that they make this kind of mistake in front of the class, but I kind of smile when they do because it's like, yes, I'll guarantee there are half of you that would make this mistake sometime, somewhere" (Amy's stimulated-recall interview, December 2013).

The Standards for Mathematical Practice, a part of the Common Core State Standards for Mathematics (CCSSM), require students to reason abstractly, look for and make use of structure, make sense of problems, and persevere in solving them (CCSSI, 2012). Amy's awareness of potential misconceptions allowed her to create an example scenario that connected to prior knowledge outside of mathematics and helped students to make sense of the procedures they used in solving systems of equations.

Kathleen.

Kathleen showed awareness of students' potential misconceptions and of conceptual connections her students needed to make within the mathematics topics they studied (Field Notes, November 2013). Awareness of misconceptions is a quality not often exhibited by beginning mathematics teachers (Borko & Livingston, 1989; Hogan et al., 2003; Leinhardt, 1989), and Kathleen's choice to pursue connections within mathematics during PTMs differed from the other two beginning teachers observed in this study. Table 4.15 shows classroom dialogue during one of the PTMs the researcher investigated.

Table 4.15

Kathleen's Classroom Dialogue with Connections in Mathematics

Speaker	Classroom Dialogue
Teacher	… The prime factorization... it's literally just writing out a big number with prime numbers. So the only numbers that you should include in your final answer should be prime ones. And, obviously, you shouldn't multiply them out and solve that out because what are you going to get? When you take 3 times 5 times 29? [Student]?
Student 8	435
Teacher	435, right. You're getting back to your whole number, but that's the way it should be. If you check it and you did it correctly and use all the primes at the end of your factor tree, then when you multiply them together it should be 435. But, leave it as 3 times 5 times 29 and then you'll be done.

The dialogue shown in Table 4.15 represents the third time this topic was discussed during the week she was observed. Kathleen explained her reasoning behind this extra explanation during her stimulated-recall interview.

> "…A lot of times they get caught up in these are the steps you take, this is what you do, this is the process you follow, and they don't always understand why, and I feel that a lot of them were missing out on what the prime factorization means and they were missing the problem and just silly mistakes because they weren't understanding what the prime factorization was and what that meant in relation to the big number. Just multiply it out and say yeah, that's 435 so instead I just wanted to try to focus them in on that idea." (Kathleen's stimulated-recall interview, December 2013).

The other PTM chosen for further analysis involved Kathleen's choice to expand upon one connection to money and not to the idea of proportional reasoning during a conversation about solving one-step equations. The researcher asked if the observed conversations were common for her classroom instruction, and she replied, "It's always kind of for me what other lessons can we learn from this, what else can we pull from this, what else do you know?...We're kind of, I would call it organized chaos, in my class in terms of focus" (Kathleen's stimulated-recall interview, December 2013). In the case of this classroom conversation, she explained that proportions had been the topic of the last unit, but she wanted to avoid confusion between the last unit and the current one. She decided this slight connection to proportions (using division to solve a one-step equation could be represented with a proportion) was not going to help them gain a better conceptual understanding, but a connection to money may help them to remember some things.

In summary, the two cases described above of one experienced teacher and one beginning teacher show responses to PTMs that went beyond emphasis on procedures to make connections within and outside of mathematics. When they noticed PTMs, these teachers chose to re-emphasize these connections for students to support students in developing deeper conceptual understanding. These results, particularly the case for Kathleen, suggest potential for beginning teachers to exhibit qualities similar to that of experienced teachers in terms of noticing and responding to PTMs with strategies that go beyond sole emphasis of procedures.

Theme 2.c: Emphasis on Motivation to Learn New Strategies

In addition to the emphases described in the previous two findings, analysis of the PTMs and stimulated-recall interviews revealed another theme of emphasis: motivation to learn new strategies for problem solving. The researcher observed five days of instruction in Amy’s classroom where students were learning to solve systems of equations by making a table, graphing them, and using substitution. Amy framed her instruction in a way that her students would be motivated to learn another method for solving these systems of equations. Amy explained in her stimulated-recall interview that she always taught this unit in a specific order to “provide some motivation for how much that would stink if you had to make a table for everything” (Amy’s stimulated-recall interview, December 2013). Table 4.16 shows dialogue during a classroom conversation that motivates the need for a method other than creating a table to find a solution to a system of equations. During this conversation, a student's strategy for solving a system of equations creates a PTM where Amy chooses to insert another example strategy given previously by a student in another section of the class. These students worked on an application problem from the Hunger Games, where they needed to find a point where two characters were receiving the same amount of presents during the games.

Table 4.16

Amy's Classroom Dialogue to Motivate a New Solution Method

Speaker	Classroom Dialogue
Teacher	Yeah, so they're just going to keep going up by twos. Uh, Katniss adds how many each day?
Multiple Students	Three.
Teacher	Three, uh, six, nine… Oh, right there, they're equal! There's the magic number! They're equal at six days. *Students talk to each other.*
Teacher	Eighteen presents. Okay, so, without even knowing it, what you just did was you solved a system of equations. What if the answer to this had been like two hundred and forty-seven days? Would a table have been very beneficial?
Multiple Students	No.
Student 15	No because, we would have like been here for like a long time and it would have taken like a really long time.
Teacher	It would have taken a very long time, yes! So is a table always going to be your best method?
Multiple Students	No.
Teacher	No, so we're going to start to find some better methods. [Student 16], I didn't see a table on yours and you got it relatively quickly. What did you do?
Student 16	Well, I did the starting amount, plus how many negatives and negative X for how many.
Teacher	So you had your careers and you had six plus two X and, then what else did you have?
Student 16	Zero plus three X.
Teacher	Ok, so Katniss, you wrote as, zero plus three X. And then what did you do? How did that help you?
Student 16	Well, I saw the six was different, so I…
Teacher	Shhh.
Student 16	put six in place of the X.
Student 17	What?
Teacher	Oh, ok, so you just figured out, you kinda just played around with numbers until you … ok! Umm I had, I had some people, I had one group in my last class who wrote something similar to this and this is what they did. They did six plus two X equaled, zero plus three X. Do you have to have zero plus in front?
Student 18	Huh uh!
Teacher	No, so they just did equals three X. And then they solved for X. So then, minus two X, they got the X equaled six. So six days.
Student 19	That's really cool.

In conversation during the stimulated-recall interview, Amy reflected on Student 16’s thought process and her reaction.

> I remember that he said equations and that was good, but it won’t always. And I don’t know if I knew for a minute what he was doing, but it won’t always be the case that it will always be. The other one didn’t have a constant term so that’s why that worked out but that wouldn’t always be the case. So I guess I tried to have him explain it a little bit and if it wasn’t going anywhere then to try to go somewhere else with the example from the other class. It’s always a tough balance because you want to have him explain it completely and figure out that one student where they had a good idea for setting up an equation and they got it right but do you take the time right then to kind of teach them substitution or do you move on to the lesson for the day which was graphing (Amy’s stimulated-recall interview).

Amy’s explanation shows that even as a more experienced teacher she found the choice difficult to balance the idea of working with the student to extend his ideas or to stop that line of thinking and bring closure to her example in another way. In the moment, however, she provided an example that helped motivate the need for a new strategy and introduce the new strategy in a way that connected to students’ prior knowledge.

Theme 2.d: Frequency of Questions Asked by Students as Related to Teacher Responses

Another result that surfaced through analysis of the observed teachers’ responses to PTMs was the relationship between the emphasis in teacher responses and the number or type of questions asked by students. The classrooms observed had differences in frequency of questions students asked and in the type of questions being asked. These results are depicted in Table 4.17. Analysis of the selected teacher responses during PTMs showed a difference in the focus (procedural, connection, or motivation) of the classroom teacher, and these differences showed some relationship between the frequency and types of questions asked by students in these classrooms. The paragraphs that follow will describe the results found in classrooms with the highest overall frequency of student questions or the highest number of conceptually oriented, "What if?" or "Why?" questions asked.

Table 4.17

Frequencies of Conceptual Questions and Total Questions Asked by Students

Teacher	Number of student questions	Number of conceptual questions asked by students
Tom	10	2
Dana	12	2
Amy	25	8
Samantha	10	0
Noah	15	4
Kathleen	20	2

Two teachers, Amy and Kathleen, chose to emphasize connections within and outside of mathematics or motivation for learning new strategies for problem solving as they responded to students during PTMs. An interesting pattern surfaced through analysis of these two teachers' classroom transcripts: students in both classrooms asked more questions than students in the other four classrooms observed. Both teachers described their classroom environment as "organized chaos" (Amy's initial interview, October 2013; Kathleen's stimulated-recall interview, December 2013). The researcher's field notes triangulate these findings with observations about "active students" and students "being comfortable with asking questions" (Field Notes from November 2013).

Kathleen mentions in particular that the students she worked with during the observations were very active participants. "They love to ask questions, bring stuff up, and I love that about them that they're able to pull in other knowledge and try to connect the pieces, and that's so much what math is" (Kathleen's Stimulated-recall interview, December 2013). Kathleen's explanation of her student's abilities also explains why she provides emphasis on connections within and outside of mathematics as she responds to them.

Amy, who utilized both connections outside of mathematics and motivation to learn new strategies, discussed the importance of involving students in making these connections to deepen students' understanding. "I think it's really easy for a student to get a number answer but a number answer doesn't do a lot to solidify their or anyone else's thinking that might have gotten it wrong or missed a question in the process in class. Only through the what if, the how's the whys can we solidify their thinking of the process …" (Amy's stimulated-recall interview, December 2013).

Noah's classroom transcripts and interview notes also revealed a higher number of student questions.

> They always ask questions and I enjoy that. Sometimes it helps me out, oh yeah; I need to show an example of this. or "oh, that is a great question, why don't we talk about how that works now" or a boy asked a question today about, kind of leading into where you have exponents on the top and the bottom that you can subtract these two. I told him "hold that question, I think we'll answer that tomorrow but you brought up a really good point and I'm glad you noticed that. (Noah's stimulated-recall interview, November 2013)

His classroom exhibited a higher frequency of PTMs than classrooms where students asked fewer questions, but his emphasis through his responses differed from that of Amy and Kathleen. Noah's responses pertained more to proper procedures than to making connections or motivating a new strategy.

Perceived Factors Influencing the Teachers' Questioning

The researcher analyzed each teacher's interview transcripts from both initial and stimulated-recall interviews using constant comparative analysis to explore research question three: What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers? Four major patterns of influence emerged from this data, and field notes from these interviews and during classroom observations also support these findings. The perceived influences of mathematics content knowledge, MKT, experience, time, and relationships with students will be discussed in the sections to follow.

Theme 3.a: Perceived Knowledge of Mathematics and Years of Experience to Improve Skills with Question Asking

A teacher with rich mathematical knowledge can address mathematical topics conceptually (Tchoshanov, 2010). Examination of interview transcripts, observation transcripts, and field notes revealed that all novice teachers demonstrated a perceived knowledge of mathematics. Samantha showed this knowledge through her explanation of the connectedness of topics within the unit she was teaching (Samantha's stimulated-recall interview, November 2013). As she explained her teaching team's decision to cut some sections from the quadratics unit to save time, she said she wished for more time to explore the discriminant and the quadratic formula conceptually. Noah expressed his knowledge in terms of curricular knowledge as an influence on his responses to students (Noah's stimulated-recall interview, November 2013). Kathleen demonstrated her mathematics knowledge by drawing upon connections between different mathematical topics as she explained her choice of responses in her stimulated-recall interviews (December 2013).

Although all beginning teacher participants demonstrated content knowledge, all talked about the improvement of their question asking skills from their student teaching experiences to the present and expressed belief that these skills would improve more with added years of experience. Samantha explained that she “didn’t remember the names of them” but preferred to ask “What comes next?” or “fill-in-the-blank” type questions. Upon reflection during her stimulated-recall interview, she listed several conceptual question ideas pertaining to discriminants and quadratic application problems that she would like to find time to ask in the future (Samantha’s stimulated-recall interview, November 2013).

Noah recalled his experience in his pre-service education program, where he read a chapter about appropriate and inappropriate types of questions and practiced writing out all of the essential questions he wanted to ask on his lesson plan assignments. Through his student teaching, he learned more how to adjust his instruction and ask questions “on the fly.” Noah explained,

> As a first-year teacher it’s a tougher to try to anticipate their questions of what will be coming that I need to be ready to answer. … I had to learn the lesson of this is your first time teaching so you’re not always going to have the answers to your questions. (Noah’s initial interview, October 2013).

Kathleen also recalled experiences in her pre-service education program that prepared her for thinking in more depth about the questions she was asking and explicitly writing them down in advance of teaching a lesson. She took these lessons with her as she began teaching. “As I came into the classroom I realized that there are things that I need them to get out of this and in order to get those things I need to have those questions planned out ahead of time." (Kathleen's initial interview, October 2013). Kathleen found benefit from the instruction and practice she already had, but she commented during her interview that more classroom observation of teaching styles and questioning would have been helpful for her. She commented, "I think experience is huge, getting in the classroom and seeing things." (Kathleen's initial interview, October 2013).

Theme 3.b: No Extrication of Experience from MKT

Previous research has suggested MKT as a potential factor of influence for instructional decision making (Hill et al., 2008; Tchoshanov, 2010). As the researcher analyzed interview transcripts for evidence of mathematics knowledge or MKT as a perceived influence upon classroom questioning and responses, it became apparent that the schematic knowledge based upon years of experience was difficult to extricate from these other types of knowledge.

Tom indicated his interest in "three different modalities" of mathematics throughout the interviews: analytical, graphical, and verbal approaches. He considered these modalities and the connections between them to be very important for learning mathematics (Tom's initial interview, April 2013). Tom also demonstrated a particular property of MKT, a teacher's ability to anticipate student's misunderstanding (Hill et al., 2008). However, Tom attributed his high level of content knowledge and MKT to his time spent in reflection upon his teaching experiences and considered this reflection on experience to be the most influential factor behind his actions in the classroom.

> Well, I certainly have a clearer picture of how I want to address it, and what it means to me over 16-17 years. … A lot of it is based off what it takes for my students to be successful slash gain conceptual understanding of a concept or idea, based off my own prior experiences which are biased, and

> I'm trying to infuse other students' perspectives so that the next time that question gets asked, or the next time that that scenario plays out I have more creative ways or tools that I can address student understanding. (Tom's stimulated-recall interview, April 2013).

Dana expressed awareness of her knowledge of mathematics, as well as an awareness of common misconceptions for students as they learned mathematical topics (Dana's initial interview, October 2013). Her influence for questioning and responses to students came from a combination of these two influences, which again prove difficult to separate experience from knowledge of content and pedagogy. "I have knowledge of how to do the problem and by experience I knew this was an application problem and they would get stuck," Dana explained about her response during a PTM in her stimulated-recall interview (November 2013). Field notes from Dana's observations also make note of Dana's awareness of misconceptions as she asks questions of students during her lessons (October 2013).

Amy's MKT became apparent through analysis of the field notes and stimulated-recall interview transcripts as she worked to think through student solutions and diagnose misconceptions. During one PTM, Amy diagnosed a student's solution process and this understanding helped her to add another example that enhanced his and other students' thinking about solution strategies in connection to prior knowledge about equations. Amy attributed her growth in MKT to her student teaching experiences, professional development experiences and prior teaching experiences.

> As you get more experience you kind of know where students are having mistakes so you can ask questions that will hopefully get them to see where those mistakes are and why they are mistakes as well as once you've gone through the curriculum a few times you can find ways to incorporate some of the high level in the class. But I also think I was lucky to have [higher education advisor] who I know helped me a lot and [a second student teaching supervisor] came and observed me and pointed out things I hadn't thought of

> before so that made my learning curve a little steeper. And I think with my AIW training right now our focus is what questions is our task asking students to do and I think as we're increasing our thinking about the task our levels of questioning in the classroom goes up as well. So I think it's a combination of PD and experience but probably mostly experience. (Amy's initial interview, November 2013).

In summary, these findings agree with prior results that show influence upon teacher actions that are only gained through experience (Borko & Livingston, 1989), although level of content knowledge and MKT was closely related (Ball et al., 2008; Tchoshanov, 2010).

Theme 3.c: Concern with Lack of Instructional Time

Concerns about instructional time filtered through the responses of every teacher during initial and stimulated recall interviews. Most decisions made during instruction that were analyzed by the researcher were made after consulting either a physical or subconscious time clock. In particular, two of the beginning teachers saw a need for concept development but were limited by time constraints for instruction. Samantha repeatedly expressed her frustration with time constraints during her interviews. One instance where she revealed this frustration was in reflecting how she would like to change her instruction the next time she taught the unit. "We didn't get to do the discriminant and I wish we could have done that. It's something we couldn't change, though, because we needed to get through." (Samantha's stimulated-recall interview, November 2013). Noah also mentioned time as a factor in his decision-making. "[My responses] typically depend on, one, how my time frame is anyway. Sometimes their questions aren't always necessary to right now in the chapter, and luckily sometimes I'll be able to say "hey, hold that until tomorrow." (Noah's initial interview, October 2013).

This concern with time was not restricted to beginning teachers, however. Tom also mentioned time constraints as he explained his decision making regarding topics or questions that differed from what he had planned (Tom's initial interview, April 2013). In addition to mention of time as a constraint in his instruction, Tom also mentioned time as a factor in his planning and reflection (Tom's stimulated-recall interview, April 2013).

Amy mentioned time as a constraint when deciding whether or not to deviate from her planned instruction and also in terms of transition between activities. "I think it's just, transitions are always hard but they're used to it hopefully from the routines in class not to be sitting for long periods of time." (Amy's stimulated-recall interview, December 2013).

Theme 3.d: Understanding of Students' Backgrounds and Relationships with Students as Influences on Questioning

A teacher's beliefs about students can play an important role in their instructional decision-making (Begeny et al., 2008). In three cases observed these beliefs pertaining students' backgrounds or relationships developed with students emerged as a perceived influential factor for questioning.

Samantha showed cultural sensitivity and awareness for the Hispanic population present in her classroom.

> In my classes I'd say around 20%. I have 2 students in my core classes that do not speak English at all. There are more Hispanics in the core classes, so we usually sit them next to bilingual students. So that is helpful but it's still hard. I took 4 years of Spanish in high school and a semester in college but I'm nowhere near fluent. I know my basic numbers and I can kind of help them out. (Samantha's initial interview, October 2013).

She also demonstrated adaptation for students based on individual situations that otherwise would have prevented them from achieving to their fullest potential. She expressed concern for her students who missed class for sickness, suspensions, and truancy, and utilized technology to help these students keep up with their classmates: “I had a student who was in an accident and smashed his hand. He has to write with his left hand and his notes aren’t legible. So I print them off and give them to him. I also print them off and put them in here so students who were gone can just grab them.” (Samantha’s initial interview, October 2013).

Tom believed that his less privileged background and wide appeal provide incentive for students to want to perform for him, which makes his approach generally effective. He also believed students must take control of their own learning. “It is my objective to try and get them engaged and own their own learning, … I try to avoid leaving a student for another student to obtain an answer.” (Tom’s initial interview, April 2013). He believed that students’ opportunities to answer the teacher’s questions contribute to engaging in their own learning.

Kathleen also exhibited extensive knowledge about her students’ background and how it affected her instruction.

> I teach an RTI class, which is a class split into 3 groups based on their math scores and I have the upper third so that’s kind of more of an enriching class period. During a normal class period I have everyone from a low ability to a high ability. They’re all from this area so grew up in a small town. A lot of them have parents who work on farms or work here in town. A lot of them work factory jobs, things like that if you’re interested in any information on the family life. (Kathleen’s initial interview, November 2013).

She also expresses the belief that students own their own learning, and her role is to guide them along the process. Her teaching style is a “go with the flow” style, and the loose goal-oriented structure she sets with her classroom discussions matches this mentality as she caters to the needs and interests of her students. “I have a plan every day obviously of what I'd like to do. But especially in a couple of my classes, if they're able to do it with a little less structure… we just kind of "ok you want to go this direction? We can chat about this stuff. Let's go this way!" (Kathleen's stimulated-recall interview, December 2013).

Summary

The findings pertaining to frequency and type of questions asked showed differences between the groups of experienced and novice teachers. Beginning teacher participants asked fewer questions than experienced teachers, and the breadth of questioning categories was slimmer for beginning teachers than experienced teachers. These findings agree with that of Chin (2006).

Upon examination of responses during PTMs, patterns of procedural emphasis were found among most teachers. Two patterns were distinctly different, however. Amy utilized connections outside of mathematics as well as motivation for learning new strategies through her actions during a PTM, and Kathleen relied heavily upon connections within mathematics.

The amount of questions asked by students and amount of conceptual, "What if?", or "Why?" questions were also described for each teacher. Of the findings for student questions asked, there appeared to be an interesting relationship between the questions asked by students and the teachers' choices to emphasis procedures, connections, or motivation for strategies.

Lastly, the researcher explored potential perceived factors of influence. Factors that surfaced through analysis of transcripts and field notes were (1) reflection on experience and MKT, (2) time, and (3) relationship with students, teachers, and parents and knowledge of student background. A subtheme that surfaced from these initial factors was that of teachable versus unteachable factors, in other words, factors of influence that can be taught in methods courses or through university field experience versus factors that can only come about through years of teaching experience.

CHAPTER FIVE

CONCLUSION AND DISCUSSION

The goal of this study was to examine patterns in teacher questioning and teacher responses to pivotal teaching moments (PTMs) for six teachers as components of classroom practice. The patterns found from these six teachers are not necessarily generalizable to all secondary mathematics teachers but suggest features of classroom practice that could provide a source for further study of a larger, more quantitative scope that could provide generalizable evidence for effective teaching practice.

For this study the researcher wanted to compare the patterns of questioning between three novice and three experienced teachers, examine patterns in their responses to PTMs for common and deviant themes, and describe the perceived influences for these responses to students. The analysis of novice and experienced teachers' patterns of questioning, noticing and responses to PTMs, and perceived influences for those patterns indicated significant differences in questioning practices and instructional decisions made during PTMs between those two groups of teachers. These results suggest insights into several questions critical to mathematics teacher education: How do novice secondary mathematics teachers exhibit differences in terms of questioning and responses during PTMs than experienced teachers? How can patterns in questioning and response to PTMs inform the creation of a measure for effective instructional practice? Can novice teachers learn and develop the skills that experienced teachers possess? If so, what supports do they need? How can teachers' perceived factors of influence for decision making relate to their level of cognitive development?

This chapter begins with a brief summary of the main findings addressing three research questions: (1) What similarities and differences exist in questioning patterns between novice and experienced teachers when guiding a classroom mathematical discussion? (2) What similarities and differences exist in responses to students during pivotal teaching moments between novice and experienced teachers when guiding a classroom mathematical discussion? (3) What perceived factors impact the responses teachers give to students' ideas, and how are these factors of influence different among novice and experienced teachers? Next, the research findings will be discussed from the following aspects: (1) types of teacher questioning in classroom discourse, (2) perspectives on questioning, and (3) factors of influence for teacher decision-making. The discussion topics do not correspond directly in a one-to-one fashion with each research question but rather approach the findings from various general perspectives. Additionally, this chapter discusses theoretical and pedagogical contributions and limitations of the study, and directions for future research.

Summary of Findings

Research Question One: Similarities and Differences in Questioning Patterns between Novice and Experienced Teachers when Guiding a Classroom Mathematical Discussion

An analysis of the classroom observation transcripts suggested a salient difference for two of the three experienced teachers in both the frequency of questions asked and feedback given and the variety of questions within different categories with regard to Chin’s questioning framework (Chin, 2007). For the five lessons observed with each experienced teacher, Tom asked on average 59 questions per lesson, Dana asked 33, and

Amy asked 42. These frequencies for the experienced teachers were much higher than those of two novice teachers. Of the five lessons observed for novice teachers, on average Samantha asked 14 questions per lesson, Noah asked 18, and Kathleen asked 43. Both the frequency of questions asked and the explanation Kathleen gave during the interviews align more with that of the experienced teachers. In terms of categories of questioning, the novice teachers had less variety than the experienced teachers. Categories that showed the most differences were framing, verbal jigsaw, and semantic tapestry. All teachers used questions from Socratic questioning most frequently. Another result of interest was that the novice teachers provided more classroom management questions than experienced teachers.

Research Question Two: Similarities and Differences in Responses to Students During Pivotal Teaching Moments among Novice and Experienced Teachers

The analysis of stimulated-recall interview transcripts, transcripts from lesson observations, and field notes for six teacher participants revealed three themes for teacher responses during PTMs. These themes represented different areas of emphasis from teachers: (1) importance of mathematical procedures or algorithms, (2) making connections within and outside of mathematics, and (3) motivating students to use new strategies for problem solving.

The first theme, emphasis on mathematical procedures in teaching, was different in each case with regard to lens for focus. One perspective combined the aspects of conceptual understanding and procedural competence. Another showed keen awareness of misconceptions and tight steering toward correct and efficient procedures. A third lens for procedures took a “follow me” approach, and a fourth viewed learning as a structured progression of procedural understanding based from textbook curriculum examples.

A second theme, connections within and outside of mathematics, was apparent for two teachers, Kathleen and Amy. Amy made explicit connections outside of mathematics, with reference to pop culture and other disciplines. Kathleen drew upon connections within mathematics, asking students to connect new knowledge to prior concepts learned.

A third theme that necessitates discussion relates to utilizing efficient problem solving strategies. Amy emphasized the necessity for students to find and utilize new, more efficient strategies for solving problems, having students share their strategies with classmates and explain why a particular strategy was or was not useful for solving particular problems.

A fourth theme to highlight from this analysis of responses to PTMs was the occurrence of student question asking and its relationship to the type of responses to PTMs. Three classrooms had high total numbers of questions asked by students (average of at least 4 questions per lesson) or high numbers of conceptual questions asked by students (at least 4 conceptual questions asked).

Research Question Three: Differences among Novice and Experienced Teachers in Perceived Factors that Impact Teacher Responses

Analyses of interview transcripts and field notes for six teacher participants revealed three perceived patterns of influence for teacher responses. Factors that surfaced were (1) Reflection on experience and MKT, (2) time, and (3) knowledge of student background and relationship with students, teachers, and parents. Some of these influential factors and the differences exhibited between novice and experienced teachers were discussed in previous research, such as experience (Borko & Livingston, 1989; Leinhardt, 1989) and MKT (Ball et al., 2008; Hill et al., 2005). The instructional pacing element of time as a factor has also been present in aforementioned literature (Borko & Livingston, 1989; Leinhardt, 1989), but other facets such as appropriate time for reflection brings a new perspective to time as an influence.

Discussion of Findings

This study's findings provide a basis for looking at teacher questioning from multiple perspectives. The sections to follow will look at the categorizations for teacher questioning and the impact on productive mathematical classroom discourse, teacher-centered and student-centered perspectives on questioning, and factors of influence for decision making.

Teacher Questioning in Classroom Discourse

Past studies of teacher quality have predominantly used broad definitions such as general teacher training factors (e.g. certification and college degrees) or general factors related to teacher practice (e.g. the ways they interact with students and teaching strategies they use). Findings of these studies are inconsistent partly as a result of these broad measures of quality (Goe, 2007). This study examined teacher questioning and responses as a way to more clearly describe factors of these teachers' instructional practices. The purposes for such detailed classification of teacher questioning and responses were to provide information useful in future research that develops measures of teachers' effective practice and to further explore relations between these specific practices and student achievement through larger-scale, quantitative studies. The current literature examines interactions between teachers and students in elementary school mathematics (Hill et al., 2008; Hill et al., 2005; Hill et al., 2004), and questioning patterns by teachers to promote students' productive thinking in the secondary science classroom (Chin, 2006, 2007). Results of this study suggest the framework set forth by Chin transfers adequately to mathematics and provides information to expand knowledge in mathematics education about interactions between teachers and students in a secondary school setting. Results from this study also suggest that secondary mathematics students can benefit from their teacher's use of questions in all categories of Chin's framework, depending on their purposes for asking questions, as questions within these categories promote mathematical discourse and engage students in thinking about mathematics from multiple representations and perspectives. Further study of a quantitative nature with a larger sample could examine teachers' use of questions from these categories as compared to the achievement of their students shown from standardized assessment data. This future quantitative study could provide more generalizable results for this specific feature of instructional practice.

The Standards for Mathematical Practice, found within the Common Core State Standards for Mathematics (CCSSM), describe practices for learning mathematics that have held longstanding importance in mathematics (CCSSI, 2012). Two of these standards, (1) Construct viable arguments and critique the reasoning of others, and (2) Make sense of problems and persevere in solving them, require students to be able to reason, explain, experience a productive struggle, and communicate using the language of mathematics. Teachers are expected to develop these practices in their students partly through purposeful questioning in mathematical discourse (NCTM, 2014). Chin (2007) writes in her work that the kinds of questions teachers ask and the way they ask these questions can influence the way a student engages into a cognitive process to construct scientific knowledge. This idea naturally extends to mathematics, as teachers' questioning can influence the way a student chooses to make sense of problems and chooses a path to find a solution. Examination of Table 5.1 shows the teachers' use of questions from all categories of Chin's framework for questioning and response (Chin, 2007). There are differences, however, in the proportion of questions from each category.

Chin's Socratic Questioning category was used most frequently by all six teachers, comprising close to half of the questions asked. One subcategory in particular, pumping, was prevalent in all classrooms. This style of questioning used a probing question to start the sequence of discourse. Following a student response, the teacher typically repeated or rephrased the student's response and then asked another question that led to the next step in the thinking process. Teachers "pumped" until closure was reached for a particular idea or problem, and the teacher summarized what was learned. Because procedural understanding is an important strand of mathematical proficiency and is a traditionally common point of emphasis in mathematics, this result was not surprising. This category of Chin's framework aligns with that of a concept defined in mathematics education as *funneling*, part of another questioning framework (Herbal-Eisenmann & Breyfogle, 2005).

Two distinctions between the three novice and three experienced teachers emerged through analysis of observation transcripts. One was the proportion of classroom management questions used and the other difference was found in the categories of framing and semantic tapestry. Compared to the three experienced teachers, the three beginning teachers showed a higher proportion of classroom management questions, such as “Is everyone following me?” or “How did you guys do on that one?” The findings of this study agree with that of previous research about beginning teachers’ primary emphasis on classroom management over student (Borko & Livingston, 1989; Hogan et al., 2003).

The other noticeable differences between teacher samples observed were in the categories of framing and semantic tapestry. These types of questions were used less frequently by all six teachers observed, but the three novice teachers showed no usage of questions from these categories. Questions in semantic tapestry were meant to help students organize ideas into a “coherent mental framework of related concepts” to build conceptual and relational understanding (Chin, 2007). These types of questions were meant to address multiple aspects of a problem to force students to think from multiple perspectives and use different representations. Framing questions tended to frame a problem in mathematics and structure the discussion that followed. Possible reasons for a lack of questions in these categories for beginning teachers could be due to lower MKT, which parallels findings from previous studies in elementary mathematics education (Hill et al., 2008; Hill et al., 2005). Another possible reason for the lack of these types of questions could be the lack of experience for beginning teachers in being able to fully plan and carry out a lesson as efficiently as an experienced teacher (Borko & Livingston, 1989) or that novice teachers emphasize content knowledge more while giving much less focus to higher order thinking skills (Torff, 2003). An important note to make is that even the three experienced teachers observed had a small proportion of questions in these two categories, which suggests the difficulty other mathematics teachers might have in asking questions of this nature. This study's findings align with that of Torff (2003) which found as a teacher gained experience and neared the category of expert, he or she emphasized higher order thinking skills more and content knowledge less. Tom, who asked the highest percentage of questions (11%) from these categories, had previously won an award for teaching and had a notable command of thinking critically about mathematics and its different "modalities," which may have put him into the status Torff defined as expert, posing questions within these categories more frequently than other teachers (Observation field notes, April 2013).

Teacher-Centered and Student-Centered Perspectives

There has been debate for many years over the dichotomy of teacher-centered versus student-centered learning environments (Belo et al., 2014; Costin, 1971; Polly et al., 2014). Teacher-centered instruction is typically defined as a more traditional approach to teaching, where teachers teach in a very direct and time-efficient manner, providing lecture, guidance or demonstrations as appropriate for a given topic (Ackerman, 2003; Polly et al., 2014; Wu & Huang, 2007). The teacher in this environment is responsible for "organizing, delivering, and transmitting content knowledge" with very little student input (Belo et al., 2014). Polly, Margerison, and Piel go further to examine teacher beliefs, saying teacher-centered educators believe the acquisition of knowledge is more important than the process (Polly et al., 2014). In contrast, student-centered instruction is based from constructivist theories that support student learning as an active construction of knowledge as opposed to passive reception of knowledge from a teacher (Lesh et al., 2003; Seung et al., 2011). Student-centered instruction allows teachers to carefully craft opportunities for students to construct this knowledge (Lesh et al., 2003; Polly et al., 2014). Student-centered beliefs center on the idea that students are responsible for acquiring and processing knowledge through hands-on experiences, laboratory investigations, and project work (Belo et al., 2014).

Simmons et al. (1999) found that a majority of 116 mathematics and science teachers exhibited beliefs from both teacher-centered and student-centered perspectives, and recent results from Belo et al. (2014) were in agreement, indicating that teachers in the study valued both teacher-regulated and student-regulated learning. These teachers acted as reflective practitioners who thought about the appropriateness of teaching behaviors in relation to a given class of students, lesson objectives, and content.

Although the researcher did not intentionally seek cases from both teacher-centered and student-centered perspectives, the differences in questioning and response patterns as well as influences for decision-making proved interesting as viewed from these two perspectives. The current literature emphasizes a salient difference between teacher questioning in teacher-centered and student-centered learning environments (Almeida & de Souza, 2010; Chin, 2007; Harris, 2000; Hoffman et al., 2012; Wu & Huang, 2007). Where discourse in a traditional classroom takes on an initiation-response-feedback (IRF) chain that is framed by the teacher and ends with the teacher evaluating the response and providing affirmation or corrective feedback, an adjustment to the last piece of the sequence opens the discourse to allow students to become "co-constructors of meaning" and be more active in constructing knowledge through classroom discussion (Chin, 2006).

The framework used in this study was originally intended to describe questioning that would provide productive discussion beneficial for use in student-centered science classrooms (Chin, 2006, 2007), but this study examined patterns in questioning for both teacher-centered and student-centered classrooms. These results suggested a spread of questioning types throughout all categories, including the environments that were teacher-centered, which suggests a possibility for students to be able to think critically and extend concept development in teacher-centered environments. Other studies (Polly et al., 2014; Wu & Huang, 2007) have reported similar success with student learning in teacher-centered environments, and Ackerman (2003) suggests "both the progressive and the traditional strands intertwine, reinforcing and amplifying each other."

We can examine the differences in frequency of questions asked in addition to examination of question types. Classroom interaction is an essential component of teaching and learning, and questioning is an important phenomenon to consider within the context of interaction. Upon examination of Table 4.3, we can consider this question: Does more questions asked imply better instruction? In particular, are we actually looking for fewer questions but better ones? A closer look at both the frequency and variety of questions teachers asked in both environments and the relation of these factors to student learning is necessary.

Dillon (1988) examined the questions asked in teacher-centered classrooms and noted a lack of engagement of students when too many questions were asked in an initiation-response-evaluation (IRE) format. This finding suggests the frequency of questions asked may be less important than the types of questions asked. If we look at the frequencies in Table 4.3, Tom, who taught in a teacher-centered environment, asked on 59 questions on average for each lesson. In contrast, Kathleen, who taught in a student-centered environment, only asked 43 questions on average for each lesson. To look at effectiveness in both of these environments, the quality of questions must be considered more carefully than the quantity. It is important to note, however, that the findings from this study were meant only to describe the questions asked by each teacher in their respective classroom environments, and the researcher cannot make claims about teacher effectiveness. This study concurs with past researchers who write that frequency alone cannot suggest effective teaching (Chin, 2007; Dillon, 1988).

Ackerman's view of intertwining strands of progressive and traditional instruction also provides insightful explanation for the use of questioning exhibited by teachers in this study. The researcher found two very contrasting uses of classroom questioning in terms of teacher-centered and student-centered learning environments with the six teacher participants. Teachers in both environments utilized questions from multiple categories in Chin's framework. These findings may suggest the possibility for teachers in both environments to include richer, more thought-provoking questions. In contrast, the findings may suggest instead that future studies should look deeper than this categorization of questioning and look additionally at the students' responses to see the actual effectiveness of teachers' and students' interactions in both environments. The next paragraph will illustrate an example from each environment.

Consider first Tom, a teacher with 17 years of experience, who had won an award for teaching. This teacher ascribed to a very classic lecture-based format for instruction but used questioning throughout the lesson as his primary teaching tool. He showed skill with framing his questions so students were able to process the mathematics from multiple representations and perspectives. This teacher asked the highest number of questions of the teachers' studied, however, which allowed less time for students to process and discuss their responses to these questions. Compare this teacher-centered instruction to that of a teacher who taught in a student-centered environment. Kathleen, a first-year teacher in a student-centered environment, asked fewer questions per lesson than did Tom. Of the questions she asked, her percentage of questions from the pumping subcategory (more traditional IRF-type questioning) was the lowest of all teachers at 29%. Tom's percentage, 32%, in the pumping category was the highest of all teachers. Additionally, Kathleen asked 11% of her questions from the constructive challenge subcategory, where she encouraged her students to think further about responses they made that were incorrect. Tom only had 3% of his questions from that subcategory. Part of these differences could be explained by the environment in which they taught.

A salient difference that surfaced upon examination from the teacher-centered vs. student-centered perspective was the purpose for teachers' questioning and beliefs about teaching and learning. While teachers who approached education from a student-centered perspective used questions to elicit student thinking and support students in extending their learning, the teachers who held teacher-centered beliefs had a purpose of evaluating what students knew and framed a lesson around a pre-planned agenda to deliver procedural and conceptual knowledge, coupled with instinctual improvisation during PTMs that were meant to propel student understanding in a positive direction.

While these results suggest an interesting view of the teacher-centered versus student-centered issue, further study of a quantitative nature would be useful to provide more conclusive information about the relationship between classroom environment and effective classroom questioning.

Teachable vs. Non-Teachable Factors

The researcher's goal in identifying the response patterns of sampled novice and experienced teachers and examining perceived influences for teacher decision making was to be able to suggest ways teachers can improve their skill with leading classroom discussions. In particular, understanding of these factors will provide information for the field of higher education to consider as they work to train pre-service teachers in planning and facilitating effective instruction. This section is organized with regard to those factors that are teachable to pre-service teachers and those that come with years of teaching experience and professional development.

Teachable factors-university methods courses.

Several patterns of influence for responses during PTMs emerged after constant comparative analysis of the six teachers' interview transcripts. Content knowledge, MKT, reflection, time, and awareness of students' backgrounds have potentially teachable aspects. The beginning teachers referenced knowledge in terms of connectedness of mathematical topics or knowledge of the curriculum. These types of knowledge fall into two MKT categories: common content knowledge -- knowledge of the mathematics and problem solving that is shared by teachers and those outside the teaching field; and knowledge of content for teaching -- a combination of knowing mathematics and knowing general pedagogy (Ball et al., 2008). These are the two categories that do not involve specialized knowledge for teaching or knowledge about how students learn mathematics.

All three beginning teachers expressed a confidence in these two types of MKT, although they acknowledged they would learn much more through their future years of experience in teaching. Examples of skills that fall into these two teachable categories of MKT would be ability to solve the problems teachers are required to teach, recognition when a student gives an incorrect solution to a problem, and knowledge of how to organize a lesson plan for a mathematics topic using a given curriculum source and pick appropriate mathematical examples to use in a lesson. Informal conversation with the mathematics methods professor for each novice teacher participant along with information from interviews with the participants confirmed additional topics of coverage in their pre-service education courses. These teachers all worked in their methods courses to write essential questions directly on their lesson plans and were also required to predict possible misconceptions for each lesson and write them on the lesson plans. Additional skills these teachers remembered were how to properly reflect on their teachings and to think about appropriate pacing as they wrote lesson plans.

Teachable factors-field experience teachings.

Two beginning teachers referenced their student teaching experiences as they explained the influential factors behind their responses during PTMs. One teacher was hired at the same school where she completed a student teaching placement and expressed more familiarity with the curriculum as a result of her student teaching experience in addition to her first year of teaching. Comfort with the curriculum as well as understanding of common misconceptions came up during interviews with the three beginning teachers. The understanding of common errors or misconceptions is part of a third category of MKT, specialized content knowledge.

Another salient point to note from this study’s results is that all three of these novice teachers noticed PTMs as they occurred. The decisions they made in response to students during these PTMs varied, and reasoning for this relates to the further development of knowledge of content and teaching. The ability to receive student contributions and decide which to pursue and which to ignore is an important piece of MKT (Ball, Thames, & Phelps, 2008), and is one these teachers showed progress to develop. These teachers all had extra hours of field experience beyond state requirements for certification and had the opportunity to learn and practice skills such as this during these field experiences.

Awareness of student backgrounds and cultural sensitivity also played a role in decision making for the three beginning teachers, as well as reflection upon their student teaching experiences. While methods courses can provide opportunity to consider cultural differences and opportunities to modify lesson design to accommodate these differences, clinical field experience provides real-life examples and opportunities to practice and apply the teachings from university courses and start to build a practical schema of student differences and a connection to appropriate best-practice teaching strategies.

Unteachable factors.

The three experienced teachers had difficulty extricating the influences of content knowledge, MKT, and their years of experience when explaining their responses during PTMs. They also acknowledged strong relationships with students as an influence on their instructional decisions and student learning. Although the previous paragraphs outline components of mathematics teaching and decision-making that are teachable in a pre-service education program, there is no substitute for years of experience in developing a teacher's schemata and the complex cognitive thought required during a

PTM (Borko & Livingston, 1989; Leinhardt, 1989; Torff, 2003). The results from this study combined with that of the current literature describe experience as a factor in a teacher's questioning ability and ease with noticing and reacting to PTMs. The growth in schematic knowledge, higher order thinking, and improvisational skills through years of experience is helpful to drive conceptual understanding forward within students' mathematical discourse.

Table 5.1 shows a summary of the first three aspects based on teachers' use of questioning and perceived influences upon responses.

Table 5.1

Matrix of Teacher Practices in Questioning in Classroom Discourse, Teachable vs. Non-teachable Factors of Influence, and Teacher-Centered and Student-Centered Perspectives

Teacher	Types of Questioning in Classroom Discourse	Perspectives on Questioning	Factors of Influence for Decision Making
Tom	Socratic Questioning (46%) Verbal Jigsaw (6%) Semantic Tapestry (7%) Framing (4%) Feedback (36%) Classroom Management (1%)	Teacher-centered (but believes student own learning)	MKT combined with content knowledge Reflection upon experience Time (sufficient time for reflection and instructional pacing) Relationships with students (wide appeal, relates to his own upbringing)
Dana	Socratic Questioning (50%) Verbal Jigsaw (5%) Semantic Tapestry (3%) Framing (1%) Feedback (37%) Classroom Management (2%)	Teacher-centered (Gradual Release of Responsibility, "My job is to teach, their job is to learn")	MKT (misconceptions) Content knowledge Experience (as a way to predict misconceptions) Time (instructional pacing) Relationships with students (emphasis on citizenship)
Amy	Socratic Questioning (43%) Verbal Jigsaw (13%) Semantic Tapestry (2%) Framing (1%) Feedback (38%) Classroom Management (3%)	Student-Centered ("controlled chaos")	MKT (perceived development of this knowledge through teaching and professional development experiences, awareness of misconceptions) Content knowledge Time (transitions and instructional pacing) Relationships with students (connect to pop culture, other disciplines)

Table 5.1 Continued

Samantha	Socratic Questioning (43%) Verbal Jigsaw (0%) Semantic Tapestry (0%) Framing (0%) Feedback (21%) Classroom Management (36%)	Teacher-Centered (Gradual Release of Responsibility)	Content knowledge Improvement with experience Time (instructional pacing) Relationships with students (cultural sensitivity)
Noah	Socratic Questioning (57%) Verbal Jigsaw (3%) Semantic Tapestry (0%) Framing (1%) Feedback (26%) Classroom Management (13%)	Teacher-Centered ("go with the flow", loose goal-oriented structure	Content knowledge Improvement with experience Time (instructional pacing and reflection)
Kathleen	Socratic Questioning (49%) Verbal Jigsaw (9%) Semantic Tapestry (0%) Framing (0%) Feedback (27%) Classroom Management (15%)	Student-Centered) ("controlled chaos")	Content knowledge Improvement with experience Time (flexibility with instructional pacing) Relationships with students (knowledge of students' economic background, students own learning)

Implications for Research

This study was a multiple case study that provided a deeper understanding of the questions used by experienced and novice secondary mathematics teachers, the ways they respond to students during PTMs, and their perceived influences for teacher responses. Future study of a larger-scale, quantitative nature is needed to produce generalizable results about the relationship of teacher questioning and student learning. There is a need for further empirical study in multiple areas, including the need for researchers to examine the relationship between teacher questioning and student achievement, development of valid and reliable teacher observation protocols and discourse productivity measures, as well as studies on a larger scale to examine teacher noticing and PTMs. In a related vein, research is also needed to examine methods for teacher training, specifically examining the components of MKT and teacher noticing within a large sample of pre-service education programs.

This study provides an example of Chin's (2007) categorization of questions that sampled mathematics teachers asked and an informative description of these teachers' influences for decision-making.

Chin's (2007) categorization of questioning shows the need for a mathematics teacher to use questions that address the multiple representations and perspectives within each topic as well as carefully framing these questions within a lesson. There are appropriate times to pump students for more explanation, times to probe students to generalize and examine pattern or structure, and other times to ask students to examine the fine details a problem. This categorization will allow researchers disseminate information to teachers about questions that go further than prompting students through a process of algorithmic thinking and toward questions that align with the standards for mathematical practice (CCSSI, 2012). When we as researchers can better clarify features of instructional practice, we have more opportunity to measure teacher effectiveness based upon these features by examining the presence of these particular features of instructional practice and their relationship with student achievement. There has already been some quantitative work done in this area (Stronge et al., 2011; Tyler, Taylor, Kane, & Wooten, 2010), but more is left to be studied. These results will provide useful characteristics to consider in development of teacher observation protocols and discourse productivity measures that add to the current body of research (Early, Rogge, & Deci, 2014; Kiemer, Gröschner, Pehmer, & Seidel, 2015; Lack, Swars, & Meyers, 2014).

The descriptions given of teacher influences for decision making can inform research in teacher education. Current literature about beginning mathematics teacher noticing of PTMs (Scherrer & Stein, 2013; Stockero & Van Zoest, 2013) is expanded by this comparison between experienced and novice teachers. As researchers gain a better understanding of the background knowledge and beliefs that impact teacher noticing of PTMs and responses, they will be more able to make recommendations for professional development and teacher education. Research literature in the area of MKT and its effect on elementary mathematics teacher practices (Ball et al, 2004; Ball et al., 2008) is further supported by this study as findings for secondary mathematics teachers are explained. In particular, this study examines the importance of content knowledge, MKT, noticing of PTMs and awareness of students' backgrounds for teacher decision making in secondary mathematics. Knowledge gained about teacher noticing of PTMs will be useful in developing teacher observation protocols with the purpose of measuring productivity of mathematical discourse or correlating with student achievement data to measure teacher effectiveness.

The main purpose for this multiple case study was to provide more specific information about teacher questioning and teacher responses during PTMs to better suggest specific measures of teacher quality. Further research can take these detailed descriptions of teacher questioning and develop methods for producing generalizable ways to connect this practice to student achievement. A more critical examination of Chin's (2007) categories of questioning along with student achievement data could give insight about how a teacher's use of questioning from these categories are most useful for student learning in terms of achievement gains. Additionally, protocols could be developed to observe teacher effectiveness in questioning and PTM noticing and response or to measure productivity of mathematical discourse as a result of teacher questioning.

The topic of PTM noticing and response has many avenues for further research in mathematics education. The current literature in mathematics education (Jacobs et al., 2010; Scherrer & Stein, 2013; Stockero & Van Zoest, 2013) could be enhanced with more study of teacher questioning in relation to the noticing and response to PTMs. Empirical studies on a larger scale can examine teacher noticing and PTMs with regard to how a teacher frames the questioning before, during, and after a PTM.

Research in teacher education could also look more closely at the possibilities for teaching all components of MKT within a pre-service education program to enhance the skills of a beginning teacher as opposed to having teachers wait to completely develop MKT through experience in teaching. The researcher is particularly interested in future study regarding the quantity, structure, and MKT focus for field experience in a pre-service education program. While much of the literature with regard to mathematics teachers' MKT looks at practicing teachers (Ball et al., 2008, Hill et al., 2008), further studies could examine this development of MKT in pre-service education programs. Results from this study suggested the importance of carefully structured field experience to supplement mathematics methods instruction, and further research could examine different curriculum models in teacher education that could suggest best practices in preparing pre-service mathematics teachers with regard to MKT.

Implications for Practice

Implications for Teaching Practice

This study's findings suggest information about classroom instructional practices. The examination of questions from these six teachers suggests a trend to ask more pumping questions than any other. In mathematics, these tend to be procedurally oriented

(NCTM, 2014). Teachers who are cognizant of this tendency can plan more questions from other categories that will address conceptual understanding and attack problems with multiple representations and from multiple perspectives. Purposefully using questions from a variety of Chin's (2007) categories will result in a broader perspective for student learning.

In addition to asking questions from multiple categories, teachers should work to open up questions and promote more discussion among students. As the traditional IRF chain is opened up, students can gain more shared authority in constructing meaning of mathematical concepts and be encouraged to think more critically (Chin, 2007).

This switch of authority from sole teacher authority to shared authority with students is critical to understand the benefits of a student-centered learning environment as well (Lesh et al., 2003). As teachers become more purposeful about the questions they ask, they must also reflect upon their roles and the roles of their students in learning, potentially re-examining or reconstructing their belief structures in this process (Seung et al., 2011). Although this study did not attempt to provide generalizable measures for teacher effectiveness by means of student achievement, the purpose for questioning was different for sampled teachers in student-centered environments than those in teacher-centered environments. Where the teacher-centered educators used questioning to stimulate student thinking throughout a pre-planned and well-structured lesson, the student-centered educators used responsive questioning for the purpose of understanding students' processes in problem solving and prompting students to consider connections within and outside of mathematics (e.g. Belo et al., 2014; Lesh et al., 2003; Polly et al., 2014). All teachers should be mindful of the impact classroom environment has on student learning.

Implications for Pre-Service Education

The results from this study can provide important considerations for teacher education as well. Some factors that influence teacher questioning patterns and instructional decision-making can be taught within a methods course, and others need to be gained through carefully planned field experiences.

Pre-service mathematics teachers need to learn about the different types of questioning, such as the categories from Chin's (2007) framework, as well as instruction with regard to lower-level and higher-level thinking questions with reference to Bloom's taxonomy or the five strands of mathematical proficiency. Pre-service teachers will be more ready to ask thought-provoking questions and facilitate productive mathematical discourse if they are allowed more time to learn about and practice questioning techniques in their methods courses. In particular, research by Lin, Hong, Yang, and Lee (2012) in science education confirmed that pre-service teachers benefit from the opportunity to reflect collaboratively as they develop inquiry teaching practices. This opportunity should also be afforded to pre-service mathematics teachers as a way to improve questioning practices.

Secondary mathematics education programs must also ensure a deep mathematics content development for secondary mathematics and development of content knowledge for teaching as well as beginning the development of specialized content knowledge (Ball et al., 2008; Grossman, 1990; Shechtman et al., 2010). Teachers must have a rich mastery of mathematical concepts and the interconnectedness between different representations and topics to be able to ask questions that promote this type of thinking within their students.

A third idea for secondary education programs to keep in mind is the importance of high-quality field experience opportunities for their pre-service teachers to be able to understand and apply mathematics pedagogy (Cooper & Nesmith, 2013). Field experiences within this program should provide students with opportunities to notice PTMs, talk with mentors about possible responses to these PTMs, and practice enacting their preplanned lessons complete with essential questions and anticipated misconceptions (Stockero & Van Zoest, 2013). Practice with regard to pacing, reflection over their teaching, and development of relationships with mentors and students will provide necessary experience needed to influence their decision making later as they begin teaching careers.

Limitations

Limitations of this study are given to readers to be able to judge the appropriateness of these results to other populations and settings.

This study focused on a comparison of three novice and three experienced teachers in terms of questioning and response during PTMs. The researcher used a framework from science education as a lens for examining teacher questioning. Other questioning patterns exist in mathematics education that could also be suitable to address my research questions. For example, the researcher could instead have used the patterns of focusing and funneling (Herbal-Eisenmann & Breyfogle, 2005; Wood, 1998), which provide a different perspective for explaining these teachers’ questioning practices.

Another limitation to this study was the selection of participants. Because the researcher chose to compare novice teachers to experienced teachers, gaining consent from novice teachers proved to be difficult, so a snowball sampling technique was employed by the researcher. All novice teachers in this study were first-year teachers coming from the same education program. A random sample could have produced much different results. Other studies have taken convenience samples of teachers from the same schools or who have the same pre-service education background (Borko & Livingston, 1989; Schuck, 2009; Stockero & Van Zoest, 2013) with similar purposes for study, but the researcher acknowledges that the information about pre-service education practice may have been richer had the researcher used representation from multiple pre-service education programs. The experienced teachers who participated in this case study had differing levels of experience, 4, 8, and 17 years, and all teachers were working in different school buildings at the time of the observations.

Another limitation that stemmed from the difficulty in gathering a pool of participants was the inability to observe teachers as they taught the same course material. Five of the six teachers were observed during an algebra class, and the sixth teacher was observed during a geometry class. The algebra teachers were conducting lessons pertaining to a variety of topics, and two teachers taught algebra at the middle school level. A review of the literature revealed some studies that compared teachers as they conducted lessons over the same subject or the same content (Huang & Li, 2012; van Zee et al., 2001) and others compared teachers who taught different content (Borko & Livingston, 1989; Chin, 2006) or similar content at different grade levels (Clermont et al., 1994). Because the main goal for this study was to be able to describe each teacher's questioning practice, and all but one teacher (who was observed as she taught a remedial algebra class) described their questioning practices as similar for all classes they taught, the researcher did not take differences in content into account when categorizing the questions teachers asked. One teacher, who asked questions differently in her two algebra classes, explained that she does not incorporate the critical thinking questions as often for her remedial students. This difference was considered by the researcher as the data suggested a slight contrast in proportion for some of this teacher's categories of questioning compared to the other two experienced teachers, but gave additional information instead about this teachers' beliefs and exhibition of pedagogical sensitivity (Belo et al., 2014) during her instruction in a particular student environment as compared to a more general instructional approach.

Conclusions

In conclusion, this study provided information for teacher educators and for the field of mathematics education to consider. The extension of Chin's questioning framework from science into mathematics education gives a new perspective to categorizing the questions teachers ask and the responses they give to students in facilitating mathematical discussion. Teachers' use of questions from all of Chin's categories will promote more productive discussion and facilitate student learning through multiple representations and perspectives. These categories will aid in further quantitative research on teacher effectiveness and in developing more accurate teacher observation and mathematical discourse instruments for use in these larger-scale, empirical studies.

An additional consideration was the difference in purpose of questioning. Chin's categories were used in both teacher-centered and student-centered environments for this study, but the six teachers observed had different purposes for the use of questions. Teacher-centered educators are likely to use questions from every category for the purpose of stimulating student thinking throughout the course of a carefully structured, teacher delivered lesson. Student-centered educators are more likely to use questions from every category for the purpose of gaining insight of student thinking and solution strategies and providing connections between strategies and representations to further student understanding.

Lastly, clear differences exist in questioning practices between the three novice and three experienced teachers studied, and experience is not the only factor to consider when examining these differences. The categories of questioning that showed the most profound differences for beginning teachers relate to their inexperience with general pedagogy practices as well as a need for more extensive content knowledge and MKT. A suggestion comes from these findings. The continued improvement of instruction in pre-service education programs depends upon examination of the factors of influence for teacher questioning and decision making that are teachable in a university setting.

APPENDIX A

INTERVIEW QUESTIONS

Initial Interview: Background Information and Philosophy of Questioning

I. Introduction

A. Explain why participant was selected

II. Focus

A. To obtain a general philosophy of their purpose(s) of questioning in the classroom

III. Interview Questions

A. How long have you been teaching?

B. Tell me about the students you are currently teaching.

a. How does the culture of your classroom support quality questioning?

C. How would you describe your teaching philosophy?

a. Is your classroom student-centered? What are the student and teacher roles in your mathematics classroom?

D. What do you know about teacher questioning as an instructional practice?

E. How would you describe your philosophy of questioning in the classroom?

F. Do you have any sort of classification of questions in your mind? Explain.

G. What are your criteria for judging whether or not your questioning is eliciting the desired outcomes?

H. Do you think about your questions or question asking anytime outside of class? When and in what ways?

I. How do you respond to student answers? What types of feedback do you give? How do students expand upon correct answers? How do students interact with one another and initiate questions?

J. What experiences have influenced how you ask questions in the classroom?

(Questions were taken from Maloney, 2012, who developed them after reading the following articles: Colvert, 1997; Raysbrook, 2000; Stough & Palmer, 2003.)

Stimulated-Recall Interview: Reflective Interview on Instructional Decision Making

I. Introduction

A. Explain what an SR interview is

II. Focus

A. Question asking during the videotaped teaching episode

III. SR Rules

A. Can stop video at anytime

B. Distinguish between actual recall and new observations

IV. Orient

A. Participant gives brief description of purpose of teaching episode

B. SR addresses following issues:

1. Teacher's perspective on what happened in the episode
2. What teacher was trying to accomplish
3. What information were choices based on

V. Questions (asked each time tape is stopped)

A. Can you recall any of your thoughts when you asked that question?

B. Did anything that occurred in class influence your decision to ask that question? Explain.

C. What information did you base that decision on?

D. How did you decide which responses were appropriate?

E. Was there anything else you thought of doing at that point but decided against? What influenced this decision?

F. Would you like to share anything else about this teaching episode?

VI. Thank participant again for their time and interest.

(Questions were taken from Maloney, 2012, who developed the questions after reading the following articles: Colvert, 1997; Powell, 2005; Raysbrook, 2000; Speer, 2005.)

REFERENCES

Ackerman, D. B. (2003). Taproots for a new century: Tapping the best of traditional and progressive education. *The Phi Delta Kappan, 84*(5), 344-349. doi: 10.2307/20440357

Almeida, P., & de Souza, F. N. (2010). Questioning profiles in secondary science classrooms. *International Journal of Learning and Change, 4*(3), 237-251.

Amit, M., & Fried, M. (2005). Authority and authority relations in mathematics education: A view from an 8th grade classroom. *Educational Studies in Mathematics, 58*(2), 145-168. doi: 10.1007/s10649-005-3618-2

Ayres, L. (2008). Semi-structured interview. In L. M. Given (Ed.), *SAGE Encyclopedia of Qualitative Research Methods* (pp. 811-813). Thousand Oaks, CA: SAGE Publications.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389-407.

Bauersfeld, H. (1992). Classroom cultures from a social constructivist's perspective. *Educational Studies in Mathematics, 23*(5), 467-481. doi: 10.2307/3482848

Begeny, J. C., Eckert, T. L., Montarello, S. A., & Storie, M. S. (2008). Teachers' perceptions of students' reading abilities: An examination of the relationship between teachers' judgments and students' performance across a continuum of rating methods. *School Psychology Quarterly, 23*(1), 43-55. doi: 10.1037/1045-3830.23.1.43

Belo, N. A. H., van Driel, J. H., van Veen, K., & Verloop, N. (2014). Beyond the dichotomy of teacher- versus student-focused education: A survey study on physics teachers' beliefs about the goals and pedagogy of physics education. *Teaching and Teacher Education, 39,* 89-101. doi: http://dx.doi.org/10.1016/j.tate.2013.12.008

Bond, T. (2008). Cognitive development and school readiness. In N. Salkind (Ed.), *Encyclopedia of educational psychology* (pp. 163-165). Thousand Oaks, CA: SAGE Publications.

Borko, H., & Livingston, C. (1989). Cognition and improvisation: Differences in mathematics instruction by expert and novice teachers. *American Educational Research Journal, 26*(4), 473-498.

Breyfogle, M. L., & Herbel-Eisenmann, B. A. (2004). Teacher education: Focusing on students' mathematical thinking. *Mathematics Teacher, 97*(4), 244-247. doi: 10.2307/20871582

Bruner, J. S. (1986). *Actual minds, possible worlds*. Cambridge, MA: Harvard University Press.

Carlsen, W. S. (1991). Questioning in classrooms: A sociolinguistic perspective. *Review of Educational Research*, 61, 157-178.

Cengiz, N., Kline, K., & Grant, T. J. (2011). Extending students' mathematical thinking during whole-group discussions. *Journal of Mathematics Teacher Education, 14*(5), 355-374.

Changsri, N., Inprasitha, M., Pattanajak, A., & Changtong, K. (2012). A study of teachers' perceived beliefs regarding teaching practice. *Psychology*, *3*(4), 346-351.

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, *28*(11), 1315-1346. doi: 10.1080/09500690600621100

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, *44*(6), 815-843.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching*, *31*(4), 419-441. doi: 10.1002/tea.3660310409

Cobb, P., Yackel, E., & Wood, T. (1992). A Constructivist alternative to the representational view of mind in mathematics education. *Journal for Research in Mathematics Education*, *23*(1), 2-33. doi: 10.2307/749161

Common Core State Standards Initiative (2012). Implementing the common core state standards. Retrieved May 10, 2013, from http://www.corestandards.org/

Collin, F. (2013). Social constructivism. In B. Kaldis (Ed.), *Encyclopedia of Philosophy and the Social Sciences*. (Vol. 18, pp. 895-898). Thousand Oaks, CA: SAGE Publications. doi: http://dx.doi.org.proxy.lib.uiowa.edu/10.4135/9781452276052.n341

Cooper, S., & Nesmith, S. (2013). Exploring the role of field experience context in preservice teachers' development as mathematics educators. *Action in Teacher Education, 35*(3), 165-185. doi: 10.1080/01626620.2013.770376

Corbin, J., & Strauss, A. (2008). Basics of qualitative research. 2008: London: Sage Publications.

Costin, F. (1971). Empirical test of the "teacher-centered" versus "student-centered" dichotomy. *Journal of Educational Psychology, 62*(5), 410-412. doi: 10.1037/h0031623

Dillon, J. T. (1988). The remedial status of student questioning. *Journal of Curriculum Studies*, 20, 197-210.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing Scientific Knowledge in the Classroom. *Educational researcher, 23*(7), 5-12. doi: 10.2307/1176933

Early, D. M., Rogge, R. D., & Deci, E. L. (2014). Engagement, alignment, and rigor as vital signs of high-quality instruction: A classroom visit protocol for instructional improvement and research. *The High School Journal, 97*(4), 219-239.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47*(1), 273-305. doi:10.1146/annurev.psych.47.1.273

Franke, M. L., Webb, N. M., Chan, A. G., Ing, M., Freund, D., & Battey, D. (2009). Teacher questioning to elicit students’ mathematical thinking in elementary school classrooms. *Journal of Teacher Education, 60*(4), 380-392. doi: 10.1177/0022487109339906

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory : strategies for qualitative research*. New York: A. de Gruyter

Goe, L. (2007). *The link between teacher quality and student outcomes: A research synthesis*. Washington, DC: National Comprehensive Center for Teacher Quality.

Goe, L., & Stickler, L. M. (2008). Teacher quality and student achievement: Making the most of recent research (pp. 1-28). Washington, DC: National Comprehensive Center for Teacher Quality.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Harris, M. (2000). Twenty-Five years ago. *Mathematics Teaching, 171*, 27. doi: 3427645

Herbal-Eisenmann, B. A., & Breyfogle, M. L. (2005). Questioning our "Patterns" of Questioning. *Mathematics Teaching in the Middle School, 10*(9), 484-489. doi: 10.2307/41182145

Hill, H. C., Blunk, M. L., Charalambous, C. Y., Lewis, J. M., Phelps, G. C., Sleep, L., & Ball, D. L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition and Instruction, 26*(4), 430-511.

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*(2), 371-406.

Hill, H. C., Schilling, S. G., & Ball, D. L. (2004). Developing measures of teachers' mathematics knowledge for teaching. *The Elementary School Journal, 105*(1), 11-30.

Hoffman, N., Steinberg, A., & Wolfe, R. E. (2012). Teaching and learning in the era of the common core (pp. 1-68). *Students at the Center*: Boston: Jobs for the Future.

Hogan, T., Rabinowitz, M., & Craven III, J. A. (2003). Representation in teaching: Inferences from research of expert and novice teachers. *Educational Psychologist, 38*(4), 235-247.

Housner, L. D., & Griffey, D. C. (1985). Teacher cognition: Differences in planning and interactive decision making between experienced and inexperienced teachers. *Research Quarterly for Exercise and Sport, 56*(1), 45-53. doi: 10.1080/02701367.1985.10608430

Huang, R., & Li, Y. (2012). What matters most: A comparison of expert and novice teachers' noticing of mathematics classroom events. *School Science and Mathematics, 112*(7), 420-432.

Jacobs, V. R., Lamb, L. L., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for Research in Mathematics Education, 41*(2),*169*-202.

Kiemer, K., Gröschner, A., Pehmer, A.-K., & Seidel, T. (2015). Effects of a classroom discourse intervention on teachers' practice and students' motivation to learn mathematics and science. *Learning and Instruction, 35,* 94-103. doi: http://dx.doi.org/10.1016/j.learninstruc.2014.10.003

Lack, B., Swars, S. L., & Meyers, B. (2014). Low- and high-achieving sixth-grade students’ access to participation during mathematics discourse. *The Elementary School Journal, 115*(1), 97-123. doi: 10.1086/676947

Leinhardt, G. (1989). Math lessons: A contrast of novice and expert competence. *Journal for Research in Mathematics Education*, *20*(1), 52-75.

Leinhardt, G., & Greeno, J. G. (1986). The cognitive skill of teaching. *Journal of Educational Psychology, 78*(2), 75-95.

Lesh, R., Doerr, H. M., Carmona, G., & Hjalmarson, M. (2003). Beyond constructivism. *Mathematical Thinking and Learning*, *5*(2-3), 211-233. doi: 10.1080/10986065.2003.9680000

Lesh, R., & Lehrer, R. (2003). Models and modeling perspectives on the development of students and teachers. *Mathematical Thinking and Learning*, *5*(2-3), 109-129. doi: 10.1080/10986065.2003.9679996

Lin, H.-s., Hong, Z.-R., Yang, K.-k., & Lee, S.-T. (2012). The impact of collaborative reflections on teachers' inquiry teaching. *International Journal of Science Education, 35*(18), 3095-3116. doi: 10.1080/09500693.2012.689023

Lincoln, Y. S., & Guba, E. G. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. *New Directions for Program Evaluation, 1986*(30), 73-84. doi: 10.1002/ev.1427

López, O. S. (2007). Classroom diversification: A strategic view of educational productivity. *Review of Educational Research*, *77*(1), 28-80.

Magolda, M. (2004). Cognitive skills/cognitive development. In A. Distefano, K. Rudestam, & R. Silverman (Eds.), *Encyclopedia of distributed learning* (pp. 62-66). Thousand Oaks, CA: SAGE Publications.

Mahmud, S. H., Warchal, J. R., Masuchi, A., Ahmed, R., & Schoelmerich, A. (2009). Values-A study of teacher and student perceptions in four countries. *US-China Education Review, 6*(7), 29-44.

Martin, T. S., McCrone, S. M. S., Bower, M. L. W., & Dindyal, J. (2005). The interplay of teacher and student actions in the teaching and learning of geometric proof. *Educational Studies in Mathematics, 60*(1), 95-124.

NCTM. (1991). *Professional Standards for Teaching Mathematics*. Reston, VA: The National Council of Teachers of Mathematics.

NCTM. (2000). *Principles and Standards for School Mathematics*. Reston, VA: The National Council of Teachers of Mathematics.

NCTM. (2014). *Principles to Actions: Ensuring Mathematical Success for All*. Reston, VA: National Council of Teachers of Mathematics.

Oliveira, A. W. (2010). Improving teacher questioning in science inquiry discussions through professional development. *Journal of Research in Science Teaching, 47*(4), 422-453. doi: 10.1002/tea.20345

Polly, D., Margerison, A., & Piel, J. A. (2014). Kindergarten teachers' orientations to teacher-centered and student-centered pedagogies and their influence on their students' understanding of addition. *Journal of Research in Childhood Education, 28*(1), 1-17. doi: 10.1080/02568543.2013.822949

Putney, L. (2010). Case study. In N. Salkind (Ed.), *Encyclopedia of research design* (pp. 116-120). Thousand Oaks, CA: SAGE Publications.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching, 44*(1), 57-84. doi: 10.1002/tea.20163

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching, 50*(3), 284-314. doi: 10.1002/tea.21063

Shapiro, A. (2006). Constructivism, social. In F. English (Ed.), *Encyclopedia of educational leadership and administration.* (pp. 200-202). Thousand Oaks, CA: SAGE Publications. doi: http://dx.doi.org.proxy.lib.uiowa.edu/10.4135/9781412939584.n122

Scherrer, J., & Stein, M. K. (2013). Effects of a coding intervention on what teachers learn to notice during whole-group discussion. *Journal of Mathematics Teacher Education, 16*(2), 105-124.

Schuck, S. (2009). How did we do? Beginning teachers teaching mathematics in primary schools. *Studying Teacher Education: Journal of Self-Study of Teacher Education Practices, 5*(2), 113-123. doi: 10.1080/17425960903306492

Seung, E., Park, S., & Narayan, R. (2011). Exploring elementary pre-service teachers' beliefs about science teaching and learning as revealed in their metaphor writing. *Journal of Science Education & Technology*, *20*(6), 703-714. doi: 10.1007/s10956-010-9263-2

Shechtman, N., Roschelle, J., Haertel, G., & Knudsen, J. (2010). Investigating links from teacher knowledge, to classroom practice, to student learning in the instructional system of the middle-school mathematics classroom. *Cognition and Instruction, 28*(3), 317-359. doi: 10.1080/07370008.2010.487961

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*(2), 63-75.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. doi: 10.2307/1175860

Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., . . . Labuda, K. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching, 36*(8), 930-954.

Stacks, D., W. (2005). Case study. In R. Heath (Ed.), *Encyclopedia of Public Relations* (pp. 118-119). Thousand Oaks, CA: SAGE Publications.

Stockero, S. L., & Van Zoest, L. R. (2013). Characterizing pivotal teaching moments in beginning mathematics teachers' practice. *Journal of Mathematics Teacher Education, 16*(2), 125-147.

Strauss, A., & Corbin, J. (1998). *Basics of Qualitative Research: Grounded Theory Procedures and Technique* (2nd ed.). Thousand Oaks: Sage.

Stronge, J. H., Ward, T. J., & Grant, L. W. (2011). What makes good teachers good? A cross-case analysis of the connection between teacher effectiveness and student achievement. *Journal of Teacher Education, 62*(4), 339-355. doi: 10.1177/0022487111404241

Sullivan, L. E. (2009). Cognitive learning theory. Thousand Oaks, CA: SAGE Publications.

Tchoshanov, M. (2010). Quantitative study on teacher quality: Case of middle grades mathematics. *International Journal for Studies in Mathematics Education, 44*(3), 1-30.

Torff, B. (2003). Developmental changes in teachers' use of higher order thinking and content knowledge. *Journal of Educational Psychology*, *95*(3), 563-569.

Tyler, J. H., Taylor, E. S., Kane, T. J., & Wooten, A. L. (2010). Using student performance data to identify effective classroom practices. *American Economic Review, 100*(2), 256-260. doi: 10.2307/27805000

US Department of Education. (2013). Race to the top fund. Retrieved May 10, 2013, from http://www2.ed.gov/programs/racetothetop/index.html

van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education, 10*(4), 571-596.

van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching, 38*(2), 159-190. doi: 10.1002/1098-2736(200102)38:2<159::AID-TEA1002>3.0.CO;2-J

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Weinstein, C., & Acee, T. (2008). Cognitive view of learning. In N. Salkind (Ed.), *Encyclopedia of educational psychology* (pp. 165-166). Thousand Oaks, CA: SAGE Publications.

Wood, T. (1998). Alternative patterns of communication in mathematics classes: Funneling or focusing? In H. Steinbring, editor, M. G. B. Bussi, editor, A. Sierpinska, editor, & I. R. V. A. National Council of Teachers of Mathematics (Eds.), *Language and Communication in the Mathematics Classroom*, 167-178. Reston, VA.

Wu, H.-K., & Huang, Y.-L. (2007). Ninth-grade student engagement in teacher-centered and student-centered technology-enhanced learning environments. *Science Education, 91*(5), 727-749. doi: 10.1002/sce.20216