TEACHERS DEVELOPING EXEMPLARY INQUIRY PRACTICES: THREE LONGITUDINAL CASE STUDIES

BY

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ABSTRACT

If students are to be successful in the ever-changing scientific world they need to be taught how to think critically, to manipulate materials, and to gather evidence to build knowledge. Most teachers fall short in providing students the inquiry instruction described in the Next Generation Science Frameworks (National Research Council, 2011). This study examined three elementary science teachers' processes as they developed inquiry practices over time. The Electronic Quality of Inquiry Protocol (EQUIP) was used to gather quantitative and qualitative evidence of the teachers' inquiry practices in terms of four factors, *Curriculum, Instruction, Discourse,* and *Assessment*. A chronological analysis was used to examine the teachers' professional development and curriculum experiences in relation to their teaching practices. The results showed that all three teachers did change their practice, although the changes varied among cases. For each case, multiple factors influenced the teachers' development. There was a strong positive correlation between the quality of the teachers' inquiry practices and the time spent in curriculum-contextualized professional development. This research indicates that when teachers are supported with curriculum and professional development over extended periods, they develop exemplary inquiry practices. Three recommendations are provided for those interested in implementing science education reform.

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CHAPTER 1

INTRODUCTION AND OVERVIEW OF THE STUDY

If students are to be successful in the ever-changing scientific world they need to be taught how to think critically, to manipulate materials, and to gather evidence to build knowledge. Most teachers fall short in providing students the inquiry instruction described in the Next Generation Science Frameworks (National Research Council, 2011). This study examines the teaching practices of three elementary science teachers as they attended professional development and used supportive curricula over a five-year time. The case study illustrated the teachers' change processes as they developed their beliefs and skills to teach science inquiry.

Inquiry based teaching includes "the creation of a classroom where students are engaged in (essentially) open-ended, student-centered, hands-on activities" (Colburn, 2006, para. 6). Learning to teach through inquiry requires a transformation from traditional teaching practices, in which the teacher transmits knowledge to the student, to constructivist methods, in which the teachers and students engage in social and physical experiences to build knowledge (Yerrick, Parke, & Nugent, 1998). The practices associated with inquiry teaching involve complex interactive experiences for both the teacher and the student with materials and language (NRC, 2011). The dynamic nature of the inquiry teaching process has made it difficult to develop common operational definitions (Akerson & Hanuscin, 2007; Colburn, 2006; Windschitl, 2009). The absence of a clear understanding of inquiry is considered one of the challenges associated with implementation (Anderson, 2007; Minner, Levy, & Century, 2010; Saad & BouJaoude, 2012).

Marshall, Smart, and Horton (2010) reported the need for a comprehensive measure of inquiry because of the confusion in the literature about inquiry practices. They deduced from the literature that, "the essence of scientific inquiry is clear—students critically and systematically engage in examining, interpreting, and analyzing questions regarding the world around them and then communicate their findings, providing convincing arguments for their conclusions" (p. 301). Marshall, Horton, and White (2009) write that a proficient use of inquiry is when:

> a teacher has demonstrated a student-centered inquiry learning environment that actively engages students in investigations, questioning, and explanations. The role of the teacher remains vital, but he or she now functions more as a facilitator who scaffolds learning experiences than as a giver of facts and knowledge. (p. 53)

Statement of the Problem

The Next Generation Science Standards (NGSS) (NRC, 2011), due to be released in 2013, is yet another call for reform in the content and teaching of science in American schools. The over reaching goal of NGSS is to attain deep, systemic, and sustained improvement of science teaching and learning. The authors of the NGSS Framework (2011) also recognized that reform efforts should be focused on classroom practice. The document stated, "Ultimately, the interactions between teachers and students in individual classrooms are the determining factor in whether students learn science successfully. Thus, teachers are the linch-pin in any efforts to change K–12 science education" (pp. 9–10). It is logical that reform goals will not be met unless a skilled teacher is in every classroom.

Past reform efforts, in all instructional areas, have had little affect on the practices of teachers and the learning outcomes of students (Hargreaves & Goodson, 2006). Elmore (1996) described that most attempts at reform only engaged schools in superficial changes, such as changes in the time structures of the school day, the types of curriculum, or the class sizes. He expresses that these changes rarely affect how the teachers use and apply their knowledge to develop student thinking. Elmore said teachers may, "change the language they use, modify superficial structures around practice but without changing the practice itself" (p.15). He explained that the "core" of schooling, "how teachers understand the nature of knowledge and the student's role in learning," is rarely the focus of change efforts (p.2). Elmore proposed that reform efforts should focus on developing teachers' practices rather than applying superficial changes.

However, recent research has identified supports that may move teachers along the professional continuum from novice to expert (Windschitl, 2009). The key areas of support posited by science education researchers include: (a) cohesive and ongoing professional development, (b) educative curricula, and (c) adequate time for teachers to adapt and reflect on changes in their practice (Bybee, et al., 2006; Heck & Weiss, 2005; Minner, Levy, & Century, 2010; Weiss, Pasley, Smith, Banilower, & Heck, 2003).

Effective professional development includes a direct relationship between the content and materials to the classroom application, a focus on student achievement, and an opportunity of continued support through classroom coaching and long-term open communication with colleagues (Blank, de las Alas, & Smith, 2007; Garet, Porter, Desimone, Birman, & Yoon, 2001; Weiss & Pasley, 2009). Curricula that increases teachers' pedagogical content knowledge includes content for the teacher at a level above the students, strategies for methods of teaching, lessons that build over time, knowledge of how students learn, and suggestions for relating the curriculum to life outside of school (Ball & Cohen, 1999). Professional development and curricula effects on teaching practices have been explored extensively by educational researchers. What remains to be explored, however, is how time and sustained learning opportunities influence teachers' growth and development.

Few studies reveal the processes of how teachers' knowledge and skills evolve over time. Of the 91 articles used in Schneider and Plasman's (2011) review of science teachers' evolution of pedagogical content knowledge, the authors found only five studies that followed teachers for more than one year. Schneider and Plasman pieced together a teacher professional continuum based on inferences from connecting multiple cross-sectional studies. Inferences made about the teacher professional continuum without empirical evidence can mislead curricular decisions and reform movements (Feiman-Nemser, 2008).

The scarcity of longitudinal research that documents teachers' growth over time has created a gap in the understanding of teacher development. The lack of longitudinal research has left the educational community to speculate on how teachers progress over time (Schneider & Plasman, 2011). The lack of longitudinal research has allowed policy makers and change agents largely to ignore the teachers' learning progression (Feiman-Nemser, 2008). The authors of the NGSS Framework implored researchers to examine teachers' learning in order to inform plans for implementation, saying, "The typical learning trajectory for teachers and how it changes with learning opportunities requires empirical investigation" (NRC, 2011, p. 13–7).

Purpose

The purpose of this multiple case study was to describe how the science teaching practices of three elementary teachers develop over time. The study explained how professional development and curricula influenced the changes in each teacher's inquiry practices over a five-year period. Inquiry-based practices involve social and physical relationships between the students, the teacher, and the materials (Colburn, 2006; Minstrell & Kraus, 2005; NRC, 1996). By tracking three teachers' cases for a five-year period, we can examine the complexity of the change process.

The three teachers' inquiry practices were measured through the observations of videotaped lessons conducted over multiple years. An observation tool, Electronic Quality of Inquiry Protocol (EQUIP), provided quantitative and qualitative results from a rating of multiple inquiry practice descriptors that were grouped into four factors: *Curriculum, Instruction, Discourse,* and *Assessment* (Marshall et al., 2010). Qualitative data from interviews and from archived lesson reflections were used to support and extend the quantitative findings on observed teacher practices. The time-series analysis uncovered trends and patterns in individual teacher's inquiry practices. A cross-case analysis provided evidence to build theory about time and supports teachers need to develop exemplary inquiry practices in the teaching of science.

Research Questions

This study was guided by three research questions:

- How have individual teachers shifted their inquiry science practices over a five-year time frame in terms of *Curriculum, Instruction, Discourse,* and *Assessment*?

- How has ongoing professional development influenced teachers' inquiry-based practices?
- How have the time and experience with common curricula influenced teachers' inquiry based practices?

Significance of the Study

This research provides an in-depth analysis of the development over time of teachers' inquiry practices. The use of data from a previously conducted research project allowed for the longitudinal study to be completed in a reasonable time frame, thus, adding to the limited body of literature on teachers' professional learning trajectories (Feiman-Nemser, 2008; NRC, 2011; Schneider & Plasman, 2011).

Unlike previous studies that rely on teachers' self reporting of attitudes and teaching behavior changes (Anderson, 2007; Lederman & Abell, 2007; Saad, & BouJaoude, 2012; Supovitz & Turner, 2000), this investigation used classroom observations and existing records of professional development experiences to augment the teachers' perceptions of changes in their science teaching. This study was based in the realities of classroom practice and, therefore, may reform future practice more easily than much of the previous single-variable studies (Darling-Hammond & Richardson, 2009; Opfer & Pedder, 2011).

Definitions of Terms

Change knowledge: Sahlberg (2006) said that change knowledge in education involves understanding the process of curriculum change and the agents that are needed to successfully move curriculum implementation into practice.

Educative curricula: Ball and Cohen (1999) posited five components of educative curricula: (1) support for content knowledge above the level of the students' knowledge, (2) strategies for teaching, (3) lessons that build over time, (4) developmental knowledge of how students learn, and (5) suggestions relating content to life outside of school.

Inquiry learning: The National Science Education Standards (NRC, 1996) described inquiry as:

> Multifaceted activity that involves making observations; posing questions; examining sources of information; planning investigations; reviewing evidence; using tools; proposing answers, explanations, and predictions; and communicating results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (p. 23).

Inquiry teaching: Marshall et al. (2009) wrote that a proficient use of inquiry is when:

> a teacher has demonstrated a student-centered inquiry learning environment that actively engages students in investigations, questioning, and explanations. The role of the teacher remains vital, but he or she now functions more as a facilitator who scaffolds learning experiences than as a giver of facts and knowledge. (p. 53)

Pedagogical Content Knowledge (PCK): Teacher's PCK involves a complex development of understanding: "from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothed it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students" (Shulman, 1987, p. 13).

Teacher change: Richardson and Placier (2001) described teacher change in terms of "learning, development, socialization, growth, improvement, implementation of something new or different, cognitive and affective change, and self-study" (p. 905). Richardson (1990) compared the literature on "teacher change", in which change is initiated and imparted to teachers by an outside source, verses "learning to teach", in which teachers initiate the change as a personal mental process. She suggested that a hybrid of the two theories in which "the practical knowledge and value premises held by the teachers, and the empirical premises derived from research" is needed for "worthwhile and effective change" (p.14).

Overview of the Dissertation

The following chapters present this study on how elementary teachers develop their inquiry practices over time. The Review of the Literature (Chapter 2) reports on the research in inquiry practices, professional development, science curriculum, and teacher growth. The Methods and Procedures (Chapter 3) outlines the research design and describe the participants and settings involved in the case studies. In addition, it will present the methods of analysis used to examine each teacher's profile and to determine patterns across cases.

Each teacher case is presented in the following chapters: Case I: Danielle (Chapter 4), Case II: Mary-Ann (Chapter 5), Case III: Hayley (Chapter 6). These chapters illustrate each teacher's professional development timeline, curriculum experience, and classroom lessons through richly detailed written descriptions. The chapters also report changes in each case's science teaching practices related to *Curriculum, Instruction, Discourse, Assessment*, time usage, and teacher's beliefs. Cross-

Case Analysis (Chapter 7) examines the patterns that emerge by comparing the three cases.

The final chapter, Discussions and Implications, discusses the conclusions related to each of the three theories that were initially posed in this study: teacher change takes time; teacher change is complex; and professional development is more effective when related to actual practice. The final chapter also provides specific recommendations for moving teachers along the professional continuum in preparation for the upcoming release of the Next Generation Science Standards.

Chapter 2

REVIEW OF THE LITERATURE

The literature in this chapter covers four main areas. It begins with issues in inquiry teaching including a brief history, current definitions of the term, and descriptions of the multiple components. The research provides evidence on how professional development has influenced teachers' inquiry practices. Next, literature is presented that describes theories and research on how science curriculum has affected the development of inquiry practices. Finally, the literature is presented on teacher professional growth.

The science education literature includes many studies that describe the use of science inquiry by classroom teachers (Harlen & Qualter, 2004; Weiss et al., 2003). Additionally, there has been extensive research relating professional development experiences and teachers' use of inquiry (e.g., Blank et al., 2007; Borko, 2004; Mouza, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Supovitz & Turner, 2000; Weiss & Pasley 2009). A smaller amount of research exists on the effects of curricula on teachers' development of inquiry (e.g. Anderson, 2007; Ball & Cohen, 1996; Erickson, 2006; Pine et al., 2006; Stokes, Hirabayashi, & Ramage, 2003), an even smaller amount of research has looked at how experienced teachers' practice shifts over multiple years with both professional development and educative curriculum (Hargreaves, & Goodson, 2006; Weiss et al., 2003). This review of the literature will begin with a wide base of inquiry practices and funnel toward the few studies that attempt to map out teachers' learning trajectories toward the use of inquiry.

Inquiry Teaching

History of Inquiry. Inquiry pedagogy has appeared as a variable of interest in the research of teaching and learning as well as instructional design since the 1960s (Barrow, 2006). Barrow (2006) described the shifts in the definitions of inquiry over time. In the 1960s, the term inquiry was akin to activity-based science, in which just by "doing" students were learning. In the 1980s, research revealed that activity alone was not enough to develop scientific literacy. Theorists and researchers decided that teachers needed to guide, challenge, and bring light to the students' metacognitive process. Moving into the 1990s, inquiry was considered in terms of the physical activity as well as opportunities for mental struggles and teachers' abilities to scaffold student thinking (Barrow, 2006).

More recently, inquiry has been referred to as "practice-based science," indicating yet another transformation (NRC, 2011). The following excerpt from the Next Generation Science Standards Frameworks explains both the recent shift in thinking about inquiry and the concern for the ambiguity of the term.

> We use the term 'practices' instead of a term such as 'skills' to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice. Similarly, because the term 'inquiry,' extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not

> merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves. (pp. 2–5)

The physical and mental activities of inquiry are joined by a new emphasis on the students written and oral interpretations of their experiences (Duschl, Schweingruber, & Shouse, 2007).

Defining Inquiry. Inquiry, as an application to science education, refers to the teaching and learning activities that build scientific content through the practiced skills of scientists and engineers (NRC, 2011).

The National Science Education Standards (1996) described inquiry as a:

> multifaceted activity that involves making observations; posing questions; examining sources of information; planning investigations; reviewing evidence; using tools; proposing answers, explanations, and predictions; and communicating results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

The use of inquiry practices is emphasized nationally by the reform initiatives. The National Science Education Standards (NSES) included the constructs of inquiry in the description of what children should know and be able to do. The National Research Council (1996) valued inquiry as central to learning science, stating, "School science education must reflect science as it is practiced." (p. 11). The NSES (1996) reported:

> Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (p. 105)

Components of Inquiry Teaching

The complex nature of teaching inquiry has lead many researchers to break down the skills into more manageable components (Harlen & Qualter, 2004; Marshall et al., 2010; Russell & Martin, 2007, Sullivan-Watts, Nowicki, Shim, & Young, 2012). Through the validation of a tool that would help determine the degree to which teachers effectively facilitated inquiry, Marshall et al., (2010) deciphered nineteen constructs that were grouped into four factors. The factors were originally determined from an analysis of the research and then were aligned to the tightly grouped constructs. The following review of the research on the components of inquiry is organized by the four factors determined by Marshall et al (2010) for the development of The Electronic Quality of Inquiry Protocol (EQUIP).

Curriculum. Curriculum components related to inquiry included depth of content knowledge, flexibility for student-led investigations, integration of process and content, and expectations of student communication (Bybee et al., 2006; Dewey, 1938; Fosnot, 2005). Fosnot's (2005) description of curriculum resembled that of this inquiry factor:

> An approach to teaching that gives learners the opportunity for concrete, contextually meaningful experience through which they can search for patterns; raise questions; and model, interpret, and defend their strategies and ideas. The classroom in this model is seen as a mini-society, a community of learners engaged in activity, discourse, interpretation, justification, and reflection. (p. ix)

Instruction. Instruction, as related to the EQUIP, has five constructs based on fundamental beliefs of constructivist-learning theory. If students are to develop lasting knowledge, then they need to be actively involved in learning both the content and the process through a deep personally meaningful experience (Abell, 2007; Bybee et al., 2006; NRC, 2011). Light and Cox (2009) describe the teacher's role as bringing in materials, highlighting issues for discussion, commenting on and comparing different student views and data, and building on gap areas of content by "adding more sophisticated and critical perspectives on the topic" (p. 84). The authors explained the tricky balance of the teacher's role in teaching through inquiry, stating "Power is typically relinquished as much as possible to the group- whilst realizing that responsibility for structuring activities cannot be completely delegated" (p.77). The teachers' and the students' roles are intertwined as teachers facilitate learning experiences in which the students are active participants in the mental and physical construction on knowledge.

Discourse. Discourse includes reflecting, communicating, and questioning to develop knowledge and skills in the science classroom (Ball & Cohen, 1999; Kuhn, 1999; Norris & Phillips, 2003; Osborne, 2007). Russell and Martin (2007) said, "In contrast to the typical question-and-answer interchanges focused on 'right' answers, discussion needs to be based on supporting and evaluating differing views in the light of evidence" (p. 1154). An evaluator on the team from Horizon Research who reviewed the Local Systemic Change initiatives observed and described the discourse in a high-inquiry-use math classroom:

> At the highest level of questioning practices observed in both elementary and secondary classrooms, there was an almost seamless discourse between teacher and students that advanced mathematics instruction to the level of unrestricted intellectual mathematics exploration. In a fourth grade classroom, the teacher and students discussed angles and lines for a full 20 minutes. Students, as well as the teacher, posed questions, offered proofs, considered hypotheses. It was the students' questions that shaped the discussion, placing the teacher in the role of the facilitator. (Banilower, Boyd, Pasley, & Weiss, 2006, p.58)

Assessment. Assessment within the inquiry lessons involves the embedded instructional dialogues throughout the learning activity (Black & William, 1998; Ruiz-Primo & Furtak, 2007). Research on formative assessment suggests that teachers' use of students' ideas to guide science instruction could improve learning outcomes; yet, this remains a rare instructional practice in most classrooms (Ruiz-Primo & Furtak, 2007). Black and William (1998) remarked that all teachers make assessments in every class they teach. Some assessment strategies are more useful in student learning and developing teacher practices than others. Teachers should engage in conversations with students, listen to students' ideas and adjust instruction in response. The dialogue between teachers and students should be reflective. Teachers should ask questions that do not have one correct answer so that students feel confident in revealing their knowledge (Black & William, 1998).

Inquiry Teaching Summary

The components of curriculum, instruction, discourse, and assessment, are described above for the purpose of reflecting on teaching practices (Marshall et al., 2010). The dynamic interactions of teaching and learning through inquiry are rarely linear or precise. "Children draw understanding from the messy world around them. As a result, it's a messy exploration, and it takes place within the context of the child and the adults around that child" (NSF, 1999, p. 27). This messiness creates challenges for helping teachers understand and develop the intricate components of inquiry. Professional development and educative curricula are two supports that research has identified as supportive in this learning process.

Professional Development's Effects on Teacher Practice

In recent years, there has been a call for creative professional development programs to fit the educational needs, budgets, and continually shifting personnel of the school systems (Duschl et al., 2007; NRC, 1996). Considerable research has been conducted on the format, the amount of time, and the content of professional development sessions. First, the different formats of professional development (e.g., workshops, institutes, classroom coaching, and collaborative learning communities) will be described. Then the research will report on the number of hours of professional development and the corresponding effects on teacher practices. Finally, a review of research that highlights professional development content and the professional development effects on teacher practices will be presented.

Professional development formats

Professional development is presented to teachers in many formats (Desimone, 2009; Little, 2007; Loucks-Horsley & Matsumoto, 1999). Often teachers attend one-day workshops, in which they go to an outside site or have an outside presenter come to their school for fixed number of hours in a day (Garet et al., 2001). Fewer teachers are afforded the opportunity to attend extended learning opportunities in the form of professional development institutes (Borko, 2004). Coaching, on the other hand, is more personalized professional development that occurs in short segments in teachers' classrooms (Knight & Cornett, 2009). Collaborative leadership professional development occurs in schools and involves learning through communication with other practitioners (Little, 2007).

Workshops. The majority of professional development sessions in the last thirty years have been based on the one-day workshop model (Garet et al., 2001). Research has found that one-day professional development workshops often do not consider the schools' goals for student learning, the teachers' previous knowledge, and/or the context of the specific school; thus, the workshops do not reliably lead to change in practice (Penuel et al., 2007). Smylie (1989) conducted a study that had teachers rank the impact of fourteen different methods for gaining professional growth in teaching. The research found that teachers listed district-sponsored one-day professional development workshops as the least effective professional development strategy (Smylie, 1989).

In another study of 1500 randomly selected schools, Pritchard and Marshall (2002) researched, "How do healthy and unhealthy districts differ in their approaches to professional development?" (p. 113). The researchers used questionnaires, interviews, observations, and student essays from 18 districts in 11 states to determine how "healthy" the schools were. They judged school health on a number of factors including school climate and strategic plans, student attitude, teacher commitment, and administrator support. Their findings showed that the professional development in healthy districts had a more strategic long-range plan rather than "hot spot" workshops. The negative feedback on one-day workshops was expanded by Klingner's (2004) review of professional development research reported workshop models "were insufficient in duration or depth to bring about sustained, substantive change in practice" (p. 249).

On the other hand, Weiss and Pasley (2009) stated that workshops could be effective in changing teacher practice, if the workshops included modeling teachers' practices with classroom materials and engaging the teachers in "explicit discussion of how and why this pedagogy helps students learn the concepts" (p. 31). In addition, many workshops were found to have positive effects on changing teacher practice and eliciting student outcomes when combined with in school follow-up sessions of classroom coaching or professional learning community activities (Banilower et al., 2006; Weiss & Pasley, 2009).

Institutes. Teacher institutes allow large groups of teachers to come together and focus on a specific learning goal for an extended period of time. They are often held in the summer when teachers can take time without negatively affecting their classrooms. Weiss and Pasley (2009) said, "The advantages of this approach include maintaining quality control and establishing a shared experience for teachers. Intensive professional development at summer institutes extending over a period of days or weeks provides teachers with "immersion" experiences" (p.17).

The research on institutes' effectiveness in changing teacher practice indicates mixed findings.   The following studies demonstrated both the positive and inconclusive effects that institutes have on teachers' use of reform-based practices. In a study of the Exploratorium's Institute for Inquiry (IFI), St. John (2001) stated that the institute was focused on modeling professional development practices, offering curricular resources, and connecting education leaders across the nation who are implementing elementary science education reforms in their home schools and districts. The evaluative report from surveys, interviews, and a triple-blind study of ten school districts concluded that the Institute "makes a significant and visible difference. That is, the reform projects and districts that IFI works with are clearly distinguishable from otherwise similar districts and projects" (p. 6). The report also claimed that because the institute is designed for district leaders, the institute has a positive influence on many more educators then just those who attend.

Not all research on the effectiveness of institutes showed change in teacher practices. Yerrick et al. (1998) researched the beliefs and practices of eight science teachers during a 2-week summer course. The institute intended to prepare teachers to implement an inquiry-oriented science curriculum. The authors reported that teachers "began to use different ways of speaking about students and content…without changing fundamental views of science and teaching" (Yerrick et al., 1998, p. 14).

Classroom coaching. Coaching refers to learning that occurs as educators engage in their daily work activities with a more experienced or knowledgeable colleague. Ball and Cohen (1996) commented, "The most effective professional development model is thought to involve follow-up activities, usually in the form of long-term support, coaching in teachers' classrooms, or ongoing interactions with colleagues" (pp. 501–502). Classroom coaching is one type of job embedded in professional development. A number of researchers asserted that learning in the context of the teacher's classroom is very powerful (Cohen & Hill, 2001; Garet et al., 2001; Penuel et al., 2007). Teaching occurs in specific interactions of individual students with certain teachers concerning unique ideas under particular circumstances. Therefore, teachers need to learn "in and from practice" (Ball & Cohen, 1999). Coaching often occurs one-on-one, with the coach modeling new strategies or supporting existing strategies through co-teaching or critically observing classroom lessons. Coaching provides opportunities for teachers to practice and to reflect on newly emerging concepts (Garet et al., 2001; Knight & Cornett, 2009; Supovitz &Turner, 2000).

Few studies have collected data on classroom coaching and the data have been primarily drawn from reports from coaches or classroom teachers themselves (Knight & Cornett, 2009). Even with the lack of research there are qualitative statements from teachers and researchers that do support the use of coaches. One example is the TI MathForward™ program that includes many elements of effective professional development, including ongoing coaching. In the implementation study of this program, teachers reported that they valued the continued coaching and the coaches' constructive feedback. The teachers reported that it helped them develop new approaches to solving mathematical problems (Penuel, et al., 2007).

Collaborative teacher leadership. Darling-Hammond (1996) described a vision for the restructuring needed to improve the quality of teaching stating, "All teachers will have access to high-quality professional development, and they will have regularly scheduled time for collegial work and planning" (p. 5). Collective work in trusting environments provides a basis for inquiry and reflection, allowing teachers to raise issues, take risks, and address shortcomings in their own practice (Ball & Cohen, 1999; Little, 2007).

Little (2007) studied teachers engaged in 'joint work' signifying the time teachers spent in "thoughtful, explicit examination of practices and their consequences" (p. 520). She observed that teachers change their practice through working together on curriculum development, problem solving concerning students and their learning, and peer observations. Parke and Coble (1997) studied science teachers from seven schools involved in working together on curriculum development activities. The teachers communicated continuously with colleagues and university staff on an intentional and thoughtful task. Parke and Coble concluded that their professional learning community approach "supported teachers to become architects for change through building upon their current conceptions instead of attempting to remediate them" (Parke & Coble, 1997, p. 785).

Format Conclusions. This review of professional development format types supplied evidence of the effectiveness of workshops, institutes, coaching, and collaborative. The majority of the research led toward a mixed- format approach as being most effective. It seems that teachers need time to focus on new strategies or content in a controlled environment, such as, in a workshop, course, or institute followed by additional support for direct application and reflection within the context of their classroom from coaching and/or collaborative teacher leadership.

Time spent in professional development

Many researchers have claimed that "ongoing professional development" is an essential element to developing teacher practices (Klingner, 2004; Weiss & Pasley, 2009). It is thought that teachers who had more hours of professional development in inquiry-based science were significantly more likely to use inquiry-based science instruction (Lederman & Abell, 2007; Supovitz & Turner, 2000). Research is only beginning to gather evidence on how sustained professional development effects the change in teacher practices over long periods of time.

The capstone report of the effect of National Science Foundation (NSF) funded Local System Change (LSC) initiatives was able to link the number of hours teachers spent in professional development to shifts in their inquiry practices (Banilower et al., 2006). The researchers concluded that lessons taught by teachers with at least eighty hours of professional development were more than twice as likely to receive a high rating on science inquiry lessons as the lessons of teachers with little to no professional development.

Another LSC project evaluation showed a relationship between the teachers' hours of professional development and their perceived frequency of inquiry practices (Heck, Rosenberg, & Crawford, 2006). The results of survey data found that teachers who experienced more hours of professional development perceived they were using more inquiry practices. The relationship between the professional development hours and the perceived use of inquiry only increased up to eighty hours of professional development. Additional research is needed to examine the factors affecting teacher growth after eighty hours of professional development and to examine the match between teacher perceptions and their actual practice.

Professional Development Content

To be effective, professional development should also be based on curricular and instructional strategies related to student learning rather than solely on theoretical teaching methods. Penuel et al. (2007) reported that university-led professional development that afforded active learning environments with "proximity to practice," were essential for reform. The researchers claim that professional development is about "helping teachers to prepare for their classroom practice [that] yields results directly translatable to practice" (p. 928).

The National Commission on Mathematics and Science Teaching for the 21st Century (2000) highlighted five effective focuses for successful professional development. They explained that professional development should deepen teachers' knowledge of the subjects being taught and allow teachers to practice the reform-based teaching skills desired in classroom practice. Professional development sessions should be based on up-to-date research and practices that have proven to be effective. The professional development providers should understand the knowledge level of the participants so the professional development session provides new skills and content for the participants. Finally, the professional development should offer strategies for teachers to assess how they are doing with the new practices when they are back in the classroom.

A large body of research debated the effectiveness of professional development focused on the development of content knowledge versus pedagogy. Tsai (2006) examined the effects of science education courses on 36 in-service and 32 pre-service teachers. The courses included the nature of science, science activities, and some reflection on conceptual change. Data collected through teacher questionnaires, short essays, and interviews revealed that both in-service and pre-service teachers' view of the nature of science had changed throughout the coursework. When Tsai compared in-service and pre-service teachers, he found that in-service teachers learned to value constructivist learning, but their practices were less likely than pre-service teachers actually to change. Science content courses that focus on the memorization of facts rather than on the nature and culture of science do not support the teachers' development of inquiry practices (Akerson & Hanuscin, 2007; Blank et al., 2007; Harlen, 1997; Lederman & Abell, 2007).

Therefore, professional development should involve both content and pedagogy and the direct relation of the content and materials to classroom practices (Blank et al., 2007; Garet et al., 2001). Professional development is most effective if teachers are able to see how to change their practices in the classroom.

Curriculum Effects on Teacher Practices

Science is a dynamic field of study based on our human experience and capacity to think. We rely daily on the benefits from scientists' innovative thinking and reliable research in medicine, industry, transportation, agriculture, electronics, and technology. *Inquiry: thoughts, views and strategies for the K-5 classroom* (NSF, 1999), posits that students should approach learning through curricula that allow them to demonstrate the mental and physical behaviors of scientists. Equipping students with knowledge and skills to be productive citizens of the twenty-first century requires a curriculum that actively involves students in their learning, challenges students to think critically, and explores scientific concepts deeply and coherently.

Since curricula are only effective if teachers implement them as they are intended (Cuban, 1992), they must include appropriate materials for student learning as well as offer support for teacher learning (Schneider & Krajcik, 2002). A National Research Council report (2007) articulated that, "the current organization of science curriculum and instruction does not provide the kind of support for science learning that results in deep understanding of scientific ideas and an ability to engage meaningfully in the practices of science" (p. viii).

Research-based science communities, such as the National Science Foundation, the American Association for the Advancement of Science, the National Science Teachers Association, and the National Research Council have all constructed new documents and policies that are meant to guide reform-based curricula as to what and how students should learn. In July of 2011, the National Research Council released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* This framework, based on current research, is meant to guide the development of future science standards and curriculum. The researchers suggested that to build a scientifically literate society, curricula should focus student learning on the following four strands of science proficiency:

1. knowing, using, and interpreting scientific explanations of the natural world;
2. generating and evaluating scientific evidence and explanations;
3. understanding the nature and development of scientific knowledge; and
4. participating productively in scientific practices and discourse (p. 37)

Therefore, reform-based science instruction requires curriculum that encourages students to ask questions, investigate, and find evidence to construct a deep level of understanding about science content.

Kit-based curriculum

Kit-based curricula provide teachers with a sequence of lessons and classroom materials to engage students in learning scientific content and practices (Pine et al, 2006). Three to four curriculum units are recommended across the course of a year that focuses on the hands-on learning of physical, earth, and/or life science. Fewer science content topics are covered in greater depth as compared to the multitude of briefly addressed topics covered in a traditional textbook approach. Research-based instructional units in the form of kits or modules are obtained from such sources as: *Science and Technology for Children* (STC) developed by the National Science Resource Center (NSRC, 1985) at the Smithsonian Institute supported by the National Academy of Sciences and *Full Option Science System* (FOSS) developed at the Lawrence Hall of Science, University of California, Berkeley.

The data from many small-scale recent studies have supported the use of a hands-on, minds-on inquiry-based curriculum in the classroom. Lynch, Kuipers, Pyke, and Szesze, (2005) studied over 2,000 eighth graders in a large, diverse middle school in Maryland. These researchers found that with an inquiry-based chemistry curriculum, students were more engaged and motivated in class and outperformed their peers who were using a traditional text-based program.

Geier et al. (2008) observed gains in middle school students and their achievement on high-stakes tests. The research found that the intervention group that had three science inquiry units, each 6 to 9 weeks in length, scored significantly higher on the earth, life, and physical science portions and the process skill subtests from the Michigan Educational Assessment Program. The students' scores on this test increased cumulatively with more inquiry experiences. These research studies support the use of inquiry-based science curriculum in the classroom.

Pine et al. (2006) compared the science achievement and attitudes of almost 1000 fifth graders who received either textbook or activity-based kit curricula. The authors found that students in both curricular groups performed poorly on the multiple-choice tests. The authors did find that students in the kit-based classes had a more positive attitude about science, including about a 20 percent increase in the number of students who ranked science as their favorite subject. The authors pointed out that the similar outcomes between textbook use and kit-based curricula might be an effect of the type of assessment, the abilities of the teachers, or the curriculum itself.

While reviewing 81 pre-service and in-service elementary teacher videos, Nowicki, Sullivan-Watts, Shim, Young, & Pockalny (2012) found that teachers using kit-based curriculum with professional development were more likely to teach accurate content than teachers using non-kit approaches. The use of kit-based curricula was the most significant indicator of highly content accuracy.

Sullivan-Watts et al. (2012) found that teachers who used kit-based curriculum were more likely to use reform-based inquiry practices than teachers who taught science using a textbook or other curricular approaches. These researchers evaluated 81 videotapes from 54 participants for effective use of inquiry practices. This study videotaped science lessons of students during their science methods course and again the following year during student teaching. A multiple regression analysis revealed that for in-service teachers, the use of a kit-based curriculum was the most significant predictor of using inquiry-based practices, explaining 27 percent of the total variance in inquiry lesson scores. In addition, pre-service teachers were found to increase their use of inquiry practices as they gained more experience with the kit-based curriculum. The comparison over time showed that the students increased their use of inquiry if they spent both years in a kit-based program or changed from a non-kit-based classroom into a kit-based classroom during student teaching. But the students' use of inquiry practices decreased when the students were removed from a kit-based program in their student teaching year.

Critics of a kit-based approach are focused on the challenges associated with the implementation of the curricula. Weiss et al., (2003) researched teachers using variations of kit-based curricula and found "only 18 percent of mathematics and science lessons nationally provide experiences for students that clearly depict mathematics/science as investigative in nature" (p. 44). The National Research Council report titled *Taking Science to School (2007*) articulated that, "the current organization of science curriculum and instruction does not provide the kind of support for science learning that results in deep understanding of scientific ideas and an ability to engage meaningfully in the practices of science" (p. viii).

Banilower et al. (2006) observed 1,620 classroom lessons, gathered 75,000 teacher questionnaires, and conducted 1,782 interviews to analyze how high quality curriculum and professional development effected classroom practice. They found that hands-on instruction associated with kit-based curriculum required more management and support then teaching through a traditional textbook approach. The researchers suggested “that lack of content knowledge, lack of confidence and experience in using the investigative model and/or the materials, and resistance to forsaking teacher-directed approaches were among the factors that limited teachers’ capacity” (p. 69).

The kit-based curricula have the components of an educative curriculum, yet the results from research provide an unsettled conclusion as to the effectiveness of the curricula. The results of research on kit-based curricula with the addition of an expository writing component have had a different outcome (Ramage, Accurso, Mitchell, Carroll, and St. John, 2006).

Science Writing Approach

The Frameworks (NRC, 2011) remind us that language is essential to inquiry practices saying, “A major practice of science is thus the communication of ideas and the results of inquiry—orally, in writing, with the use of tables, diagrams, graphs, and equations, and by engaging in extended discussions with scientific peers” (p. 3–31).

Language and learning theories. The development of the literature on writing within the science classroom has been guided by knowledge of how children learn through language and on the need for teachers to understand what children know (Norris & Phillips, 2003; Vygotsky, 1978). This review of literature on curricula that includes the science writing approach begins with general research on language use and learning. Then more specific studies are presented that look at science writing curricula and the curricular effects on teacher practices.

Attaining scientific literacy is more than just having the knowledge and skills to define words and locate information. Rather, it requires an active construction in the development of new knowledge and the ability to interpret and communicate that knowledge. (Norris & Phillips, 2003). Bruner (1977) said, "We know how to do those things long before we can explain conceptually what we are doing" (p. 151). Language without experience or content development is symbols or sounds without meaning. In the quote below, Hawkins (1978) portrays a conversation that might occur in a traditional classroom where empty vocabulary is developed instead of scientific thinking and concepts:

> And she said, 'No, I don't mean that. I want you to notice this and tell me what's happening. 'Finally he looked at the pendulums and he saw what she was asking. He looked at it, and he looked at her, and he grinned and said, 'Well, I know the right words but I don't understand it either.' (p. 64)

The theoretical rationale behind the inclusion of writing and oral language in students' proficiency of science comes from an understanding of how students learn. Social constructivists recognize that language is a social product learned through social experiences and is a foundational instrument in learning (Bruner, 1977; Dewey, 1938; Duckworth, 1987; Piaget and Inhelder, 1969; Vygotsky, 1978). Oral and written communication helps students work through the complex subject of science and, in turn, science provides the experiences and content knowledge that aids the development of language. Yore, Bisanz, & Hand (2003) reported the importance of language in learning science:

> [Language] is an integral part of science and science literacy—language is a means to doing science and to constructing science understandings; language is also an end in that it is used to communicate about inquiries, procedures, and

science understanding to other people so that they can make informed decisions and take informed actions. (p. 691)

Language and science research. There is a small, but growing body of evidence on successful integration of writing, speaking, and science. Stokes et al. (2003) researched the effectiveness of the Seattle Public Schools Expository Writing and Science Notebooks Project. Through expert review and analysis of student notebooks and a teacher survey, they found positive results in student learning, teacher enhancement, and implementation of curriculum. A qualitative study was done that looked at the relationship between teacher participation in over seven hours of professional development on using notebooks and students' test scores. The researcher found that the students who had teachers who had professional development scored significantly higher than their peers on the Washington Assessment of Student Learning. The researcher admitted that the sample of teachers with the required hours of professional development was too small to make a powerful statistical analysis. This challenge to the research is important not only in that it weakens the research findings, but also it brings light to the challenges of implementation.

Ramage, Accurso, Mitchell, Carroll, and St. John (2006) reported another qualitative study of 45 teacher interviews and a dozen classroom observations. The researchers collected evidence that writing can help develop scientific understanding. The research found "the evidence showed that science notebooks provided a place for students to make the link from the hands-on activity to the science concept, making their investigations authentic and purposeful" (p. 4). They also realized that teachers did not initially know how to teach expository writing to support science, and they were successful in doing so only after professional development.

Teacher Growth

Change theories. Most research studies, especially those that evaluated the effectiveness of an intervention, reinforced the notion of *teacher change*. Teacher change is often thought of as something done to teachers, an intervention that fixes teacher practices (Richardson, 1990). In contrast, *teacher growth* theories presume that change is a personal and social process that occurs in the context of multiple variables associated with education. Opfer and Pedder (2011) explained that learning occurs within and between professional development events, learning community contexts, personal experience, and individual characteristics. They conclude professional learning should be considered an individual experience involving observable patterns of interactive, non-linear successions of events over time.

Teacher professional growth assumes that over the course of a teacher's career, she or he has the capacity to develop the pedagogical content knowledge necessary for reform-based science instruction (Schneider & Plasman, 2011). The teacher's learning process is often reported as a continuum in which teachers move from novice to expert through a series of processes. In the National Research Council report *How People Learn* (2000), the authors identified five steps in the continuum: developing awareness, building knowledge, translating knowledge into practice, practicing teaching, and using reflection to renew practices. The teacher continuum is said to be both a personal and social journey (Ball & Cohen, 1999; Borko, 2004).

Cuban (1992) reported that innovations fail to move teachers across the professional continuum because teachers do not fully embrace intervention strategies. Instead, educators alter the strategy by fitting it into their current practice. But what we know about the process of student learning theories is that prior knowledge plays a role in learning new material. Teachers as learners, similar to student learners, are going to assimilate new teaching strategies into existing schema. Coburn (2004) found that teachers reacted to innovation by moving through a continuum beginning at rejection and ending with accommodation. This process he calls *sense making* occurs when teachers take in certain learning opportunities from their environment, decipher them, and then resist or accept to change their practice. Researchers may develop different terms for how teachers' practices grow, but researchers agree that the teacher learning process must involve intensive support structures, experience, and time (Louks-Horsley & Matsumoto, 1999).

Professional learning research. Not many studies have provided the educational community with knowledge on how experienced teachers' practices progress over multiple years. In fact, Schneider and Plasman (2011) reviewed research published on teacher development between 1986 and 2010 and only found five articles that studied teachers for 2 or more years. The researchers examined a total of 91 studies to find patterns in teachers' development process of their pedagogical content knowledge. The research was framed with an understanding that learning is "continuous and coherent, an incremental sequence from novice to expert" (p. 532). The researchers found that teachers thought in more sophisticated ways about teaching overtime but that professional development for more experienced teachers did not get progressively more advanced. The experienced teacher had similar outcomes in the research as early career teachers. In some cases, the research found that teacher pedagogical content knowledge actually declined over time.

Marshall, Smart, and Horton (2011) found that not all components of inquiry practices progress at the same rate. The researchers used the EQUIP observation tool to assess 22 math and science teachers practices before, during, and after they participated in a yearlong intensive professional development program. The greatest observed growth occurred within the factors of *Instruction* and *Curriculum*. The teachers perceived their growth in *Instruction* but did not perceive their growth in *Curriculum*. The factors of *Assessment* and *Discourse* only showed a slight increase in the quality of inquiry use. The composite rubric scores from the post professional development observations revealed that while teachers improved their practice, they are only barely reaching proficiency in *Instruction* and *Curriculum* and are struggling to develop their inquiry practices to a proficient level in the *Discourse* and *Assessment* factors.

Another case study research that followed seven teachers for three years found that professional development and supportive materials were effective in changing teachers' practice (Mouza, 2009). Mouza (2009) used archived data from a previous study on the effects of professional development to enhance the teachers' use of technology in the classroom. The follow-up data collection occurred two years after the implementation of the professional development and was conducted with the intention to "investigate the sustainability and growth of teachers' learning, identify the conditions that facilitated or hindered teachers' capacity to further develop their thinking, knowledge, and practice with regard to technology, and map the trajectory of teachers' learning over a 3-year period" (p. 1196). The findings of the study reported that most teachers were able to hold onto practices developed during the professional development sessions, but once the professional development was discontinued, teachers did not further develop their practices.

Teacher growth conclusions. Research that examines simple cause-effect relationships without considering the complex context of the classroom will reinforce the teacher change theories. When teacher change theories are applied to practice they rarely have lasting effects on developing teacher practices (Elmore, 1996; Spillane, 2002). More research is needed that follows teachers over longer periods of time (NRC, 2011). When research is able to "trace the learning-to-teach process", then a paradigm shift in educational change theories might occur and result in more effect reform (Richardson, 1990p. 12).

Summary of the Literature

The literature has clearly described that teachers should be incorporating inquiry into their instruction of practices if they are to align with current reform efforts (NRC, 1996; NRC, 2011); however, inquiry practices are not currently the norm in teaching science (Dorph, Sheilds, Tiffany-Morales, Harty, McCaffrey, 2011; Horizon, 2002). Recent research has highlighted the need for professional development and educative curricula in order for teachers to successfully teach inquiry (Weiss & Parsley, 2009).

Research Questions and Propositions

Questions

The questions that narrowed the scope of this study are:

- How have individual teachers shifted their inquiry science practices over a 5-year time frame in terms of *Curriculum, Instruction, Discourse, and Assessment*?
- How has ongoing professional development influenced teachers' inquiry-based practices?
- How has the addition of an expository writing program to an existing kit-based curriculum influenced teachers' inquiry science practices?

Propositions

The following propositions are derived from literature reported above. Yin (2009) states, "Each proposition directs attention to something that should be examined within the scope of the study" (see Chapter 2, para. 11). The propositions provide a frame within which the researcher and the reader can relate to the findings.

Proposition 1: All inquiry factors (i.e., *Curriculum, Instruction, Discourse, and Assessment)* will increase in each of the data collection periods for each of the teachers. Rationale: The teachers in this study have the supports that research identifies as essential in developing inquiry practices, including the use of hands-on, educative curriculum materials and ongoing coherent professional development (Ball & Cohen, 1999; Schneider & Krajcik, 2002; Yore et al., 2003).

Proposition 2: Teachers who receive the greatest amount of professional development during the data collection period will have greater increases in the use of inquiry practices. Rationale: A number of studies have concluded that ongoing professional development is essential to the development of the complex practices involved in teaching inquiry (Banilower et al., 2006; Blank et al., 2007; Saxe, Gearheart, & Nasir, 2001).

Proposition 3: After the implementation of an expository science-writing program, the factors of *Curriculum* and *Discourse* will show a more rapid adoption of inquiry practices. Rationale: Effective use of writing has been found to support both teachers and students as they learn to organize their thinking, to clarify content knowledge, and to connect content to inquiry processes (Ramage et al., 2006; Stokes et al., 2003). In addition, writing structures can provide frames for talking. Developing language, both spoken and written, supports students' and teachers' abilities to participate in conversations based on evidence (Fulwiler, 2007).

Chapter 3

METHODS AND PROCEDURES

This chapter presents the case study methods used to research the three teachers' shifts in practices over time. It begins with a description of the study participants and their settings with justification for the selection of these teachers. Then the sources of data are presented. Next, the study variables of time, professional development, curriculum, teacher's perceptions, and teacher's practices are described. The instrument used to measure the teachers practices, Electronic Quality of Inquiry Protocol (EQUIP) is explained in terms of validity and reliability, the factors measured, and the level of inquiry outcomes. Next the chapter illustrates the data collection and analyses procedures. Finally, the protocols for analysis of the data, the measures taken to raise the study's reliability and validity, and the researcher's attempts to avoid bias are described.

Selection of case study method

Given the nature of the research questions, case study method provided the best fit to test the stated propositions. Yin (2009) defined the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used. Under the theoretical lens that it takes a combination of interrelated factors to shift a teacher's instructional growth, it will be important to collect data that encompasses the teacher's growth process in the classroom and incorporates all the teacher's professional learning opportunities. Stake (1995) said that case studies are used to focus on the relationships between a large number of variables and the ways in which the variables may or may not follow similar paths over time. In addition, Yin (2009) expressed the need for the use of case studies when boundaries between the subject and its context are not clear and when the phenomena must be studied within its real-life context.

Multiple cases allow for replication logic to be applied to the study findings. Replication logic corroborates and extends the findings beyond the first case. Yin (2009) said that multiple cases should be regarded as repeated experiments and should not be confused with sampling designs that attempt to generalize toward a larger population. Each of the three cases was compared across cases to see if a literal replication existed. Yin (2009) explained that literal replication could be used to support a developing theory. "If all cases turn out as predicted . . . [they provide] compelling support for the initial set of propositions" (Chapter 2, para. 42). If the cases do not turn out as predicted, the findings might invoke questions about other variables.

Participants

Case selection

Case study research is done to highlight "distinct, excessive, uncommon, influential, most similar, and most different cases" (Yin, 2009). The teachers in this study were similar because they all had access to research-based curricula materials, Science and Technology For Children (STC) modules and Full Option Science System (FOSS) modules, and opportunities for professional development recommended by the NGSS Frameworks (NRC, 2011). Yet, comprehensive support is rarely provided to teachers throughout the United States. In a study of 543 teachers in one state, 85% of the teachers surveyed reported that they had no professional development in science for at least 3 years (Dorph et al., 2011).

Stake (1995) recommended that case selections be chosen to capitalize on what can be learned within the limitations of the available time and the location of the researcher. The number of possible cases for researching teachers' growth within a realistic time frame was limited by the available historical data. The selection of cases in the current study was based on the following criteria:

- teachers of elementary science in grades 1–5;
- participants in a network that supports teachers in the teaching and learning of inquiry science and that records professional development activity; and
- participants in a prior research project of science teaching practices, for whom video lessons are archived from at least two points in time between September of 2006 and June of 2011.

These conditions narrowed the local accessible field down to six teachers. All six teachers were asked to participate in the study. Three of the six teachers gave their informed consent to participate in the research as required under regulations for the protection of human subjects. After the teachers agreed to participate in the study, it came to the researchers' attention that one of the three teachers, Hayley, only had archived data from 2009. The researcher decided to include Hayley in the research even though she only had two points of data over the 5 years. The data from this case were still able to strengthen or discredit developing theories on teacher growth.

Case I: Danielle

Danielle has 19 years of experience teaching in four different states. She taught 2 years in an inner city school as a third grade general education teacher. She spent another few years teaching English in seventh and eighth grades in a magnet school for the arts. After spending 6 years at home with her children, she moved to the district in which she currently teaches and was filmed. By 2012, Danielle had taught primarily in fourth grade in the same district for 14 years.

Case II: Mary-Ann

Mary-Ann has been a classroom teacher in grades one and two for 24 years. Following her undergraduate degree, she was a substitute teacher and ran a tutoring program before being hired in the district in which she currently works. During the data collection for this research, she taught second grade in two different elementary schools in the same district.

Case III: Hayley

Haley has been a classroom teacher for 18 years. She began her career as a computer literacy middle school teacher. After 2 years, she moved to her current district and became a seventh grade mathematics teacher for 3 years. Hayley has spent the last 13 years as a fourth grade classroom teacher in the same elementary school.

The Setting

The teachers for this case study all taught in the elementary schools of the same suburban school district. In 2008, the district had 3,737 students in grades K–12. Ninety-five percent of the students were recorded as “white,” 18% of the students were eligible for free and reduced lunch, and 10% of students were receiving special education services

(Information Works, 2008). Four small towns had regionalized to make this district. Each town has its own elementary school.

In 2006, this district joined an established science education university-based collaborative. The collaborative started as a partnership with five school districts and the local university in 1996. The district of the participant teachers joined the collaborative in 2006. By that time, the collaborative had grown to incorporate eight districts and the university. The goal of the collaborative was to increase student learning "by providing high-quality science instruction that is informed by national science education standards and supported by high quality materials and continuing professional development support" (Young, Beauman, & Fitzsimmons, 2008, p. 272). A common curriculum that utilized NSF-developed science kits (Full Option Science Systems-FOSS and Science and Technology for Children-STC), aligned with the science standards followed by the state, was provided for all teachers. The project facilitated the teaching and learning of science with a continuous implementation of the curriculum through ongoing mandatory professional development for all teachers and administrators in the district.

The success of science instruction in the participant district was demonstrated by the results of the high-stakes science state test in fourth grade. The average percentage of proficiency in the district in 2008 was 54.1%. In 2012, the district had increased the proficiency to 73.3%. This was significantly higher than the state average proficiency of 46%. Therefore, the district, supported by ongoing professional development and educative curriculum, increased its proficiency on statewide science tests by almost 20% and outperformed the state proficiency level by 27% (RIDE, 2012).

Human Subjects' Research Protocol

The proposal for this research was approved by the Institutional Review Board on Human Subjects (Appendix A) The three teacher participants agreed to the study after reading and signing the Informed Consent forms approved by the Institutional Review Board at the researcher's University (Appendix B). There were no potential risks associated with participation in this study. The participants were asked to participate and told that they may withdraw at any time. There was no financial reward for participating or consequence for not participating. In addition, the student consent forms were signed by the students' guardians and returned to the researcher through the teacher (Appendix C). The researcher obtained a letter from the superintendent of the district for permission to conduct research in the schools (Appendix D). The researcher assigned code names during the data analysis process for all teachers, schools, and districts. All identifiers were stripped from the data. The data are kept on an electronic database with encrypted password protection.

Sources of Data

Five sources of data were used to investigate the research questions. Multiple sources of data allowed for a clear and valid identification of how the variables in the study interacted with each other. Some of the data sources were collected from the archives of a previous research project, Change Associated with Readiness, Education, and Efficiency in Science Reform (CAREERS). The letter for permission to access the archived documents can be referenced in Appendix E.

Videotaped lessons

The key source of data was derived from observations of videotaped science lessons. In the fall of 2007, the fall of 2009, and the spring of 2012 the teachers were asked to teach an inquiry-based lesson from their district's curriculum (Sullivan-Watts et al., 2012). These lessons were videotaped in their entirety and stored digitally on a hard drive. Information gathered from the videotaped lessons included the quality and quantity of each teacher's inquiry practices.

Database

The teachers' professional development experiences were retrieved from the database of the university-based science education collaborative. The database was organized through Filemaker™ software. The professional development experiences were entered into the database when teachers attended workshops or when science specialists went to schools. Information gathered from the database included the topic, the date, the number of hours, the location, and the format (e.g., workshop, classroom coaching, institute, professional collaboration) of the teachers' professional development experiences.

Interviews

Semi-structured interviews were used to obtain the teachers' perceptions of how professional development and curriculum influenced the growth patterns in their inquiry practices. The interviews were held after the observational data had been collected and an initial analysis completed. In this manner, the teachers were able to review the EQUIP ratings and scoring, provide their perceived reasons for shifts in their practices, and help interpret how the multiple variables of professional learning experiences interacted with their learning trajectory. The interviews lasted about an hour and were completed at a convenient time and place for the teacher. The questions asked to initiate discussions in the 2012 interviews were:

(1) Do you feel you teach similarly or differently then you did 5 years ago?

(2) To what do you attribute the difference or lack of difference in your teaching over time?

(3) How do you feel about teaching science? Have you always felt this way?

(4) What professional development sessions have been most beneficial in changing your practice or in making you think differently about teaching inquiry?

(5) How does the curriculum support or hinder you as you prepare to teach an inquiry lesson?

Additionally, three questions taken from the archived lesson reflection documents were asked in the 2012 interview. The three questions were:

(1) How comfortable were you with the content?

(2) What was the approximate amount of time that you talked as a teacher compared to the students' responses and interactions?

(3) If you could do the lesson again, what, if anything, would you change to improve the lesson?

The interviews were immediately transcribed and emailed to the appropriate respondent. Respondents then had an opportunity to review and, if necessary, correct the contents of the interview. The information gathered from the interviews was used to understand the teacher perceptions over time and to extend and elaborate on the information received from the videotaped lessons and the database.

Archived interview transcripts

The interviews conducted in 2007 and 2009 were videotaped and transcribed as part of a previously conducted study. The interview questions (Appendix F) elicited responses that showed teachers' views of what promotes and opposes the use of inquiry teaching. The questions also gathered information about the teachers' professional learning experiences. The interview transcriptions were used to corroborate the information retrieved from the university-based collaborative database. The answers to the questions were also compared over time and considered in terms of how teachers' perceptions changed in relation to experience, curriculum, and professional development.

Archived lesson reflections

Lesson reflections, completed by the teachers as part of a previously conducted study, were comprised of the teachers' typed responses to questions. The teacher participants reflected and wrote the answers to the questions, immediately following the digital viewing of the lesson. Multiple questions under the headings of content, environment, instruction, and learners asked the teachers to describe and reflect on their lessons (Appendix G). The researcher was able to retrieve lesson reflections from each of the videotaped lessons in 2007 and 2009. The archived lesson reflections were used to extend lesson descriptions and develop changes in teacher perceptions through the comparison of the teachers' responses over time.

Variables

The variables involved in this research included three predictor variables and two outcomes variables. The predictor variables are time, professional development, and curriculum. The teachers' inquiry practices and their perceptions on the use of inquiry in their classrooms were the outcome variables.

Time and experience

The data collected from this research spans a 5-year period. All the data collected was organized onto a timeline plot to highlight the sequence of events. Time as a variable was particularly considered in terms of years of experience with curriculum. For example, by the time Danielle was filmed in 2012 she had already taught the unit on insects for 5 years.

Professional development

The teachers had access to many different professional development opportunities through the 5 years. As part of the professional development collaborative the teachers were required to attend a 5-hour initial curriculum training for each grade-level science kit they were scheduled to teach. The teachers were also required to attend follow up curriculum workshops after one to three years of teaching the grade-level science kits. Additionally, the district of the participants mandated that all teachers be trained in the expository writing program, *Writing in Science* (Fulwiler, 2007). Among the three teacher cases, individuals participated in some or all of the following professional development sessions.

Initial curriculum workshop content. All teachers attended the initial kit-specific workshops before using the materials with their students. During the workshop, the participants were immersed in the pedagogy and content of the unit through participating in kit-based lessons and reflecting on each lesson as a teacher. The instructor modeled inquiry pedagogy related to the lessons while the participants constructed their own content knowledge and strengthened their facilitation skills. Participants worked in small groups and were encouraged to build relationships with other teachers that were at the same point in the curriculum implementation.

Follow up curriculum workshop. The teachers were required to attend a follow-up after a year or two of teaching a specific module. Some teachers opted to return to follow-ups after teaching a module for many years. During the follow-up sessions teachers were actively engaged in module lessons with more in-depth reflections on content and pedagogy. The 6-hour follow-up sessions were co-instructed by a university-selected science education specialist, a practicing classroom teacher, and a scientist. The session goals included current standard curriculum connections (i.e., math and English/language arts); questioning strategies; enhancing computational thinking; making connections to current, local real-world science; developing formative and summative assessments; and developing skills around the use of science notebooks. Participants shared what was working well and what was challenging about the units. They brainstormed solutions to obstacles specific to the unit and general to the teaching of hands-on science.

Science writing workshop. The science writing workshops had three central goals. The first goal was to provide a common message within grade level teams and across grades K-8 of the major components and expectations of Fulwiler's (2009) *Writing in Science* program. The second goal was to have the teachers experience the science-writing strategies with a lesson from their specific curriculum. For example, the *Writing in Science* program provides strategies to engage all students in thinking and talking before they write and to help students organize their thinking through the use of writing frames. The purpose of this experience was for teachers to construct understanding of the steps involved in teaching science writing within the context of the science lessons they teach. Finally, the workshop aimed to provide evidence for the effectiveness and the need for the expository writing program to enhance the development of scientific literacy.

Science writing follow-up coaching. The follow-up for science writing was conducted in the teachers' building and classrooms. The intent of the follow-up was to assess the strategies the teachers were using well and the strategies they were ready to implement next. These sessions consisted of classroom observations and grade level meetings. In some schools every teacher was observed for 10 minutes and grade level teams had 50-minute meetings with the science specialist observers. In other schools both the specialists and their grade level teammates observed one teacher, followed by a reflection meeting with all teachers.

Writing in Science institute. The content of the Writing in Science Institute focused on the interaction between hands-on inquiry science and expository writing. The institute's activities supported the implementation of the Writing in Science protocols. Betsy Rupp-Fulwiler and a few of the Seattle Lead Coaches provided learning sessions in which the participants experienced their own expository writing as part of their own hands-on inquiry. The participants also observed teachers who were already using these strategies in their classrooms. They attended Seattle's Lead Science Teachers meeting to observe how the teachers analyzed student work for the purpose of improving classroom instruction. The Institute facilitators supported the participants as they planned for the implementation of the strategies from Writing in Science in their own districts.

New trainer day. The new trainer day workshop was designed to build science education leadership within the consortium of teachers and to develop adult education facilitation skills. This workshop was a selected group of teachers that had used best practices in the classroom or demonstrated leadership qualities and a commitment to science education when they attended workshops. The goal was to recruit teacher trainers and to build leadership capacity in the schools throughout the project.

Curriculum

Prior to 2006 the teachers taught science how and when they wanted. In 2006 the participants were introduced to a common kit-based curriculum. In 2010, the *Writing in Science* approach was added to the kit-based curriculum. This involved the teachers in restructuring their lessons over two periods (usually conducted on two separate days). The first period involved conducting an investigation from the kit-based curriculum. The second period involved engaging the students in learning to communicate their knowledge scientifically. The 2012 videotaped lessons were all taken during the investigation day. The two curricula are described in more detail below.

Kit-based curriculum. The teachers received National Science Foundation developed "science kits" when the district joined the university- based collaborative. In the first year, the teachers used two of the kit modules, and every year after that they taught three modules per year. The kit-based curriculum provided the teachers with a sequence of lessons and materials designed for students to engage in deep study and hands-on work (Erickson, 2006). Scientists and educators developed the kits using research on how children learn science and research on what teachers need to teach using inquiry practices. The Full Option Science System (FOSS) is a research-based science curriculum for grades K–8 developed at the Lawrence Hall of Science, University of California at Berkeley. The National Science Resources Center (NSRC), a division of the Smithsonian Institution, developed the Science and Technology for Children (STC™) kits, a science and engineering practice-centered curriculum for grades K–10.

Writing in science. In 2010, the university-based collaborative began the implementation of an expository writing program. The science-writing program was designed to enhance student learning of scientific concepts, scientific thinking, and scientific skills. In addition, the program provided the students with structures for communicating their learning (Fulwiler, 2009). The program provided teachers with techniques for how to set up a notebook, what to include, and how to effectively teach writing to students.

Teacher perceptions

The teachers perceptions of their use of inquiry was recorded over time in the interview transcriptions and the lesson reflections. These data were looked at for major shifts in thinking or 'Ah Ha' moments and for patterns that emerged over time or between cases. The literature review and the data analysis support the claim that teacher perceptions were a key element in the understanding of how teachers' practices change over time (Anderson, 2007: Jones, & Carter, 2007; Kyle, Bonnstetter, & Gadsden, 1988). Profound statements were used to extend, defy, or collaborate other research findings. The teachers' thoughts were also compared over time to examine how the teachers' thinking changed in relation to the other four variables.

Teacher practices

The teachers' inquiry practices were observed and considered in terms of their quality and quantity. The observed videotaped lessons were written in narrative form to provide descriptive details of how one lesson differed from another. Also the teachers' practices were measured in a quantitative manner to compare empirically the lessons over time. The researcher used the observation instrument, EQUIP, to measure the teachers' levels of inquiry on nineteen constructs organized into four factors. The measurement instrument is described in detail and demonstrates the complexity involved in measuring teachers' use of inquiry practices.

The Instrument: EQUIP

Validity and reliability

The Electronic Quality of Inquiry Protocol (EQUIP) is a valid and reliable observational tool that provides both quantitative benchmarks and qualitative descriptors of inquiry practices in the context of the classroom. In the 2-year development of EQUIP, the researchers were able to establish validity and reliability. Face validity was determined through the meetings, emails, and phone conversations with multiple researchers from three different universities (Marshall et al., 2010). In the pilot study of 102 classroom observations, EQUIP's Cronbach alpha ranged from 0.880–0.889 and established reliability. The pilot study included 16-paired observations in which over 85% of one observer's assessment was explained by another observer's assessment. A factor analysis added content validity to the already determined face validity and reliability. The analysis showed that the 19 indicators were tightly aligned to four factors that are presented as constructs in the instrument (Marshall et al., 2010).

Inquiry factors and constructs

The four factors determined by the factor analysis were labeled: *Curriculum, Instruction, Discourse,* and *Assessment*. The factors are further broken down into constructs. Each factor has four to five constructs (Table 1).

Table 1. The constructs that compose the four factors of EQUIP

Factors	**Curriculum**	**Instruction**	**Discourse**	**Assessment**
Construct 1	Content Depth	Instructional Strategies	Questioning Level	Prior Knowledge
Construct 2	Learner Centrality	Order of Instruction	Complexity of Questions	Conceptual Development
Construct 3	Integration of Content and Investigation	Teacher Role	Questioning Ecology	Student Reflections
Construct 4	Organizing & Recording Information	Student Role	Communication Patterns	Assessment Type
Construct 5		Knowledge Acquisition	Classroom Interaction	Role of Assessing

Each factor is described in terms of the constructs and levels of inquiry associated with that factor.

Curriculum inquiry factors. This factor has four constructs titled: *Content Depth, Learner Centrality, Integration of Content and Investigation,* and *Organizing and Recording Information*. At the pre-inquiry level (rubric score 1), the lesson provided "superficial coverage of the content" which focused on either knowledge or processes but not both. The students were not engaged in the activities and they "recorded information in prescriptive ways." At an exemplary inquiry level (rubric score 4), the lessons provided deep content connected to "the big picture" and integrated process skills. The students had control over the design of the investigation and how they recorded their information.

Instruction inquiry factors. This factor has five constructs: *Instructional Strategies, Order of Instruction, Teacher Role, Student Role,* and *Knowledge Acquisition*. At the pre-inquiry level (rubric score 1) on the rubric, the teacher is described as the "center of the lesson" and used lecture as the main form of instruction and the students were passive learners of low-level knowledge. At the exemplary inquiry level (rubric score 4), the teacher was a facilitator of the students' thinking and processes. The students "are consistently and effectively active as learners."

Discourse inquiry factors. This factor has five constructs entitled *Questioning Level, Complexity of Questions, Questioning Ecology, Communication Patterns, and Classroom Interactions*. At the pre-inquiry level (rubric score 1), the teacher controlled the communication. The questions were focused on singular right answers and "rarely followed-up with further probing." At the exemplary inquiry level (rubric score 4), both students and teachers were involved in developing and carrying out conversations. The conversations and questions led to critical thinking with explanations based on evidence.

Assessment inquiry factors. This factor has five constructs, entitled *Prior Knowledge, Conceptual Development, Student Reflection, Assessment Type, and Role of Assessing*. At the pre-inquiry level (rubric score 1), the teacher did not assess prior knowledge and used conventional measures to assess students' factual knowledge. At the exemplary inquiry level (rubric score of 4), authentic measures were used to assess students' processes, concepts, and thinking. Students were encouraged to provide evidence for their actions and reflect on their own learning.

Levels of inquiry

The level of inquiry is determined by the rubric descriptors for each of the nineteen constructs. The rubric allows the researcher to match the observed action with a descriptor. The descriptors are aligned to outcome scores. On all of the nineteen constructs a teacher may score 1, 2, 3, or 4 for a total score range between 19 and 76. A score of 1 is a level of pre-inquiry; a score of 2 is a level of developing inquiry; a score of 3 is a level of proficient inquiry; and a score of 4 is a level of exemplary inquiry. The rubric for the first construct *Content Depth* in the *Curriculum* factor can be seen in Figure 1. This construct's Pre-inquiry, Level 1 descriptor is "lesson provides only a superficial coverage of content" a Developing Inquiry, Level 2 descriptor is "lesson provided some depth of content but no connections made to the big picture" a Proficient Inquiry, Level 3 descriptor is "lesson provided depth of content with some significant connections made to the big picture" and Exemplary Inquiry, Level 4 is "lesson provided depth of content with significant, clear, and explicit connections to the big picture."

Table 2

An example of one (of the 19 total) construct's rubric descriptors and inquiry levels

VII. Curriculum Factors					
Construct Measured		Pre-Inquiry (Level 1)	Developing Inquiry (Level 2)	Proficient Inquiry (Level 3)	Exemplary Inquiry (Level 4)
C1	Content Depth	Lesson provided only superficial coverage of content.	Lesson provided some depth of content but with no connections made to the big picture.	Lesson provided depth of content with some significant connection to the big picture.	Lesson provided depth of content with significant, clear, and explicit connections made to the big picture.

The EQUIP instrument can be found in Appendix H. The instrument provides the descriptors for all 19 constructs.

Time usage

In addition to the level of inquiry scores in *Curriculum, Instruction, Discourse, and Assessment*, several time usage indicators (see Appendix I) were measured while watching the videotaped lesson. A video analysis tool, Studiocode™ , was used to determine the percentage of time each lesson spent on the following codes: (1) students' level of cognitive thought (recipient of knowledge, lower order, apply, analyze and create); (2) lesson components (engage, explore, explain/extend); and, (3) teacher's use of assessment strategies (no assessment, monitoring, formative, summative).

Data Collection and Analysis Procedures

In case studies, data collection and analysis can proceed simultaneously (Creswell, 2008; Yin, 2009). The timeline for data collection was bound by the availability of the teachers during the public school calendar. The researcher recorded the final videotaped lessons in May and June of 2012. The archived lesson videos and documents were collected at the same time.

The researcher then viewed all lesson videos multiple times. A critical colleague reviewed two videos and the results were compared and discussed with the researchers. Scores were determined and the composite quantitative rubric scores were calculated to provide an overall inquiry score for *Curriculum, Instruction, Discourse,* and *Assessment*. The inquiry scores from the EQUIP were plotted on a line graph. The percentage of time spent on the different dimensions of each time usage code was calculated with Studiocode™ and exported into the Excel computer program. The categorical data were compared over the years and visually displayed in bar graphs. While watching the video lessons for a third time the researcher wrote the lessons in narrative form. After recording the narrative of the lesson, key events in the narrative were determined to present example evidence of the EQUIP rubric score from the lessons. The key examples were marked with indicators in parentheses and placed at the end of the sentence in which the key event occurred.

The three teacher participants were shown their data and interviewed to find explanations for the shifts in their practices. The interviews were transcribed during the interview and member-checked for accuracy. Then the archived data were carefully read. Common themes and significant shifts in thinking were recorded into a word document organized by words and phrases to represent the topics or patterns. The data were then summarized, member-checked, and rewritten for clarity and accuracy.

Data Analysis and Reporting Techniques

Thick descriptions

The qualitative descriptions of the lessons and professional development experiences were written as narratives to provide key examples of actions that illustrated a particular rubric score. The rubric scores were placed in parentheses throughout the teachers' narratives for the reader to reference with the rubric measure in Appendix H

Visual analysis

Multiple graphs were developed to allow for the comparison of data over time. The professional development sessions were plotted on a timeline along with initial implementation of curriculum and dates of the videotaped lessons. The EQUIP composite factor scores were recorded on line graphs and the time usage data were presented in bar graphs. All the graphs were analyzed by visually examining levels, trends, and variability of teachers' inquiry practices during the data collection periods. In this descriptive statistic technique, the *level* refers to the mean of the observed practices at each data point (Matyas & Greenwood, 1990). The *trend* references the best-fit line between the first data collection observation and the final data collection observation. The *variability* refers to the rate of increase or decrease between each data collection. The final conclusions and recommendations were written using evidence from the individual findings and the cross-case analysis.

Pearson's correlation coefficient

The professional development sessions were categorized into two groups. One group included the professional development that provided direct connections to the activities in the teachers' grade level curriculum. The other group included professional development sessions that provided the teacher with instructional concepts and leadership development that were not embedded in grade level curriculum activities. The professional development hours were calculated for each category and total professional development hours were recorded. The correlation between professional development hours and teachers scores on the EQUIP was computed through the PEARSON function in Excel.

Pattern matching

Two strategies were used in combination to link the data to the propositions. The first was a simple pattern matching (Yin, 2009). This testing consists of connecting an observed pattern (e.g., how teachers' practices changed over time) with a hypothesized pattern (e.g., a continuous increase in inquiry-teaching practices will occur) and deciding whether these patterns correspond or do not correspond. The pattern matching, particularly with multiple cases, is useful in construct validity. Yin stated, "If identical results were additionally obtained over multiple cases, literal replication of the single cases would have been accomplished, and the cross-case results might be stated even more assertively" (Chapter 5, para. 40).

Reliability, Validity, and Bias

Reliability. In addition to the multiple cases used to increase reliability of the findings, two procedures were used to test the reliability of the individual teacher's inquiry scores. First, a critical colleague scored two randomly selected videos to determine inter-rater reliability. Of the 38 total constructs 34 were scored consistently across raters. The discrepancies were discussed and used to guide the researchers continued observations. In addition, the researchers viewed and scored each video lesson two times over the course of a month. If the scores were not consistent the researcher viewed and scored the video lesson a third time. The median score from the three observations were used. This test-retest reliability procedure was used to assess the consistency of the EQUIP scores from observation to observation.

Validity. Multiple strategies were used to validate the outcomes and determine the trustworthiness of the information (Merriam, 1998). This research was able to link different sources of information, from the observations, database, interviews, and archived documents. For example, the findings on professional development experiences from the database were compared with the teacher responses to what professional development they received as during the 2009 interview. In addition, the researcher used the construct validity of member checking. All data were presented to the teacher participants so they could review it for credibility and accuracy.

The report of the findings provides the reader with opportunities to develop their own conclusions. First a detailed, thick description will describe the teachers' video lessons and their professional development experiences (Creswell, 2003). Then graphs are used to display the consistency of data patterns within and across cases. The graphs are open to the judgment of the reader, and the ability of the reader to read descriptive narratives and view the data increases external validity (Bloom, Fischer, & Orme, 2003).

Bias. The design of the case study was carefully planned to avoid bias. The researcher considered five basic attributes to avoid bias while conducting a case study that included asking good questions, being a good listener, being adaptive and flexible, having a firm grasp of the issues, and being unbiased of preconceived notions (Yin, 2009). The researcher took multiple efforts to minimize bias throughout the study.

Avoiding bias particularly in terms of preconceived notions was a challenge because of the researcher's involvement in the participants' professional growth. A relationship between the researcher and the participants, on one hand, is beneficial to the research because trust had been established over a period of time (Stake, 1995). On the other hand, participants needed extra assurance to provide candid answers to interview questions about their professional development experiences. The researcher remained flexible and open to emerging data even when it was contradictory to the proposed theory. Information that revealed the contradictions to the propositions was as useful in understanding learning growth patterns as information that corroborated the propositions.

Chapter 4

Case I: Danielle

This chapter presents the first of three teacher cases. Danielle taught fourth grade through the duration of the study timeline. Her video lesson in 2007 was from the FOSS Magnetism and Electricity module in which the students are posed with a problem to complete a circuit to light a bulb. In 2009 Danielle's video lesson was again from the FOSS Magnetism and Electricity module but in this lesson the students are presented with a design challenge of building an electromagnet. In 2012 the lesson was from the STC Land and Water Module and involved students adding rocks and hills to stream table models and observing how the objects changed the flow of water.

The chapter is divided into two major sections: Descriptive Narratives and Change in Inquiry Practices and Beliefs. The Descriptive Narrative section illustrates the sequence of events that Danielle experienced over the course of five years. It begins with Danielle's professional development and curriculum experiences in science prior to the study timeline. A timeline provides a visual image of the sequence of events so the reader can see the relationship of professional development and curriculum experiences to the videotaped lessons over time. Next, each event is described through rich, detailed, text descriptions. The narrative is organized chronologically as depicted in the timeline.

Each videotaped lesson description is partitioned into three phases of the lesson: engage, explore, and explain. Each phase of the inquiry lessons are described by the 'time usage', Inquiry Component Instruction Code from the EQUIP (Appendix I). Throughout the videotaped lesson description there are factors, followed by a code in the form of an alphanumeric combination placed in parentheses. For example, the following excerpt is taken from Danielle's 2007 lesson narrative: *one student reported a long list of what we would not have if we did not have batteries, including schools. Danielle responded "true" and called on someone else (Discourse 5-1).* The word '*Discourse'* refers to the factor; the '5' signifies the 5th construct in the *instruction* factor, called *Classroom Interactions*; and the number after the dash, in this case the '1' identifies the rubric score. So in this example, the description of the 5th construct in the *Discourse* factor at level 1 reads, "Teacher accepted answers, correcting when necessary, but rarely followed-up with further probing". In this example Danielle missed an opportunity for a rich discussion to occur, having been instigated by the student's thinking that there could be no schools if we did not have electricity. Her response of "true" was evidence of why she scored at a pre-inquiry level on the *Classroom Interaction Construct*.

The second section in the chapter, Change in Inquiry Practices and Beliefs, presents the quantitative and qualitative outcome variables including the composite inquiry scores from the four EQUIP factors over time; the change in scores from constructs in each of the four factors, *Curriculum, Instruction, Discourse,* and *Assessment*; the change in time usage indicators; and the change in the teacher beliefs of teaching inquiry.

Descriptive Narrative

Initial professional development opportunities 2006 to 2007

Prior to joining the educational collaborative, Guiding Education in Math and Science Network (GEMS-Net), Danielle's preparation for teaching inquiry science was limited. When Danielle was asked about her preparation she admitted that she did not remember having a 'science methods' class and then said, "I don't think I had much. I did take college astrology, no, I mean astronomy. I can't really remember it was a long time ago" (Danielle, personal communication, December 2, 2009). Danielle attended her first professional development experience in science after her district joined GEMS-Net in 2006. She had already been teaching elementary school for 13 years. Danielle's professional development timeline began in November of 2006, one year before her first lesson was videotaped for research. Danielle attended two, five-hour, initial curriculum workshops on two consecutive days. Experienced teachers facilitated the workshops to help Danielle and her colleagues become familiar with the 4th grade curriculum that included *STC Land and Water* module and the *STC Motion and Design* module. Danielle taught those two units for the first time in the 2006-2007 school year. On September 28, 2007, one month prior to the videotaping of the first lesson, Danielle attended the initial workshop for *FOSS Magnetism and Electricity*. Her professional development total of fifteen hours was all spent in Initial Curriculum Workshops. She had the opportunity to participate in the lessons from the units modeled by experienced teachers and to reflect on the content and pedagogy with other professionals.

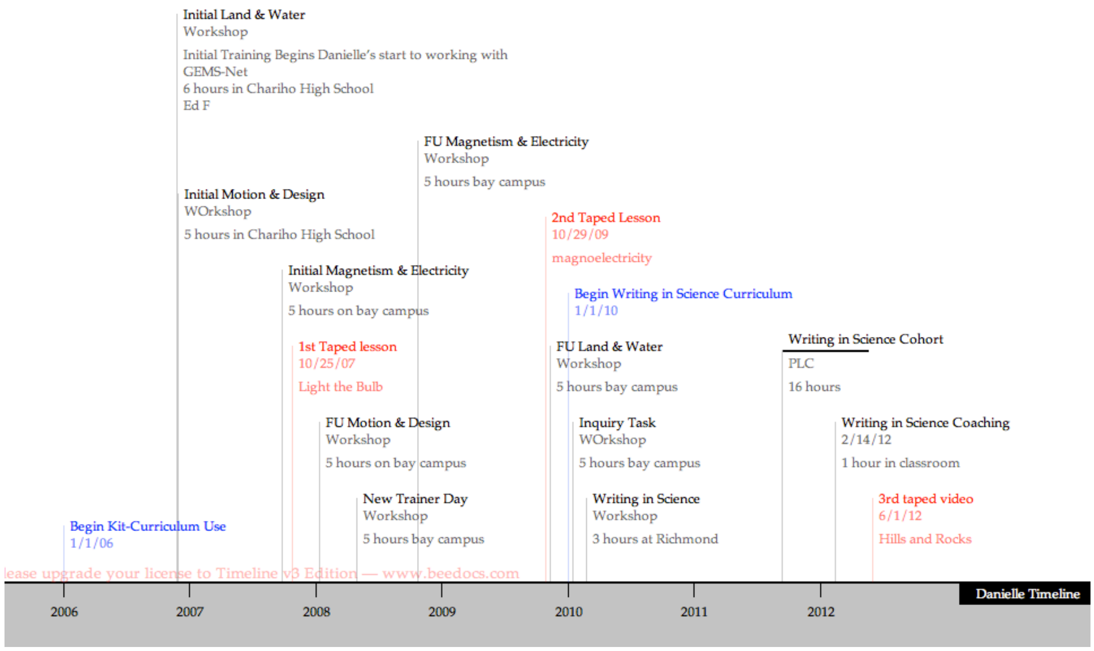

Figure 1. Timeline of Danielle's professional development, curricula use, and videotaped lessons

Description of Danielle's lesson in 2007

On October 25, 2007 Danielle was filmed for research. She was asked to prepare and teach a lesson that utilized "inquiry practices." Danielle's lesson was the fifth lesson from the Full Option Science Systems (FOSS) modules *Magnetism and Electricity*. The lesson activity involves the students learning to complete a circuit using a bulb, a wire, and a D-Cell battery. The students had spent the previous four lessons learning about magnetism and were now making a shift into electricity. This was the first time Danielle had taught this lesson.

Engage. The engagement portion of Danielle's lesson lasted 35 minutes. The first three minutes involved her students writing about what the world would be like with no batteries. Then a few students shared their thinking with the class. The sharing occurred while students sat in at their desks, which were facing in all directions as the desks were clustered in sets of four or five (Discourse 3-2). Danielle responded as she did throughout the lesson by accepting students' answers without challenging their thinking. For example, one student reported a long list of what we would not have if we did not have batteries, including schools. Danielle responded "true" and called on someone else (Discourse 5-1). The students moved into their science groups (Discourse 3-2). These groups of four children were given a set of materials and the teacher began asking them to find things. Danielle said, "We have a D-Cell. Can you find the D-Cell?" No one responded. The teacher facilitated student thinking, bringing them through process of elimination to figure out that the battery is a D-Cell. She then required students to apply the concepts of magnetism and the processes of observation to a new situation (*Instruction* 5-3) in the following conversation:

Teacher- What do you notice about the D-Cell?

Student- It has a negative and a positive.

Teacher- What else have we been studying that has a negative and a positive?

During this exploration of the material the teacher provided new vocabulary words, such as 'filament' and asked content questions before the students had a chance to explore those concepts (*Instruction* 2-2). When the teacher asked, "How does the energy make a bulb light?" the students could not clearly answer her. Likewise, when the teacher had the students work together to 'predict' how to connect the wires to make the bulb light up, the students were guessing because they had no experience on which to base their predictions. The teacher was not successful in engaging students in discussion

(*Discourse* 3-2). For example, once the prediction worksheets (*Curriculum* 4-1) were taped to the front of the room the teacher said, "Let's take a look at your predictions." Then paused for 30 seconds and said, "I think you are ready to make your light bulb light" (*Assessment* 1-2).

Explore. The exploration portion of the lesson involved the students working together with the materials to get the bulb to light. The students were all engaged in the activity that taught an initial understanding of a circuit (*Instruction* 1-3, *Assessment* 2-3). The students were active learners manipulating materials and sharing ideas with each other as they investigated (*Instruction* 4-3). The investigation design allowed for some flexibility because the students were not following a procedure on how to light a bulb (*Curriculum* 2-3), but rather the students were using problem solving skills to construct their understanding of what needed to be connected to complete a circuit (*Curriculum* 3-3). The teacher walked from group to group monitoring their progress (*Instruction* 3-3). She asked a few low-level questions during the exploration like, "What are you doing here? Would it be helpful for Michael to help so you have enough hands?" She did not encourage students to reflect on their learning during the exploration part of the lesson (*Assessment* 3-2), instead she accepted their thinking. For example, a student said they need tape and the teacher replied that they did not need tape and then handed them a Fahnestock clip. Another time a student was saying that his battery was getting hot and Danielle said, "It does get hot, doesn't it" (*Discourse* 5-1).

Explain. The explanation portion of the lesson began with the teacher stopping the investigating with the gentle sound of a rain stick and asking the students, "Look at your predictions. Have they changed?" She then handed the predictions back to the groups and had them record their findings in red. She also reminded them to finish answering the questions on their worksheet (*Curriculum* 4-1; *Assessment* 4-2). When the prediction sheets had been revised in red Danielle posted them on the board and asked the class to observe the shape of the wires. When a student said it was like a circle, the teacher gave a quick explanation that the circle makes a circuit to get the bulb to light (*Instruction* 2-2). Danielle then instructed the class to work in their groups to come up with three big ideas from that day's lesson. The students worked for about seven minutes and then she announced, "Times up; let's see what you learned today." She had the big ideas written on three separate sentence strips facing backward so the students could not read them. She turned one over at a time, read it to the class, and asked for a few students to share what they wrote that was similar (*Assessment* 3-2). At the end of the lesson she reviewed the vocabulary on the board and asked the students what else they learned today. A few students shared and then she asked them to complete the worksheet and hand it in.

Danielle's professional develop experiences November 2007 to October 2009

A few months after the first taping, on Jan 11, 2008, Danielle attended her first Follow Up Curriculum workshop for Science and Technology for Children (*STC) Motion and Design*. This workshop used lessons from the curriculum Danielle had experience teaching. The goal of this workshop was to reflect on the process of teaching inquiry and to develop a deeper level of content knowledge. In May of 2008 Danielle attended a New Trainer Workshop in order to develop adult facilitation skills for the purpose of facilitating future curriculum workshops for her colleagues. In October of the 2008-2009 school year Danielle attended the *Magnetism and Electricity* Curriculum Follow Up. Danielle commented that these workshops facilitated shifts in her belief system;

“Coming to the workshops, being with other teachers, and the GEMS-Net folks and the real scientists they bring things in and make you think differently about the content” (Danielle, personal communication, August 1, 2012). She taught all three units again that year. Between the first and second taping Danielle received 15 additional hours of professional development. Ten of these hours were in professional development focused on her teaching and curriculum. Five of these hours were intended to build leadership skills. Going into the second filming Danielle had received a total of 30 hours of professional development.

Description of Danielle’s lesson 2009

On November 29, 2009, Danielle was taped for a second time. The lesson was the twelfth lesson in the FOSS *Magnetism and Electricity* kit. Although the filming from 2007 to 2009 was within the same week of the school year, she was much farther along in the unit. Danielle commented that she was farther along in the unit because she was teaching more science in 2009 than she was in 2007 (Danielle, personal communication, August 1, 2012). The students had already explored magnetism, electricity and now were putting the two ideas together to design an electromagnet. This lesson was the third time Danielle had taught this unit/lesson.

Engage. Students began the lesson seated at their desks grouped in clusters of three. Danielle said in a practiced voice, “In the real world we don’t have the means to reverse gravity, but we have cars that don’t touch the ground. One way we do this is with the use of electricity and magnets that can be turned off and on. These giant magnets also move heavy metal objects. I was thinking about a big old junkyard crane. The crane operator could turn the crane off and on. Could you make a miniature junk yard crane that turns on and off?" (*Assessment* 2-3). The students in the class nodded and exclaimed 'yes.' She then orally instructed the students to list in their science notebooks what they might need to build their junkyard crane. When the students were done they gathered together at the rug. The class sat on the rug with their notebooks open, and a few students shared their list. Sometimes Danielle challenged student thinking (*Discourse* 2-3). For example, Danielle asked a student, "Why do you think you would need a metal bar?" and "What would a switch do?" Other times Danielle missed opportunities for following up student answers with prompts that could enhance the learning experience. She asked a student, "What would you need a motor for?" The student replied to make the magnet run. Danielle nodded her head and moved on to asking about the wires without probing deeper or clarifying that the motors they had previously explored are receivers not conductors (*Discourse* 5-2). She then demonstrated how the rivet does not pick up the washers like a magnet would. The group brainstormed how they will get the rivet to pick up the washers. Danielle asked many questions focusing on recall of prior lessons, such as "What do we need to have to complete a circuit?" and "What is happening in the wire when the circuit is closed?" (*Assessment* 1-3). Danielle clearly restated the goal, "Your challenge today is to develop a magnet that will turn off and on. Your new materials are a really long wire and a rivet." (*Curriculum* 3-3). She asked them while they were working to think about the following two questions: "How do I make my magnet turn on and off?" and "How is this temporary magnet different from a permanent magnet?" (*Assessment* 3-3).

Explore. Danielle passed out a worksheet describing the students' design challenge. The worksheet had a Star Wars picture. The children began trying to read it on their own, but Danielle realized they are struggling so they read it aloud as a whole class (*Assessment* 5-3). There was a scenario that set a problem and provided background information. The reverse side of the sheet listed the materials that each group of three have for the challenge (*Instruction* 1-3). During the exploration students were working actively (*Instruction* 4-3). Danielle asked most questions to keep the students on track and a few questions that challenged students to apply knowledge (*Discourse* 1-3). Sometimes the teacher moved to the next question before the student had formulated their thinking into an answer (*Discourse* 5-2). Questions Danielle asked were: "What do you think you should do with the long wire?" " What do you know about a circuit?" "Is that an open or closed circuit?" "Why do you think I gave you a long wire?" "Try it and see what happens." "Is your switch open or closed?" "Is anything working?" "Do you have a complete circuit?" (*Instruction* 3-3) When the first group announced that they figured out how to pick up a washer with the rivet, Danielle stopped the class and had the whole class listened to what the first group did to make it work (*Instruction* 2-3). After a few more minutes of exploration most of the groups had succeeded in making an electromagnet (*Instruction* 4-3). Daniele challenged students more by asking them to test how to make the electromagnet stronger (*Discourse* 2-3). She facilitated the students understanding by saying she noticed many of them wrapped the wire messily and asking what they could do differently (uniformed tight wrapping), and she pointed out how long the wire was and asked what they could do with the extra wire (more winds) (*Curriculum* 3-3). The students continued to investigate.

Explain. Students come to the rug in a tight circle. The teacher began the conversation by asking, "How did you get your rivet to be magnetized?" (*Instruction* 3-

3). The teacher attempted to follow up student responses and challenge their thinking. For example, when a student says he/she wrapped the wire in the middle of the rivet, the teacher asked, “Does everyone agree it has to be in the middle” and then called on other children who disagreed asking them to share their thinking (*Discourse* 2-3). Danielle also connected the scientific processes with the content. For example, she asked the students about the number of winds of the wire on the rivet and suggested they try all doing the same number to “make a fair test. So everyone is doing the same thing like real scientists,” but she provided no explanation of what could be learned by conducting the fair test (*Instruction* 5-3). New vocabulary words were reviewed (*Instruction* 2-3). She asked them the following questions: “How is your magnet different from a permanent magnet?” “What can your new magnet do that this one (permanent) can’t do?” “An electromagnet can be turned off and on?” “How do you make the electromagnet?” “What do you use to make an electromagnet?” “Could you use materials from home? Like what?” “How do you make it stronger?” (*Curriculum* 3-3). The students went back to their groups to all try out 35 winds at the head of the rivet to conduct a ‘fair test’. Danielle passed out stabled paper and reminded them to begin to write what they had to do to create an electromagnet. She encouraged groups who were struggling to look at another group’s electromagnet (*Discourse* 3-3).

After students successfully picked up multiple washers using their electromagnet, students clean up their materials and began to work on the ‘How to Build an Electromagnet’ books independently (*Curriculum* 1-3). Danielle posted the new vocabulary words and sentence strips with the big ideas onto the whiteboard.

Danielle's professional development experience from October 2009 to May 2012

Two weeks after her second video lesson, Danielle attended her third Follow Up Curriculum Workshop for *STC Land and Water*. Danielle commented, "I like going to the PD at the University. You are treated like a professional and you get verification of what you are doing and then be able to take the next specific step" (Danielle, personal communication, August 1, 2012). In January of 2010 Danielle attended another five-hour Inquiry Task Workshop that focused on preparing students for the high-stakes statewide science testing.

Danielle was introduced to the science writing approach in February of 2010. She received a three-hour Initial Science Writing Workshop in which all the teachers from kindergarten through grade four were introduced to specific teaching strategies for expository writing and protocols for developing student thinking and communication through the use of notebooks. In the beginning of the 2011-2012 school year, Danielle joined a group of over 20 multi-grade level teachers from four different districts in a book-study of *Writing in Science in Action* by Betsy Rupp Fulwiler. She spent a total of sixteen hours analyzing the text with her colleagues and discussing and sharing new strategies for the classroom. In February of 2012, she received an hour of classroom coaching that centered on the strategies written in *Writing in Science*. She received feedback on what was working well and what next step strategies might help in her classroom. When Danielle was asked what professional development has been most influential to her teaching she commented, "I think the science writing has been really good. I have to think like the kids are thinking while I was planning and the scaffolding strategies really help" (Danielle, personal communication, August 1, 2012).

Before going into the final videotaped lesson in May of 2012 Danielle had received 60 hours of professional development and been introduced and absorbed into the science writing approach. Going against the research that states science is the subject elementary teachers are least prepared to teach, Danielle says, "I like teaching science because it is hands-on, I probably am more comfortable with science now then any other subject because I have had so much training" (Danielle, personal communication, August 1, 2012).

Description of Danielle's lesson 2012

On May 1, 2012, Danielle was videotaped for the third time for research. The lesson was the eleventh in the Science and Technology for Children (STC) kit *Land and Water*. The students had already explored different earth materials, their interaction with water and had observed how water causes erosion and deposition. The students had to shift their thinking for this lesson from looking at what the water does to the land to looking for what the landforms do to the flow of the water. The teacher added a portion of a following lesson which involved the addition of small plastic cubes representing houses because she was not going to get to the final lessons that involved the content on how land and water impact building sites. Danielle thought it was important that the students connect that piece to the unit. This was the sixth time that Danielle had taught this lesson.

Engage. The class began with a four-minute 'quick write' in their science notebooks. The writing prompt given out loud by the teacher was: "What are some of the things you have learned about land and water?" (*Assessment* 1-3) Some students began immediately and fill the page quickly, some created a bulleted list, and others played with their pencils, not getting much onto the paper (*Curriculum* 4-3). The teacher called the students to the rug in the front of the room where they sat in one tight group. Danielle, sitting on a low stool, began the conversation by asking the students to share what they had learned so far in the *Land and Water* unit. She attempted to record the students' ideas on the Smart Board, but she changed her plan when it became evident that her recording skills would not keep up with the students' eagerness to share (*Assessment* 1-3). Individual students reported learned properties of soil and that water cause erosion and deposition of land. Another student said that the more water that is flowing the more erosion and the deeper the river forms. They spend just over 10 minutes with a teacher questioning/ single student response conversation on recalling the content from prior lessons. During this time Danielle used photos of rivers and coastlines on the smart board and encouraged students to use their prior knowledge to explain the interactions of land and water (*Discourse* 2-3). The teacher read the focus question for the new lesson from the smart board: "Lesson 11: How does the shape of land effect the water?" She then told the students to take one minute to write a prediction in their science notebooks about how the shape of the land will affect the water flow (*Assessment* 2-4). The teacher engaged the classroom in discussion by asking the students to turn toward the student sitting beside them and share their predictions with each other (*Instruction* 3-4). The classroom volume went up as students shared their thinking with partners (*Discourse* 4-3). After two minutes the teacher stopped the student discussion and asked the students to share their predictions (*Discourse* 3-3). Student thinking included the land might act as a dam, the water might go around the land portion, and the water flow might be powerful enough to rake right through the land. Danielle told the class, "You are going to test your predictions." (*Instruction* 3-4) She then scrolled down to a four–step procedure on the Smart Board:

1. Quickly make a few hills in your stream table
2. Now place the rocks anywhere on the soil.
3. Quickly draw your stream table as it looks now.
4. Make your prediction- "What path do you think your water will take?"

Danielle sent the students to their science groups.

Explore. Groups of three students busily set up their standard stream tables that consist of a clear plastic storage box with soil components filling three-quarters of one side and a rubber cork blocking a hole on the empty side. A small bucket was placed under the hole and a plastic cup sits over the soil filled side of the container. The students worked together to build hills and place large rocks creating unique landforms (*Instruction* 4-4). When the students had placed their hills and rocks and had drawn their stream tables with a prediction line indicating what they thought would happen (*Curriculum* 2-3), Danielle informed them that they are going to get little plastic houses and said, "You need to think about where you would want to put your home." A student responded, "I want mine on the end of the cliff." Teacher said to the whole class, "But you really need to think about what you already know and everything we have learned about land and water." (*Discourse* 1-3). After placing their houses, the students began pouring the water into the cup at the head of the stream table, creating a stream, and allowing it to drain through the uncorked hole at the other end. Danielle walked around asking questions. The questions sometimes probed for understanding and other times challenged the students to reason or justify (*Discourse* 2-3). Examples of questions Danielle asked were:

> "What do you notice the land is making the flow of the water do?"
>
> "Your house is going to fall. Why did that happen?"
>
> "Why do you think it would be important to build your house on a hill?"
>
> "What do you think would happen to the land over time if the water were continually flowing?"
>
> "Where would you build your house next time and why?"
>
> "Did anything you observed surprise you?"

The large majority of all of Danielle's questions and comments were for furthering student thinking.

Explain. After Danielle rotated to every group asking the students questions that invited them to discuss ideas and evaluate their findings, she collected them together on the rug for a large group discussion and meaning-making session. The students shared out "How the land affected the water flow?" (*Curriculum* 3-3). After sharing how the land changed the flow of the water, the students eagerly moved onto a discussion as to where they placed their house (*Discourse* 4-3). The students used evidence from their observations to support their thinking. For example, one girl said "My house was on the hill and it was OK because water doesn't flow up hill." Danielle expanded their thinking beyond their stream table model by asking what other natural or manmade things would affect the flow of water (*Curriculum* 1-4). She ended the lesson by asking the students what a builder would need to consider when deciding where they would build a house (*Assessment* 4-3).

Change in Inquiry Practices and Beliefs

Composite EQUIP scores for *Curriculum*, *Instruction*, *Discourse*, and *Assessment*, time usage, and teacher beliefs are examined for change over time. In order to report Danielle's growth patterns, the rubric scores derived from the EQUIP observation tool will be presented. Levels of inquiry practice were determined on each of the nineteen constructs for all three lessons. The four levels presented correspond with the rubric scores as follows: a score of 1 is a pre-inquiry level, a score of 2 is a developing inquiry level, a score of 3 is a proficient inquiry level, and a score of 4 is a exemplary inquiry level. The example rubric in Table 2 shows how the rubric descriptors, the rubric scores, and the teachers' level of inquiry align. Since this study analyses the teachers' growth in practice, the constructs with the greatest growth over the five years are supported with examples from the observed lessons. Finally, although the research outcomes were originally only concerned with teacher practices, the researcher found it pertinent to report the changes in teacher beliefs about teaching with inquiry practices. The teachers' perceptions of their change process strengthen the understanding about how and why teachers' practices change over time.

Composite EQUIP rubric scores

The EQUIP scores from Danielle's lessons increased in all four factors, *Curriculum, Instruction, Discourse,* and *Assessment*, over the entire data collection period (Figure 1). Initially, in 2007, the mean of all four factors was 2.26 out of 4.00. This score is within the developing inquiry level on the measure. The authors of EQUIP describe this level of teaching as "a teacher is familiar with getting students engaged and active, but that students are largely involved in more prescriptive forms of inquiry. Additionally, instruction is still heavily teacher-focused" (Marshall et al., 2009, p. 53). In 2012, the mean score of the four factors score increased to 3.36 out of 4.00. The authors of the measure describe this as, "By Level 3, a teacher has demonstrated a student-centered inquiry learning environment that actively engages students in investigations, questioning, and explanations. The role of the teacher remains vital, but he or she now functions more as a facilitator who scaffolds learning experiences than as a giver of facts and knowledge" (Marshall et al., 2009, p. 53).

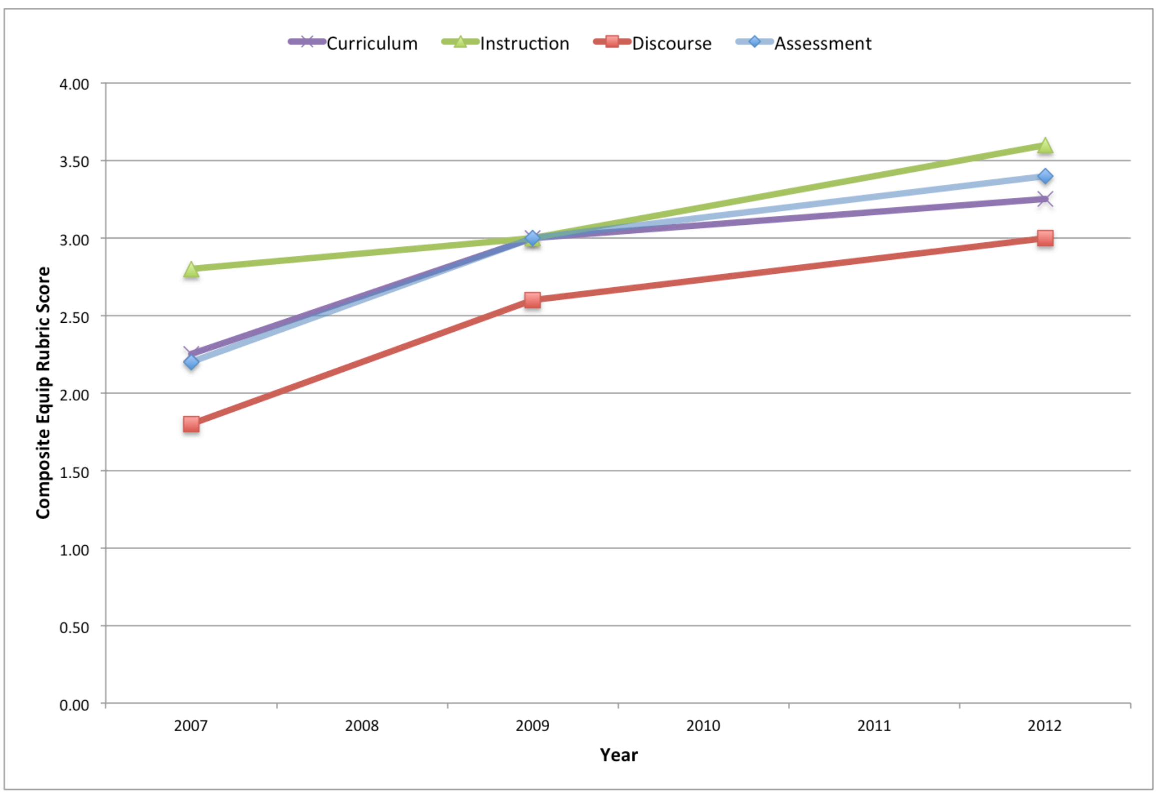

Figure 2. Danielle's inquiry scores over time

The means of Danielle's inquiry factor in 2007 ranged from 1.8 to 2.8; whereas in 2012 the means ranged from 3.0 to 3.8. *Instruction* was the highest scoring factor in 2007 and remained the highest in 2012. *Discourse* was the lowest scoring factor in 2007 and remained the lowest through the study until 2012. *Curriculum*, *Discourse*, and *Assessment* had a greater increase between 2007 and 2009 than they did between 2009 and 2012, whereas, the factor of *Instruction* had a greater rate of increase from 2009 to 2012.

The change of inquiry levels in each construct across the five years of data collection ranged from a 0 to a 2-point increase. Of the nineteen constructs that make up the four factors, the majority increased by 1 point. Only three of the nineteen total constructs did not change at all (i.e., *Knowledge Acquisition, Learner Centrality*, and *Integration of Content & Investigation*). The four constructs that had the greatest shift in practices with a 2-point increase were *Student Reflection, Classroom Interactions, Content Depth,* and *Organizing and Recording Information*.

Change in *Curriculum*

There are four constructs that constitute the *Curriculum* factors. The second and fourth constructs, *Learner Centrality* and *Integration of Content & Investigation*, began at a proficient level (rubric score 3) of inquiry and remained unchanged through all three data collection periods. Each lesson allowed for flexibility during student investigation in which small groups of students explored and built knowledge through manipulation of materials linking the investigation to the learning concept.

Factor	Construct	2007	2009	2012	Total Change
Curriculum	C1- Content Depth	2.00	3.00	4.00	2.00
Curriculum	C2- Learner Centrality	3.00	3.00	3.00	0.00
Curriculum	C3- Integration of Content and Investigation	3.00	3.00	3.00	0.00
Curriculum	C4- Organizing & Recording Information	1.00	3.00	3.00	2.00
Curriculum	Total	9.00	12.00	13.00	4.00
Curriculum	Mean	2.25	3.00	3.25	1.00

Figure 3. Danielle's inquiry scores on the constructs in the *Curriculum* factor

Within the *Curriculum* factor, *Content Depth* and *Organizing and Recording Information* both had a 2-point increase. The *Content Depth* construct rose from a level 2, *developing inquiry* to a level 4, *exemplary inquiry*. In the first lesson, the level of content remained at an observational level. The students reported how the wires needed to be connected to light a bulb without providing reasoning for why this might be. In Danielle's final videotaped lesson, she "provided a depth of content with significant, clear, and explicit connections made to the big picture" by having the students use what they learned from their stream table activity to explain what they should consider about land and water when they built a house.

The construct *Organizing and Recording Information* scored at the pre-inquiry level in 2007 because students recorded their information on a closed exercise worksheet. In 2012, Danielle's lesson raised 2 points to a 'proficient' inquiry level because the students recorded their information in blank lined science notebooks. The students illustrated their stream table and drew where they predicted the water would flow. Students recorded their thinking in non-prescriptive ways.

Change in ***Instruction***

The *Instruction Factor* remained Danielle's highest scoring factor across all three data collection periods. All constructs within the *instruction* factor (*Instructional Strategies, Order of Instruction, Teacher Role, Student Role, and Knowledge Acquisition*) increased by 1 point between 2007 and 2012. Four of the five constructs increased between 2009 and 2012. Danielle's lessons all involved the students in active investigations that provided opportunities for students to construct understanding before the content was explained. By 2012, Danielle showed evidence of being a skilled facilitator who effectively engaged her students in the development of process and understanding.

Factor	Construct	2007	2009	2012	Total Change
Instruction	I1-Instructional Strategies	3.00	3.00	4.00	1.00
Instruction	I2-Order Of Instruction	2.00	3.00	3.00	1.00
Instruction	I3-Teacher Role	3.00	3.00	4.00	1.00
Instruction	I4- Student Role	3.00	3.00	4.00	1.00
Instruction	I5-Knowledge Acquisition	3.00	3.00	3.00	0.00
Instruction	Total	14.00	15.00	18.00	4.00
Instruction	Mean	2.80	3.00	3.60	0.80

Figure 4. Danielle's inquiry scores on the constructs in the *Instruction* factor

Change in ***Assessment***

The *Assessment* factor constructs of *Prior Knowledge, Conceptual Development, Assessment Type,* and *Role of Assessing* all increased 1 point, whereas the construct

Student Reflection had a 2-point increase. The majority of the increase in scores within the *Assessment Factor* occurred between 2007 and 2009.

Student Reflection was at a level 1 in 2007 because Danielle only encouraged students to reflect on their thinking at the end of the lesson and only required students to think on the knowledge level. In 2012, the *Student Reflection* construct rose to a level 3 because Danielle consistently encouraged students to use evidence in their thinking throughout the whole lesson and to share their thinking with others. An example of this is that she informed students that they were going to receive plastic houses to place in their stream table. A student said, "I want mine on the end of the cliff." The teacher responded, "But you really need to think about what you already know and everything we have learned about land and water and everything that could happen if your house were on the edge of a cliff before you make a decision. Talk to your team before you decide."

Factor	Construct	2007	2009	2012	Total Change
Assessment	A1-Prior Knowledge	2.00	3.00	3.00	1.00
Assessment	A2- Conceptual Development	3.00	3.00	4.00	1.00
Assessment	A3-Student Reflection	2.00	3.00	4.00	2.00
Assessment	A4- Assessment Type	2.00	3.00	3.00	1.00
Assessment	A5-Role of Assessing	2.00	3.00	3.00	1.00
Assessment	Total	11.00	15.00	17.00	6.00
Assessment	Mean	2.20	3.00	3.40	1.20

Figure 5. Danielle's inquiry scores on the constructs in the *Assessment* factor

Change in *Discourse*

The *Discourse* factor began as the lowest EQUIP Score and remained the lowest at every data collection period. There was a 4-point increase in the *Discourse* factor between 2007 and 2009, and only a 2-point increase from 2009 to 2012. Most of the constructs of the *Discourse* factor, including *Questioning Level, Complexity of Questions, Questioning Ecology, and Communication Patterns,* increased from a level of *developing inquiry* in 2007 to *proficient inquiry* in 2012. In 2007, Danielle's questions rarely challenged students beyond the understanding level, and the teacher typically controlled the conversation. In 2012, most of the questions Danielle asked challenged students "up to application or analysis levels" and "to explain, reason, or justify" (Marshall et al., 2008).

Factor	Construct	2007	2009	2012	Total Change
Discourse	D1-Questioning Level	2.00	3.00	3.00	1.00
Discourse	D2-Complexity of Questions	2.00	3.00	3.00	1.00
Discourse	D3- Questioning Ecology	2.00	3.00	3.00	1.00
Discourse	D4- Communication Pattern	2.00	2.00	3.00	1.00
Discourse	D5- Classroom Interactions	1.00	2.00	3.00	2.00
Discourse	Total	9.00	13.00	15.00	6.00
Discourse	Mean	1.80	2.60	3.00	1.20

Figure 6. Danielle's inquiry scores on the constructs in the *Discourse* factor

The construct, *Classroom Interactions,* began at the pre-inquiry level and rose two points to a level of proficient inquiry. In 2007, Danielle accepted student answers to her questions. She often replied with "Good" or "True," but rarely followed up with further probing. In 2012, Danielle almost always followed up student responses with "Why do you think that?" or "How do you know?" thus requiring the students to justify their thinking with evidence. This deeper questioning level facilitated the students in taking the information and making connections between the evidence and their own understanding.

Change in time usage indicators

The time usage indicators measured the percentage of time Danielle or her students were engaged in particular characteristics of the lesson. Three time usage codes are presented. *Cognitive Codes* refers to the students' lower or higher order of thinking, *Assessment Codes* refers to the teacher's use of different Assessment types, and *Inquiry Instruction Codes* refers to the phases of the lessons.

Cognitive Codes. The data in Figure 7 illustrates the time students spent using different levels of cognitive thought. In all lessons, Danielle was able to involve students in thinking at the 'application' level. By 2012, Danielle's students were "consistently and effectively active as learners" and she required them to spent time evaluating and analyzing evidence.

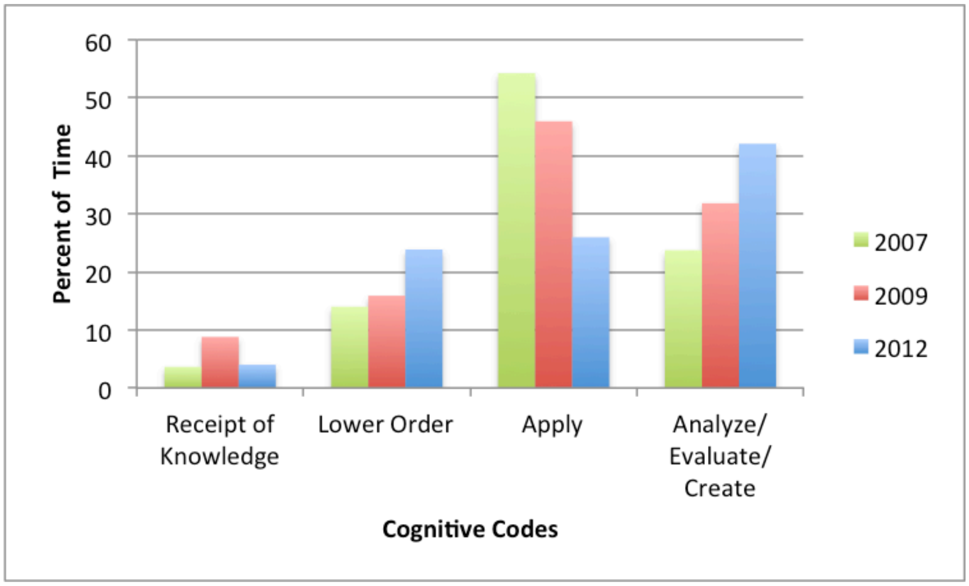

Figure 7. Students' levels of cognitive functions during Danielle's lessons

Assessment Codes. Danielle spent most of her time during the 'explore' phase in 2007 'monitoring' the students and managing the lesson and the materials. She made comments such as "What are you doing now?" and "Do you need more hands to get that done?" The graph in Figure 8 is derived from the EQUIP time coding on assessment strategies. It shows Danielle's shift from time spent 'monitoring; students' behavior and materials management to using questioning as 'formative' assessment. In 2012, the majority of her time was spent formatively assessing students' knowledge through asking questions that pushed the level of student thinking. For example, she asked each group, "What do you think would happen to the land over time if the water were continually flowing?"

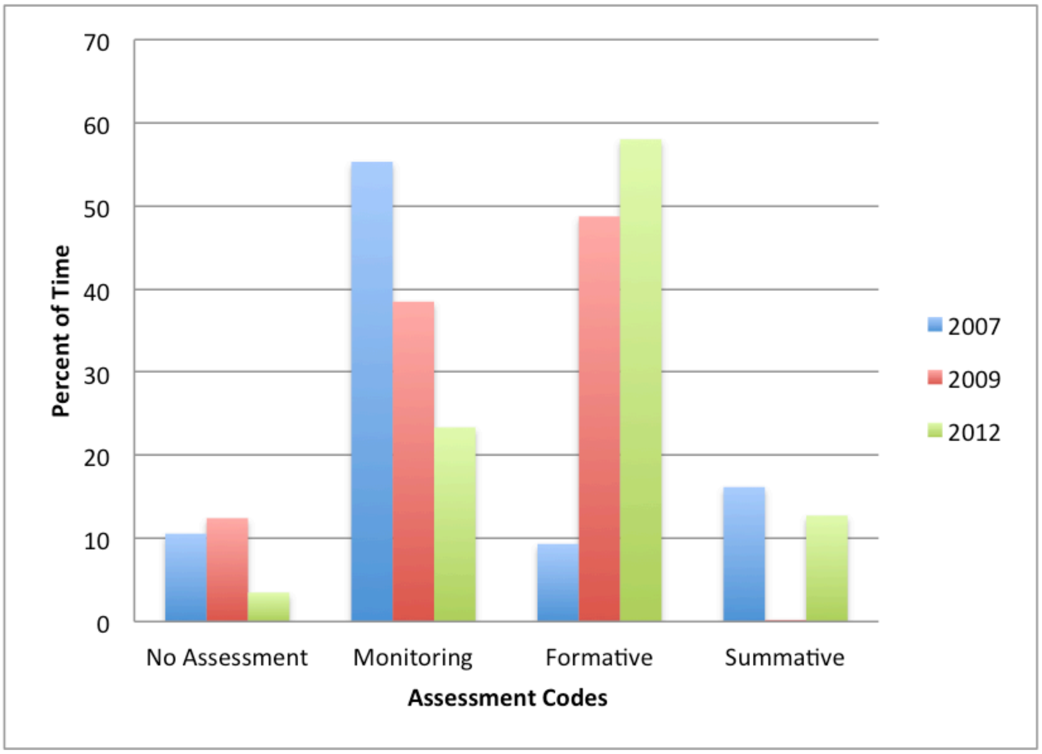

Figure 8. The time Danielle spent on different assessment strategies during her lessons

Inquiry Instruction Codes. The Inquiry Instruction Codes measured the time each lesson spent in the '*engage*', '*explore*', and '*explain*' portion of the lesson. In 2007, the time was mostly spent on the '*engage*' portion of the lesson and the least time was spent in the '*explain*' portion of the lesson. In 2009, the time was mostly spent on the '*explore*' portion of the lesson and the least time was also on the '*explain*' portion. In 2012, Danielle spent more of the lesson on the '*explain*' portion than in 2007 or 2009.

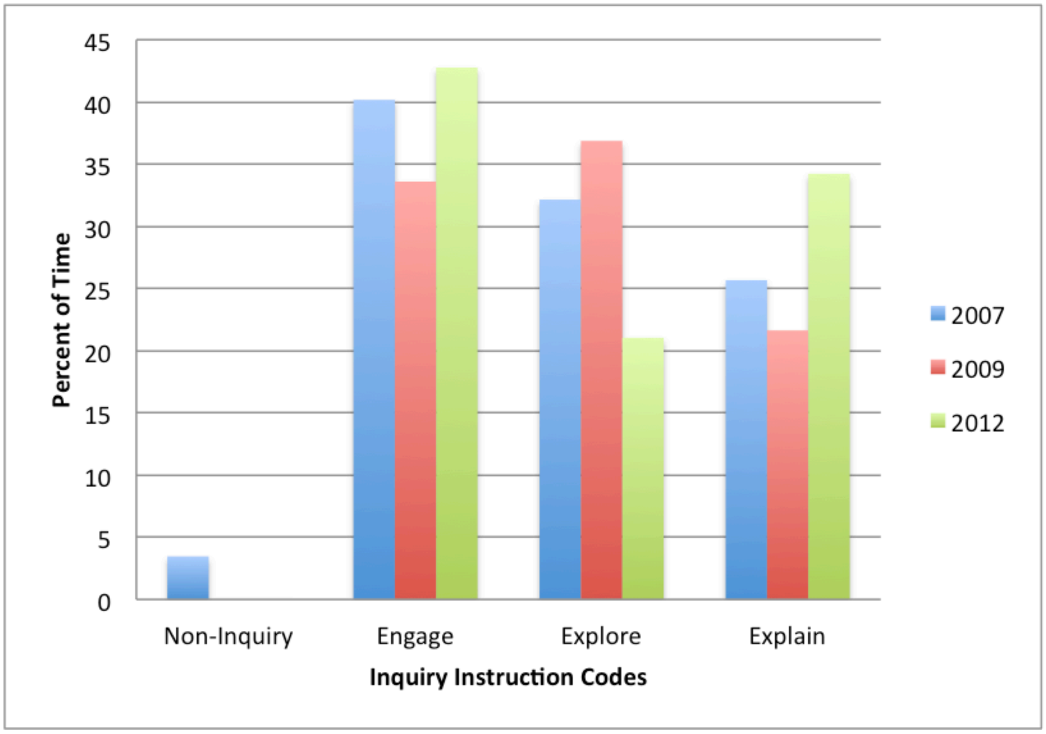

Figure 9. Danielle's time spent on different phases of each lesson

Danielle's self-reflection of her perceived change over time

Danielle was interviewed in 2007, 2009, and 2012. Many similar questions were asked in all three interviews. Her responses were considered chronologically to identify shifts or patterns in her thinking. In 2012, Danielle was asked if she taught science differently today then she did five years ago. Her response was, "Totally different! Way different! Now we explore and figure the problems out together" (Danielle, personal communication, August 1, 2012). She referred to thinking of her students as scientists now instead of receivers of knowledge. The transformation from a more traditional teacher-centered classroom to a student/ teacher constructivist classroom took time. For example, she responded differently in her reflections from 2007 and 2009 and her interview in 2012 when she answered the question, 'What was the approximate amount of time that you talked as a teacher compared to the students' responses and interactions?' Danielle's responses to the same question over time can be read in Figure 10.

Source: Reflection 2007	Source: Reflection 2009	Source: Interview 2012
"I feel the students and I shared time interacting with each other and the group almost equally. "	"I talked 40%... don't know… a lot!"	"I didn't talked as much … 70% was them 30% was me."

Figure 10. Danielle's perceptions of teacher talk time versus students' interaction time

Danielle's responses indicated her belief that over the 5-year period she "lectured" less and involved her students in discourse and activity more. In 2009, she also indicated an awareness of the need to let her students interact more and for her to talk less when she claimed that 40% of the time talking was "a lot" with an exclamation point.

Danielle also perceived a change in her confidence with the content. This change is reflected by her perceived comfort with teaching the lessons in 2007, 2009, and 2012 seen in figure 11.

2007: Reflection Paper	2009: Reflection Paper	2012: Interview
Not at all!!!	On a scale of 1 to 10 maybe a 6.	An 8 because I am pretty comfortable but I think there is always something more to be learned.

Figure 11. Danielle's response to "How comfortable were you with the science content you were teaching?"

In her 2012 interview, Danielle attributed the change in her comfort level to, "The more you are exposed to the kits and the more you think about how it connects to the real world …well that helps a lot. Also exploring with the kids and my co-workers, and the PD providers…getting my own hands-on experience (she laughs) and then applying that to teaching" (Danielle, personal communication, August 1, 2012).

Danielle views herself as a life-long learner and this was evidenced by her desire to learn about her teaching practices from this research. She fears that all the work she has put into learning and teaching science will come to a halt with new policy changes. She claims, "Science is fun still. No other subject is fun anymore. They will probably change things in science too, and then I won't like it. My children are spending most of the day being robots; in science, they have a chance to explore…to think… to get dirty..and I do too" (Danielle, personal communication, August 1, 2012).

Chapter 5

Case II: Mary-Ann

This chapter presents the second of three teacher cases. Mary-Ann taught second grade through the duration of the study timeline. She moved from one school in her district to another in 2008. Her video lessons in 2007 and 2012 were both lessons focusing on observations of insects. Her 2009 video lesson topic was phases of the moon.

The chapter is divided into two major sections: Descriptive Narratives, and Change in Inquiry Practices and Beliefs. The Descriptive Narrative section describes the sequence of events that Mary-Ann experienced over the course of five years. It begins by describing Mary-Ann's professional development and curriculum experiences in science prior to the study timeline. A timeline of Mary-Ann's professional development experiences, curricula experiences, and videotaped lessons for the five years study period provides the reader with a visual account of the events that may have influenced the teacher practices and beliefs. Next, each event is described through rich, detailed, written descriptions. The narrative is organized chronologically as depicted in the timeline.

Each videotaped lesson description is partitioned into three parts *Engage, Explore*, and *Explain*. These phases of an inquiry lessons are described by the time usage codes from the Inquiry Component Instruction Code on the Electronic Quality of Inquiry Protocol (EQUIP). Throughout the videotaped lesson description there are factors followed by a letter number combination in parentheses. For example, the following is taken from Mary-Ann's 2007 lesson narrative: In this lesson the students were to apply what they knew about the structures and behaviors of insects and extend their knowledge to observe insects that live in the water (*Instruction* 5-3). The word *Instruction* refers to the factor; the '5' signifies the fifth construct in the *Instruction* factor called *Knowledge Acquisition*; the number after the dash, in this case a '3', identifies the rubric score. So in this example, the description of the fifth construct in the *Instruction* factor at a level three reads, "Student learning required application of concepts and process skills in new situations". Students were to apply their existing knowledge of land insects and their observation skills to study new insects that live in the water is evidence of why this construct was scored a level three.

The second chapter section, Change in Inquiry Practices and Beliefs, presents the quantitative and qualitative outcome variables, including the composite inquiry scores from the four EQUIP factors over time; the change in scores from constructs in each of the four factors, *Curriculum, Instruction, Discourse,* and *Assessment*; the change in time usage indicators; and the change in the teacher beliefs of teaching inquiry.

Descriptive Narrative

The purpose of the narrative is to understand the teacher experiences within the social context of the classroom. The narrative switches between the teacher professional development experiences and descriptions of the videotaped lessons as they occurred chronologically. Sandelowski (2007) writes "The mind is put to rest by the illustration of sequence and order, the appearance of causality and the look of necessity" (p. 163). The following timeline and narrative provide special reasoning about the sequence of the events. It also provides the reader with solid background knowledge and justification for the reporting and analysis of the EQUIP inquiry scores.

Initial professional development opportunities 2006 to 2007

Mary-Ann had few learning opportunities prior to the timeframe of this research study. She recalled having had one science methods course in college but admitted remembering little from it because "that was a very long time ago" (personal communication, December 1, 2009). She did not recall taking any other science courses during her undergraduate education except one psychology class. Mary-Ann did attend a few science education workshops/courses for graduate credit, including Active Watershed Education Course and NASA Workshop for Educators.

Mary-Ann attended her first professional development recorded in the GEMS-Net database when her school district joined the project in 2006. At the start of the collaborative project's influence she had already been teaching elementary school for 18 years. In 2006, the district's Kindergarten, 1st, and 2nd grade teachers participated in an Introduction to Inquiry teaching workshop. The six-hour workshop used general science activities designed by the Exploratorium's *Institute for Inquiry* to build an understanding of the practices involved in teaching through inquiry. The following day Mary-Ann attended two initial curriculum workshops for durations of two-and-a-half hours each. Experienced teachers facilitated workshops to help Mary-Ann and her colleagues become familiar with the Grade 2 Full Option Science System (*FOSS) Insects* module and the *FOSS Solids and Liquids* module. Mary-Ann taught those two units for the first time in the 2006-2007 school year.

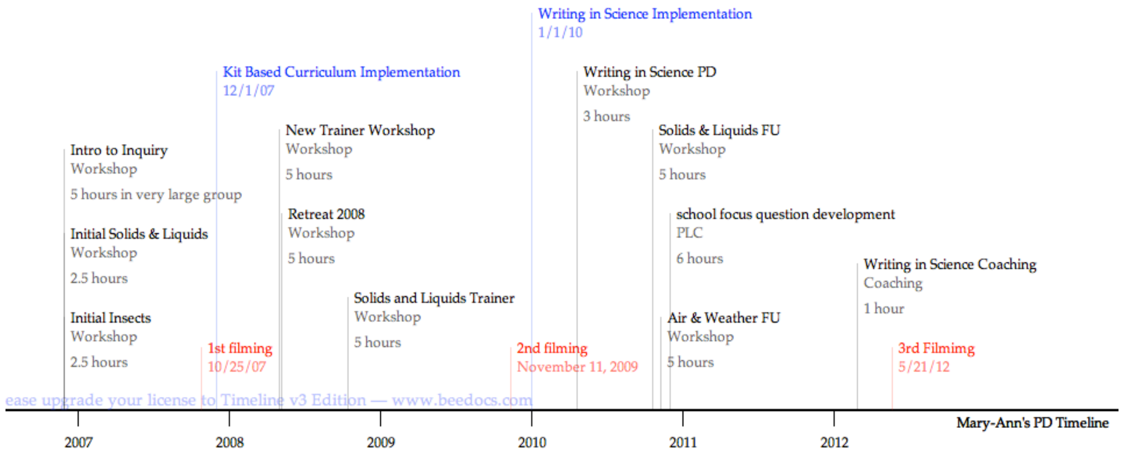

Figure 12. Timeline of Mary-Ann's professional development experiences

Description of Mary-Ann's Lesson in 2007

Mary-Ann's lesson, taped in November 2007, was focused on the observations of aquatic insects. Before this lesson the students had observed 'land' insects, such as, mealworms, caterpillars, waxworms, and milkweed bugs. In this lesson the students were to apply what they knew about the structures and behaviors of insects and extend their knowledge to look at insects that live in the water (*Instruction* 5-3). This lesson was the second time that Mary-Ann taught the *Insects* unit.

Engage. The second grade students sat on the floor in front of the whiteboard. The teacher introduced the lesson with a two-minute review of the students' prior knowledge (*Assessment* 1-2). She asked simple questions that required knowledge level answers. For example, Mary-Ann asked "Who can tell me about metamorphosis?" and a student responded, "change" (*Discourse* 2-2). She then asked more specific questions about simple and complete metamorphosis (*Assessment* 3-2; *Assessment* 5-2). The students brainstormed different insects that they had studied through hands-on investigation or reading selections. The teacher introduced the three questions that were written on the white board and she asked her students to think about the questions throughout the lesson.

What is so special about insects?

Can any insects live in or around water?

What special features help these insects survive?

Mary-Ann introduced the focus of this lesson by filling in the word "water" in the second question. She then asked if anyone knew of an insect that lived in or around water? Only one student seemed to be able to answer but many students answered the next two questions that called on prior knowledge. The teacher asked students what insects needed to survive and what features were specific to an insect (*Assessment* 2-2). She recorded the students' correct responses on the board.

The teacher then explained how the students in groups of 6 would rotate through 3 stations. Students sorted through animal picture cards to identify which cards were aquatic insects and which cards were not in one station. In another station, students looked at charts to identify aquatic insects that are in our local area. The third station (where the teacher focused her instruction) involved students observing aquatic insects in two buckets of 'pond' water. The teacher reminded the students to consider the three questions on the board while they worked through all three stations (*Assessment* 3-2).

Explore. During exploration the students moved as a group between the three stations. The camera did not focus on the two stations that Mary-Ann did not facilitate. The stations not videotaped were lead by knowledgeable adults; one station was lead by a student teacher and the other a classroom assistant. These stations allowed students to manipulate picture cards. The outcome of both of these stations was pre-determined and intended for the students to arrive at one correct solution (*Curriculum* 2-2).

The third station was where the classroom teacher and the camera focused. Students at this station had to observe live aquatic insects. During the observations the students were free to watch and touch the insects (*Curriculum* 2-3; *Instruction* 4-3). Three students stood around each bucket and actively conversed about what they were observing (*Discourse* 3-3). The following conversation occurred at the beginning of the first observing group.

Teacher-"So I want you to look at them very carefully. You can each take a microscope (she meant a hand lens) to help you"

Student- "I don't see them"

Teacher-"I think that is one of their survival features. If I were a bird how could I eat them if they are under the leaf and I don't see them?" (*Curriculum* 1-2)

Mary-Ann did not wait for a response. She moved quickly onto another topic. She asked, "How do you think they might be getting air under water?" Students brainstormed ideas. Mary-Ann responded to student ideas by replying "Maybe" and "Do you think so?" (*Discourse* 5-1)

The teacher moved quickly between providing short lectures and asking simple questions. Conversations with students were interjected with questions from the teacher that were intended to extricate student knowledge. However, the teacher's wait time was shorter than students' think time (*Discourse* 4-2).

Students asked questions about what they were observing and the teacher generally followed up with a short lecture. For example, a student asked why a crayfish was on the insect chart. The teacher said, "The reason they put crayfish on there is …remember when I explained about the bigger group of invertebrate animals. These fit that category just like insects fit that category" (*Instruction* 2-2). Students were not prompted to provide evidence for their thinking.

Explain. After 1 hour and 8 minutes the students were called back to the rug. Once the students were settled, Mary-Ann said, "We were trying to find out what was special about insects. Why there are so many different kinds in so many different places …We took a longer look at water insects today. They are called aquatic. I tried to get my group to focus on special features. Does anyone have anything that they could add to our discussion of aquatic insects that we could put on the chart paper?"

The students verbally reported six specific concepts that the teacher then recorded on the chart paper (*Curriculum* 4-1). The teacher facilitated the development of the concepts by asking questions to prompt the students' observations. The conversation remained between the teacher and individual students. The ideas came from the students (*Instruction* 1-3), and the teacher helped the students reword their thinking to be more scientific by using specific terminology. The teacher often followed up questions from students with a lecture. For example, a child said "they could fly" and the teacher helped the student to identify 'they' as water boatmen and then wrote, "Water boatmen have wings". Mary-Ann implied that 'having wings' was the observable evidence. She encouraged the students to take time in the future to continue to observe them to see if they could really fly. Mary-Ann provided her own thinking on the subject, "I doubt if they do in fact fly. I guess if they disappeared out of the bucket we might think that they did in fact fly away."

Students also asked questions and the teacher responded by providing an answer. For example, a student asked, "How… they have so skinny legs right? How do their legs not go through the water when they go (action of swimming)?" The teacher tells the students her own thinking from her observations of the legs, "I think it is because the legs bend and are wider at the bottom" (*Instruction* 2-2). After the conversation and the recording of the observations the teacher ended the lesson by informing the students that later that day they would draw and write about the insects they observed.

Mary-Ann's professional development experiences November 2007 to October 2009

After the first videotaped lesson Mary-Ann attended two leadership opportunities provided by GEMS-Net. The first was the New Trainer Workshop intended to develop adult facilitation skills for the purpose of facilitating future curriculum workshops for her colleagues. The second workshop was the project's annual retreat attended by the project's volunteer scientists, classroom teacher leaders, and University educators. In May of 2008, the retreat was held at an outdoor education center. Half of the day was spent building relationships among the diverse groups through team building exercises, and the other half was spent on strategic planning activities for the future development of the project.

In October of the 2008- 2009 school year Mary-Ann assisted a Science Education Specialist from the University-District Collaborative on presenting the Solids and Liquids Initial Workshop to teachers who were about to use the kit for the first time. When

Mary-Ann was asked what professional development she found most helpful, she responded, “As a trainer I got to step back and really be more reflective. You have to stop and think about it and how to explain it to someone else… that is a deeper level of knowing. Talking with teachers at workshops lets you know other ways… additional best ways to do lessons. GEMS-Net makes it comfortable for teachers to really talk to one another”. (Mary-Ann, personal communication, May 21, 2012). Between the first and second taping Mary-Ann received fifteen additional hours of professional development. Five of these hours were in professional development focused on her teaching and curriculum. Ten of these hours were intended to build leadership skills. Going into the second filming, Mary-Ann had received a total of twenty-five hours of professional development.

Description of Mary-Ann’s Lesson 2009

Mary-Ann’s videotaped lesson from 2009 was designed to develop student thinking on how the moon changes phases over time. Students had previously recorded what the moon looked like on the night of their birth by drawing the shape of the moon with white chalk on black paper. On the windowed wall of the classroom the teacher had organized and posted the student-drawn moons by “putting the ones that looked alike together.” This lesson was modified from a lesson within the *FOSS Air and Weather* unit. This was the third year that Mary-Ann had taught the *Air and Weather* unit.

Engage. The lesson began with a review of the data the students collected in a previous lesson (*Assessment* 1-2). The students were at their desks and Mary-Ann had focused the students’ attention on the wall covered with student-drawn moons. Early in the lesson Mary-Ann stated the objective questions by listing them aloud and in succession: "Do you see any changes in how much of the moon you can see?, Are there any patterns in the moons appearance?, How can we figure out what is coming up next in the night sky?" (*Discourse* 3-1) and then Mary-Ann stated, "Those are some of the big questions I want you to think about." (*Assessment* 3-2)

Mary-Ann asked a variety of questions about the student-drawn 'birthday' moons. For example she asked, "What do you notice about the birthday moons?" The students noticed that there were more crescent birthday moons than anything else. One child listed all the different phases of the moon. Another student made unsupported claims about the rotation of the moon and the earth. Students were unable to provide language on how the moon waxes (you see larger amount of it) and wanes (you see a smaller amount of it) (*Discourse* 4-2). Mary-Ann eventually orally supplied the terms 'waxing' and 'waning' and described what the terms meant (*Instruction* 3-2).

A few students were asked to place labels on the wall. The labels were designed to entitle the group of moons already on the wall. The student and teacher placed labels of 'new moon', 'waxing crescent', 'first quarter', 'waxing gibbous', 'full moon', 'waning gibbous', 'last quarter', and 'waning crescent'. The teacher then informed the class that, "If you need those words they are up there for your writing and your thinking" (*Instruction* 2-2).

Mary-Ann gathered students on the rug. She informed the students, "We are going to see what we can see about the night sky with our models." Mary-Ann presented the materials a flashlight as the sun, a large green foam ball as the earth, and a white small foam ball as the moon. Mary-Ann chose a few children to help her model the process of moving the moon-ball around the earth-ball, while holding the flashlight still.

She asked the students what they could see when the small styrofoam ball was moved around the larger green ball. The students responded tentatively. They did not provide evidence of reasoning for their answers. The students struggled to place themselves in the correct position 'being on earth' to see the correct lighted part of the foam ball moon. One student said "it looks like a lunar eclipse" and the teacher responded, "could be… there are lunar eclipses". The students had a hard time seeing the demonstration model, so Mary-Ann provided the students the opportunity to test out their own models.

Explore. Students worked in groups of four to demonstrate the model of the sun, earth, and moon (*Instruction* 4-3). While the students explored the models, the teacher was managing and monitoring classroom behavior. She asked questions designed to focus the students on what they should be observing, such as:

"What do you see?"

"You're too close…Do you see any light?" and

"Do you see any shadow?" (*Discourse* 3-1) Student conversation at times centered on the parts of the model moon that were lit up and other times the conversation focused on whose turn it was to hold which piece of the model. After about eight minutes of exploration Mary-Ann brought the class back to the rug for a whole group discussion.

Explain. Once at the rug, Mary-Ann asked "How many children got a good idea about the moon's orbit around the earth?" She didn't wait for a response but moved into showing the students a computer image of the changing phases (*Assessment* 5-1). She then showed the October moon chart that she had created, and then together the class added four more days of data onto the calendar. The students had collected the data as homework the previous week.

After the class had recorded their observed data, Mary-Ann said, “I’m thinking about what might come next and for you to make a prediction. That is an important word, ‘prediction’, because I think good scientists would think about what they are learning and try to predict what might happen next” (*Curriculum* 3-3; *Assessment* 2-3). Mary-Ann added the word ‘prediction’ to the word bank and gave instructions that the students would be making predictions soon.

Mary-Ann asked questions about what the students noticed about the moon’s phases in October. The first student said that there were eight full moons. Mary-Ann responded that numbers could help scientists to explain their thinking (*Curriculum* 3-3). She charted the number of moons in each phase including eight full moons in the month of October. With the teacher facilitation the class decided how many moons there were for each phase within the month of October (*Assessment* 2-2). They determined based on the shape they drew on their homework that there were seven full moons. At one point Mary-Ann said, “raise your hand if you agree” when a student claimed there were five new moons. One student said, “Yes” and Mary-Ann replied, “OK” (*Discourse* 2-1; *Discourse* 5-1).

Mary-Ann talked through describing the shifts in moon phases. A few children were saying the phases with her. Mary-Ann said, “I’m thinking. I don’t know if you are thinking this with me” (*Instruction* 3-2)…and then she attempted to get the students to come up with the idea that one cycle of phases is equal to one orbit of the moon around the earth. Only a few children seemed to respond to her prompting (*Assessment* 4-2).

The class then charted their homework on the classroom wall together (*Curriculum* 4-1). They predicted, as a class, that there would be seven full moons in November. Mary-Ann referred them back to the data from the October calendar. At one point Mary-Ann described predicting as "your smartest guess." Mary-Ann did not ask the students to include the evidence or data to justify the predictions (*Discourse* 2-2).

The class conversation was controlled by the teacher's questions (*Discourse* 4-2). Students provided their level of understanding as they responded to the teacher's prompts. One child commented that the moon might be in a different phase when you looked out of different windows of your house. The teacher responded "OK" (*Discourse* 5-1). At another point in the discussion, Mary-Ann cleared up a student's misconception. The student had reported he had recorded a new moon on a night that was cloudy. Mary-Ann responded that just because the clouds blocked your ability to see the moon does not mean it is a new moon (*Assessment* 2-2). Further on in the lesson, Mary-Ann used a voting method to determine the appropriate data. She counted the number of students who thought November 2nd would be a full moon and the number of students who thought it would be a gibbous moon. She recorded the moon that most students thought, rather then basing the data on evidence (*Instruction* 1-2).

Mary-Ann then gave each student his or her own calendar. She directed them to record the moon's phases for the three days they had selected as a group and then to predict seven more days on the calendar by drawing the moon with a crayon (*Curriculum* 4-1). She informed the class that every day for the next seven school days they would glue the actual observed moon phase on top of the students' predicted moon phase. Mary-Ann said, "You can't be a great thinker and a great scientist without thinking and trying and making some smart guesses and then if you make a mistake and say, oh, I didn't guess right, you probably will learn even more from noticing that" (*Curriculum* 3-3). The lesson ended after one hour and 17 minutes with students filling out a cloze exercise worksheet about the moon (*Curriculum* 4-1).

Mary-Ann's professional development experience from October 2009 to May 2012

Mary-Ann was introduced to the science writing approach in April of 2010. She received a three-hour Initial Science Writing Workshop in which all the teachers in kindergarten through fourth grade learned specific teaching strategies for expository writing and protocols for developing student thinking and communication through the use of notebooks. On reflection of implementing the science writing approach Mary-Ann said, "The science notebooks have been a big shift. I used to run out of time, and I would sum it (the lesson) up. Now they (students) are taking the time to sum it up themselves. They are accountable to the test, so they need to write. Also, I am also letting them organize their data. I might suggest and guide, but they are doing it." (Mary-Ann, personal communication, May 21, 2012).

In the beginning of the 2010-2011 school year, Mary-Ann attended two five-hour curriculum follow-up workshops. These workshops used lessons from the units Mary-Ann had experienced the previous three years. The goal of these workshops was to reflect on the process of teaching inquiry and to develop a deeper level of pedagogical content knowledge. Upon returning from the follow-up session, Mary-Ann led her school grade-level colleagues through the process of writing focus questions and organizing data collection for notebooks for all of the grade 2 units.

In February of 2012 Mary-Ann received an hour of classroom coaching that centered on developing strategies presented in Betsy Fulwiler's *Writing in Science* text. Mary-Ann received personal feedback on what was working well and what next-step-strategies might help in her classroom.

Before going into the final videotaped lesson in May of 2012, Mary-Ann had received seventeen additional hours of professional development and had been introduced and introduced to the science writing approach. Mary-Ann had received a total of 45 hours of professional development between the start of the 2006-2007 school year and the end of the 2011-2012 school year.

Description of Mary-Ann's lesson 2012

Mary-Ann's 2012 lesson focused on comparing and contrasting the students' structures and behaviors with the structures and behaviors of a classroom insect. The observations of an insect and the recording of data on a 'box and T-chart' provided the means for the students to focus on the question, "How am I different from an insect?" This observation is the seventh year that Mary-Ann has taught this unit.

Engage. The lesson began with the students sitting together on the rug. Mary-Ann elicited prior knowledge by asking questions about the previous observations and readings they had done on insects (*Assessment* 1-3). The students reported what they had learned about insects. At one point in the conversation, Mary-Ann facilitated the students thinking about the parts and structures of an insect by helping the students recall a lesson from the previous unit. This question required a depth of content that made connects across science content domains. The lesson she had the students recall was from a physics unit completed four mouths prior. The students had built a tower with different materials and analyzed how the structure is dependent on the properties of its parts. She facilitated the class discussion around how the parts of an insect might affect the whole insect (*Instruction* 5-3).

She handed each child a small model of an ant and said, "You can look at the size of it, the color of it, some of the things scientists might be interested about when they are studying something." This instance was a clear connection between the content and the scientific processes involved in studying insects (*Curriculum* 3-4).

The focus question "How am I different from an insect?" was introduced by the teacher and written on the Smart Board. The teacher attempted to ask students to think about categories or ways people were different from insects, such as habitat, diet, or survival, but students replied to her prompting with more specific responses. Instead of offering the category of 'size,' the students replied that insects are small and we are big. After a few more similar student responses the teacher decided to follow the students' thinking (*Assessment* 1-3). She brought the categories back up at the end of the lesson in order to organize the students' sharing session.

Students then wrote their focus question in their notebooks. They chose which insect they wanted to study (*Curriculum* 2-3) and then discussed important vocabulary from the focus question (*Discourse* 1-3). As a whole group they designed a data collection chart (*Curriculum* 4-3). Although the teacher suggested a T-Chart with insects in one column and themselves in the other, the students had control over how to design their T-Charts as well as what they could include in it. As they physically drew the chart in their notebooks, some students added pictures; others just put a line down the middle. One student created his data collection chart with boxes, but then in the investigation realized the spaces in the boxes were not large enough, so he erased and redesigned the chart. As evidence of the students' ability to control how to record the information, the teacher said to one girl at the end of the lesson, "You did something different in your science notebook. At the bottom you added something about a prediction or an 'I wonder' statement. Tell the class about what you wrote." (*Curriculum* 4-3)

Explore. Students worked in groups of two to four to observe their chosen insect (*Instruction* 4-4). Students thought, discussed, and recorded many differences between themselves and their insect. In one instance the children found a molted exoskeleton of a mealworm in the classroom habitat. The following conversation between a child and the teacher occurred in which the teacher probed the students to develop an operational definition of 'molting' (*Instruction* 1-3):

Student- I have another difference. We just grow, we don't shed. They shed and grow.

Teacher- And have we collected evidence that they shed?

Student- I just saw one right there.

Teacher – Yes it looks like them. So that would be evidence of them …what's the word? If you see an exoskeleton and they shed.

Student- It is evidence that they are going to move into the next stage.

Teacher – Its moving on but what does that mean it is doing?

Student- It is growing

Teacher –Yes, it doesn't fit in its exoskeleton, it grows out of it and sheds"

Student- Oh, it molts

During the *explore* phase the teacher walked around the room, alternating between monitoring students and asking questions that provided her with formative feedback (*Discourse* 2-3). One example of the teacher following up on student thinking was when the teacher asked a student about the differences she recorded. The student replied, "I have two legs. They have 16 legs." The teacher said, "I don't know about 16 legs. How many legs do insects have?" The teacher and student used a larger diagram of the insect on the classroom wall to look at the number of legs and other structures on the waxworm (*Discourse* 5-3).

The teacher successfully encouraged conversation among groups with direct words like "Maybe talk to your group. See what they have compared to what you have and talk to each other about additional information you might find (*Discourse* 3-3). She also encouraged curiosity with phrases like, "I am noticing that the waxworms look different.. Could you do some wondering about that?" (*Assessment* 5-4) After 25 minutes of exploring and recording information Mary-Ann called the students to gather for a conversation.

Explain. The children all sat on the rug with their science notebooks opened on their lap to the page where they had recorded their information (*Discourse* 2-3). The teacher asked the students what they had found out. The teacher was prepared to record the student ideas into her predetermined categories on the smart board. She quickly realized the students had too much to say and changed her plan again about recording the information (*Instruction* 4-4). Instead, she said that the next day the class would spend time organizing their data before they wrote about their findings. Many children reported out their data and the teacher prompted the students to only share something that had not been said before.

In addition to attempting to have students listen and respond to each other, the teacher followed up with students to make them think more deeply about the animal (*Discourse* 5-3). The following conversation demonstrates how the teacher followed up with a child's reported observation and encouraged the student to use his scientific skills to further investigate the answer.

Student- The Milkweed bugs' habitat is cotton balls and sunflower seeds and ours isn't

Teacher- Is that what their habitat would be in the wild?

Student- No

Teacher- Where might it get its water?

Student- I don't know

Teacher- That might be something to wonder about? What type of mouth does the milkweed bug have? Could you see the mouth of those insects or were they too small?

Student- kind of like a munching mouth

Teacher – A munching mouth? That's what you think…could you see the munching mouth?

Student – Not really. I thought it had a munching mouth because of the shape of the head

Teacher- I think that is something we should wonder about and as they get bigger we will be able to see their mouths better (*Instruction* 3-4)

The teacher closed the lesson with a question that brings the content and processes to a very 'big picture' thinking idea (*Curriculum* 1-3). She posed the question, "Why do scientists study insects?" She encouraged the students to take time over the next few days to think about it before they shared their thinking. She assured the students that they would revisit the data and write their 'compare and contrast' the following day (*Assessment* 3-3).

Change in inquiry practices and beliefs

Composite EQUIP scores for *Curriculum*, *Instruction*, *Discourse*, and *Assessment* are described in term of change over time. In order to report Mary-Ann's growth patterns, her level of inquiry will be presented in terms of the rubric scores derived from the EQUIP observation tool. Levels of inquiry practice were determined on each of the nineteen constructs for all the three lessons. The four levels presented correspond with the rubric score as follows: a score of 1 is a pre-inquiry level, a score of 2 is a developing inquiry level, a score of 3 is a proficient inquiry level, and a score of 4 is a exemplary inquiry level. The example rubric in Table 2 shows how the rubric descriptors, the rubric scores, and the teachers' level of inquiry align. Since this study is analyzing the teachers' growth in practice, the constructs with the greatest growth rate in rubric scores over the five years are supported with examples from the observed lessons. Finally, although the research outcomes were originally only concerned with the teacher practices, the researcher found it pertinent to report the change in the teacher beliefs about teaching with inquiry practices. The teacher's perception of their change process strengthens the understanding about how and why teachers' practices change over time.

Composite EQUIP rubric scores

The mean of the EQUIP scores from Mary-Ann's lessons increased from 2007 to 2012, but were not consistent for all factors throughout the three data collection periods. In 2007 the mean of all four factors was 2.20 out of 4.00. The authors describe this score, which is within the developing inquiry level on the measure, as "involving students in active investigations with teacher-led instructional practices" (Marshall et al., 2009). In 2009, Mary-Ann's lesson remained in the developing inquiry level on the measure. There was actually a slight decrease in the mean of all four factors on the rubric. In 2012, the mean inquiry score increased 1 rubric point from the 2007 score of 2.2 to 3.20 out of a total of 4.00. Mary-Ann's final videotaped lesson inquiry score is in the proficient inquiry level on the EQUIP measure.

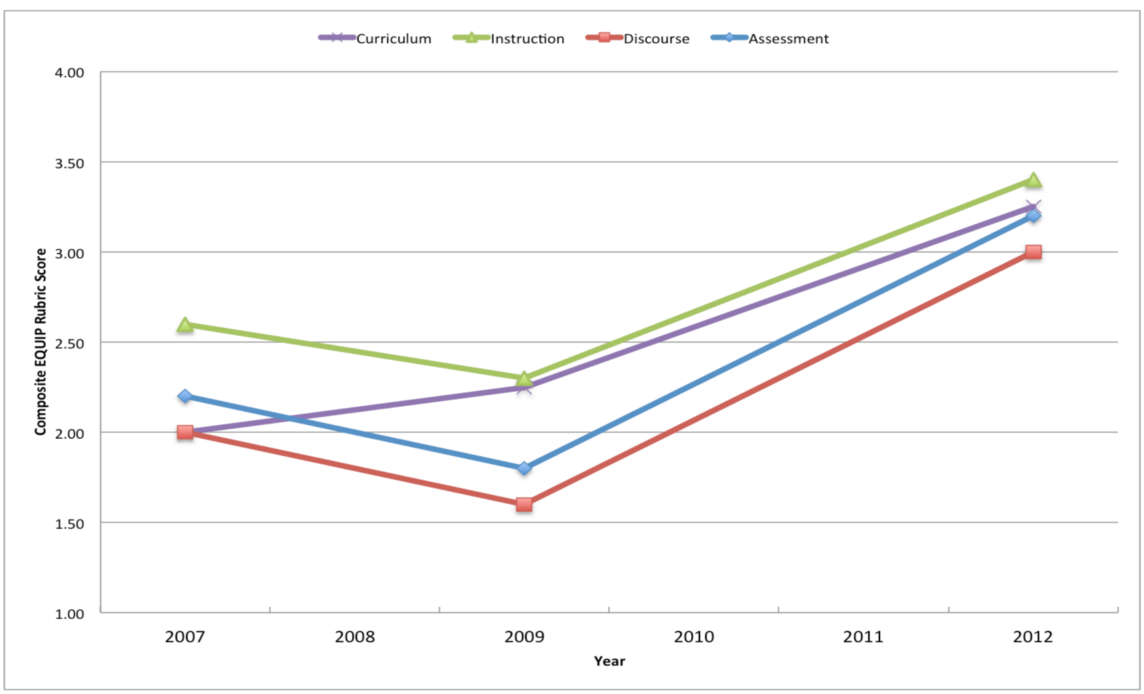

Figure 13. Mary-Ann's levels of inquiry teaching and how they changed over time

The range of Mary-Ann's factor scores in 2007 was 2 to 2.6, whereas the range of her factor scores in 2012 ranged from 2.8 to 3.4. The *Instruction* factor was the highest scoring factor in 2007 and remained the highest in 2012. The *Discourse* factor was the lowest scoring factor in 2007 and remained the lowest through the study until 2012. Between 2007 and 2009, *Instruction, Discourse, and Assessment* had a slight decrease in rubric scores, whereas the *Curriculum* factor had a slight increase. Mary-Ann had the greatest increase in use of practices within the *Curriculum, Instruction, Discourse, and Assessment* factors between 2009 and 2012.

The change in the level of inquiry for each construct across the five years of data collection ranged from no change to a 2-point increase. Of the nineteen constructs that make up the four factors, five constructs increased 2 points (i.e. *Role of Assessing, Classroom Interactions, Teacher Role, Integration of Content and Investigation, and Organizing and Recording Information)*, nine constructs increased by 1 point (i.e., *Prior Knowledge, Conceptual Development, Student Reflection, Questioning Level, Complexity of Questions, Communication Pattern, Order of Instruction, Student Role, and Content Depth*) and five constructs remained unchanged (i.e., *Assessment Type, Questioning Ecology, Instructional Strategies, Knowledge Acquisition, Learner Centrality*).

Change in *Curriculum*

There are four constructs that constitute the *Curriculum* factors. The construct of *Learner Centrality* began at Proficient Inquiry in 2007 and ended at Proficient Inquiry in 2012. Although it dropped in 2009, this research is focused on the long-term change over time. The construct of *Content Depth* began at the Developing Inquiry level in 2007 and increased 1 point to Proficient Inquiry in 2012. Two of the constructs, *Integration of*

Content & Investigation and *Organizing & Recording Information,* had a 2-point increase from 2007 to 2012.

Factor	Construct	2007	2009	2012	Total Change
Curriculum	C1- Content Depth	2.00	2.00	3.00	1.00
Curriculum	C2- Learner Centrality	3.00	2.00	3.00	0.00
Curriculum	C3- Integration of Content and Investigation	2.00	3.00	4.00	2.00
Curriculum	C4- Organizing & Recording Information	1.00	2.00	3.00	2.00
Curriculum	Total	8.00	9.00	13.00	5.00
Curriculum	Mean	2.00	2.25	3.25	1.25

Figure 14. Mary-Ann's inquiry scores on the constructs in the *Curriculum* factor

Integration of Content & Investigation increased 2 points, from Developing Inquiry to Exemplary Inquiry. In the first lesson, the students were actively investigating the aquatic insects, but there was a lack of follow-up to connect the activity back to the explanation session at the end. With prompting, the students reported observations. Those observations were not brought back to the focus question on what special features allow insects to survive in the water or to think about the students' prior knowledge of insects.

The construct *Organizing and Recording Information* scored at the Pre-Inquiry level in 2007 because the teacher was the only person who recorded any information during the lesson. In 2012, Mary-Ann's performance rose 2 points to a Proficient Inquiry level, because the students recorded their information in blank lined science notebooks. The class decided to collect data in a box and t-chart. The students drew their own chart in their notebook. Every child was responsible for collecting and recording data. As evidence of the students' ability to control how to record the information, Mary-Ann said to one girl during the explain phase of the lesson, "You did something different in your science notebook. At the bottom you added something about a prediction or an 'I wonder' statement. Tell the class about what you wrote."

Change in *Instruction*

The *Instruction Factor* remained Mary-Ann's highest scoring factor across all three data collection periods. Two of the five constructs within the *Instruction* factor, *Instructional Strategies and Knowledge Acquisition* scored a the Proficient Inquiry level. *Order of Instruction and Student Role* both increased 1 point across the five years of data collection. The greatest increase for Mary-Ann within the *Instruction Factor* was the construct of *Teacher Role*.

Factor	Construct	2009	2012	Total Change
Instruction	I1-Instructional Strategies	3.00	3.00	0.00
Instruction	I2-Order Of Instruction	3.00	4.00	1.00
Instruction	I3-Teacher Role	3.00	4.00	1.00
Instruction	I4- Student Role	3.00	4.00	1.00
Instruction	I5-Knowledge Acquisition	3.00	4.00	1.00
Instruction	Total	15.00	19.00	4.00
Instruction	Mean	3.00	3.80	0.80

Figure 15. Mary-Ann's inquiry scores on the constructs in the *Instruction* factor

Teacher Role received a score in 2007 at a Pre-Inquiry level, remained at the same level in 2009, and increased 2 points, reaching an Exemplary Inquiry level in 2012.

In both 2007 and 2009, Mary-Ann was the center of the learning activities. She asked many questions, but often followed up with her own short "lectures." For example, during the explanation of the moon phases in the 2009 lesson, Mary-Ann said, "I'm thinking. I don't know if you are thinking this with me," and then without waiting for student response, went on to describe how the moon changes over the month. In 2012, Mary-Ann "constantly and effectively acted as facilitator" (Marshall et al., 2008, Instruction sect). For example, while the students were reporting their observations of insects, a student made an incorrect assumption about the insect's mouthparts. After some questioning of the student, Mary-Ann responded to the class, "I think that is something we should wonder about together." She then began the facilitation of developing the students' thinking by suggesting the students continue to observe the insects' mouthparts as the insects got bigger.

Change in *Assessment*

The *Assessment Factor* constructs of *Prior Knowledge, Conceptual Development,* and *Student Reflection* all received scores of 2, Pre-Inquiry in both 2007 and 2009 and increased 1 point to a 3, Proficient Inquiry in 2012. The construct *Assessment Type* was Proficient Inquiry in 2007 and 2012, although it did drop 1 point in between, in 2009. The construct *Role of Assessing* was at a Developing Inquiry level in 2007, dropped one point to Pre-Inquiry in 2009, and then increased 3 points to obtain an Exemplary Inquiry level in 2012. This 3-point shift between 2009 and 2012 is the greatest increase in inquiry score across all nineteen constructs for all data collection periods.

Factor	Construct	2007	2009	2012	Total Change
Assessment	A1-Prior Knowledge	2.00	2.00	3.00	1.00
Assessment	A2- Conceptual Development	2.00	2.00	3.00	1.00
Assessment	A3-Student Reflection	2.00	2.00	3.00	1.00
Assessment	A4- Assessment Type	3.00	2.00	3.00	0.00
Assessment	A5-Role of Assessing	2.00	1.00	4.00	2.00
Assessment	Total	11.00	9.00	16.00	5.00
Assessment	Mean	2.20	1.80	3.20	1.00

Figure 16.Mary-Ann's inquiry scores on the constructs in the *Assessment* factor

In 2007, Mary-Ann scored Developing Inquiry on the *Role of Assessing* construct because she "solicited information from students to assess understanding" (Marshall, 2008, Assessment section). She asked questions during all phases of the lesson to check for a surface level of understanding. For example, she had the students list the insects' needs before moving into the *explore* portion of the lesson. In 2007, Mary-Ann's questions required little explanation from the students. At one point she asked, "How many children got a good idea about the moon's orbit around the earth?" She did not wait for a response, but moved into showing the students a computer image of the changing phases. In 2012, Mary-Ann not only "effectively assessed student understanding," but she "challenged evidence and claims made" and "encouraged curiosity and openness." (Marshall et al., 2008, assessment section). For example, when a student claimed that she observed 16 legs on her waxworm, Mary-Ann walked with her to a detailed diagram from a previous lesson. She asked the student to count the legs and talked with her about the other structures that might look like legs on a small insect. Mary-Ann also explicitly encouraged curiosity. At one point, she was observing with the children and said, "I am noticing that the waxworms look different than yesterday. Could you do some wondering about that?" Another time she asked a student, "Where might it (the insect) get its water?" When the student responded that he didn't know, Mary-Ann responded, "That might be something to wonder about."

Change in *Discourse*

The *Discourse* factor began as the lowest EQUIP Score and remained the lowest at every data collection period. The *Discourse* factor also took the greatest decrease in score on the 2009 lesson. The constructs *Questioning Level, Complexity of Questions*, and *Communication Patterns* followed the same pattern. They remained at the Developing Inquiry level from 2007 to 2009 and then increased 1 point in 2012. Two constructs had multiple point changes throughout the data collection. *Questioning Ecology* did not change from 2007 to 2012, but is a category that is significant to discuss because it decreased by 2 points in 2009 and increased by 2 points to return to Proficient levels of Inquiry for 2012. *Classroom Interactions* scored as Pre-Inquiry in both 2007 and 2009 and increased by 2 points to a Proficient level in 2012.

Factor	Construct	2007	2009	2012	Total Change
Discourse	D1-Questioning Level	2.00	3.00	3.00	1.00
Discourse	D2-Complexity of Questions	2.00	3.00	3.00	1.00
Discourse	D3- Questioning Ecology	2.00	3.00	3.00	1.00
Discourse	D4- Communication Pattern	2.00	2.00	3.00	1.00
Discourse	D5- Classroom Interactions	1.00	2.00	3.00	2.00
Discourse	Total	9.00	13.00	15.00	6.00
Discourse	Mean	1.80	2.60	3.00	1.20

Figure 17. Mary-Ann's inquiry scores on the constructs in the *Discourse* factor

The *Questioning Ecology* construct in both 2007 and 2012 was scored as Proficient Inquiry. In both lessons, Mary-Ann successfully engaged students in investigations and conversation. Both of these lessons involved students working in groups to observe insects. The students were on task and discussed their observations with their peers during the *explore* portion of the lessons. In 2009, however, the *Questioning Ecology* construct dropped down to a Pre-Inquiry level. During the lesson on the phases of the moon, the students did not successfully engage in discussions. During the exploration portion of the lesson, the children were in groups manipulating a model of the sun, earth, and moon. The majority of the conversations centered on management how to determine which child was going to work which piece of the model. In the explanation part of the lesson, one child commented that the moon might be in a different phase when you looked out different windows of your house. The teacher responded, "OK" and allowed another student to share a different experience. The teacher's ability to engage the students in conversation definitely jumped back up to proficiency in 2012. During the 2012 *explore* portion of the lesson, Mary-Ann invited students to participate in conversation explicitly. At one point, she said to a student, "Maybe talk to your group. See what they have compared to what you have and talk to each other about additional information you might find."

Change in time-usage indicators

The *time usage* indicators measure the percentage of time Mary-Ann or her students were engaged in particular characteristics of the lesson.

Cognitive codes. The student cognitive codes assessed the amount of time students spent at different levels of thought. In both 2007 and 2009, the students spent the majority of the lesson on 'lower-order' thinking. These activities often took the form of responding to knowledge-level questions. In 2012, the students spent half of their time in the ‘application’ level of thought, which included comparing observable information and working through problem-solving activities. Also in 2012, the students spent 15% of the lesson at the measure’s highest level of cognitive thought, including justifying, verifying, and interpreting knowledge.

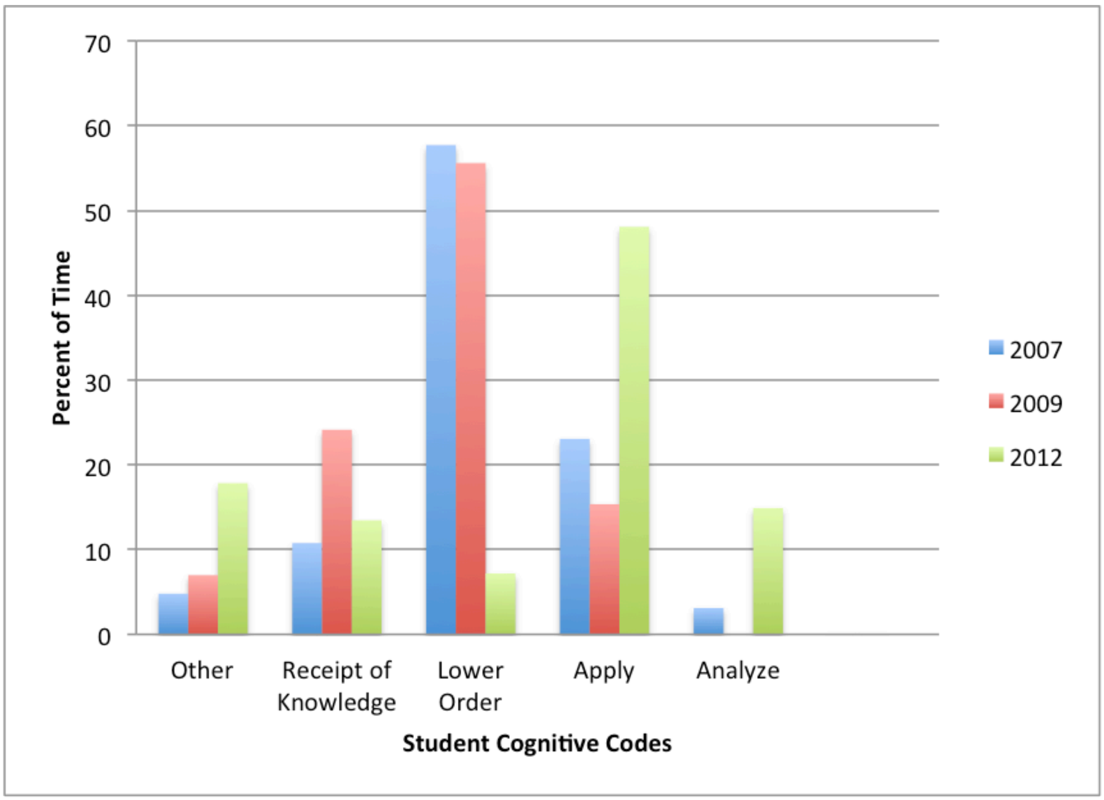

Figure 18. Time Mary-Ann’s students spent on different levels of cognition

Assessment codes. The data on time spent using different assessment techniques shows that Mary-Ann decreased her time spent ‘monitoring’ the class and increased the time spent on ‘formative assessment’ over the three data collection periods. From 2007 to 2009, she decreased the percentage of time ‘monitoring’ in half from 60% to 30%. In

2012, she spent only 10% of her time 'monitoring' the class. On the other hand, Mary-Ann increased her time on 'formative assessment' techniques about 10% each year. By 2012, she spent 35% of the time using 'formative assessment' strategies.

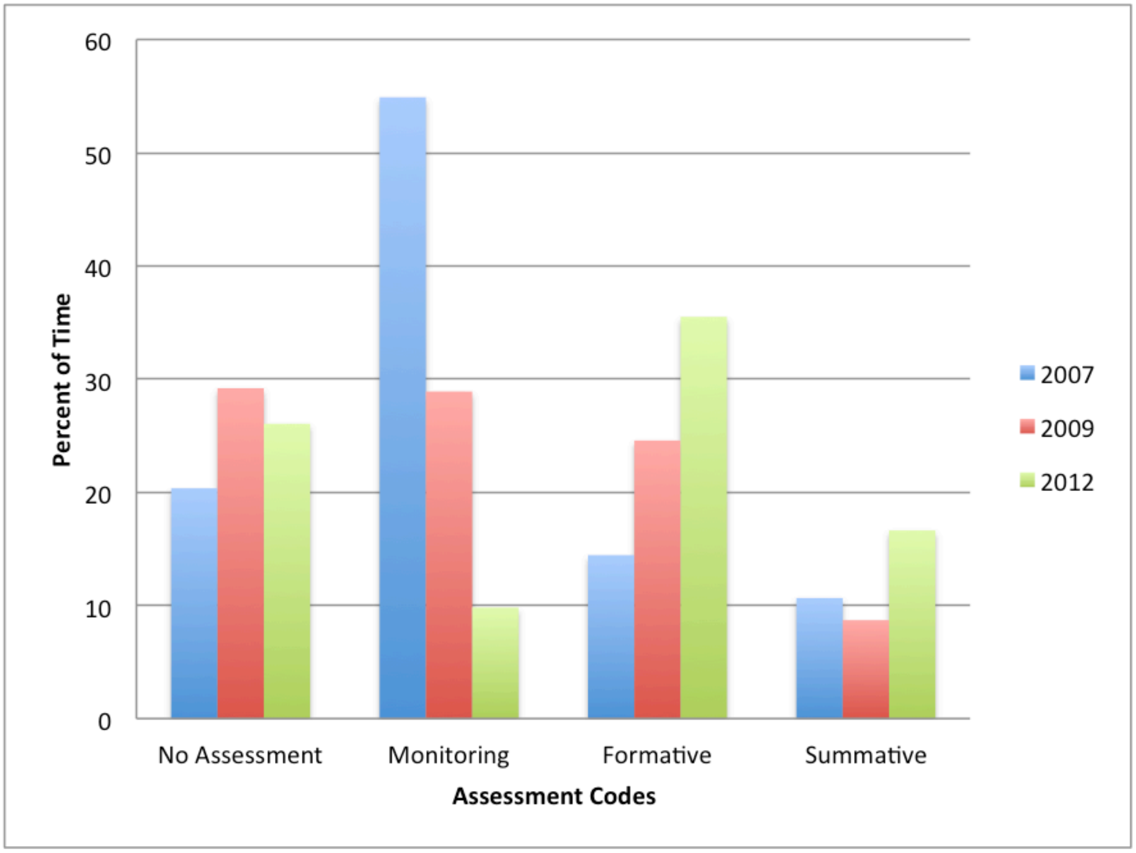

Figure 19. Time Mary-Ann spent using different Assessment strategies

Inquiry instruction codes. The *Inquiry Instruction* codes measured the time each lesson spent in the '*engage*', '*explore*', and '*explain*' portions of the lesson. The data are not consistent within or across the data collection years. In 2007, most of the time was spent on the '*explore*' portion of the lesson. In 2009, more than half of the lesson time was spent in the '*explain*' portion of the lesson. In 2012, there was almost an even spread with each portion of the lesson, lasting about one-third of the total lesson time.

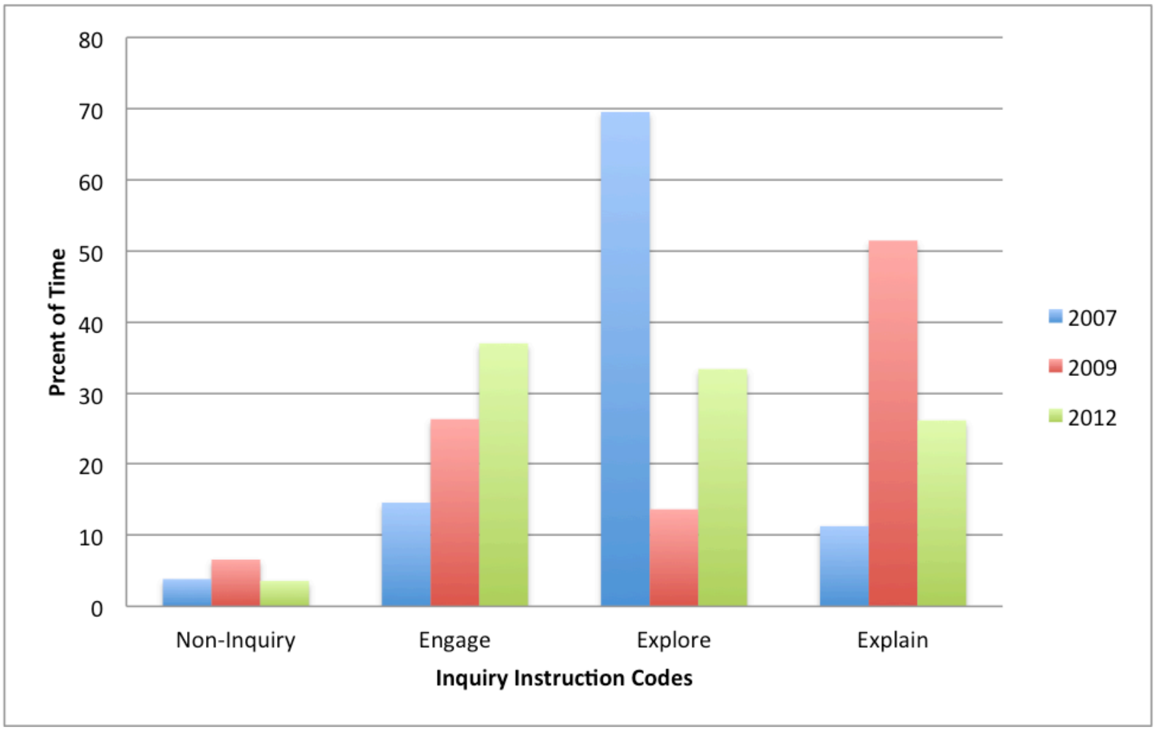

Figure 20. The amount of time Mary-Ann's class spent on each phase of the lesson

Mary Ann's self-perception of her change over time.

In the 2012 interview, Mary-Ann was asked if she taught science differently today than she did five years ago. Her response was, "Yeah, I feel I teach differently. In the beginning (starting with the curriculum and PD), we were given a way to teach and I was sorting that out and following it, but as time goes by you take it on as your own and you're more comfortable with it so you can take risks and try things out" (Mary-Ann, personal communication, August 1, 2012). She was aware of moving through what Hall and Hord (1987) call the "stages of concern." In the stages of concern teachers with a new curriculum model begin by asking themselves, "What is it and how does it work?" and as the teachers' thinking about the curriculum develops over time, they begin to ask, "How can I change it to make it better?"

Mary-Ann reflected on the kit curriculum over the three years of data collection. In 2007 when Mary-Ann was interviewed, she admitted, "I was a little apprehensive about the kits. They do take up a lot of time, but the children love them. They're acting more like scientists. It seems to be well worth the effort." (personal communication, Dec 1, 2007) In 2007, she also claimed that the materials could make it hard to teach inquiry science. She said it was challenging because "the physical set-up—making sure you're all set to go, sometimes readying the kits is hard. It's not that easy or fast to find what you want." Sometime between 2007 and 2009, Mary-Ann shifted her thinking about what was helpful and not helpful about the curriculum. When she was asked in 2009 what helped her teach inquiry she responded, "Well, I do really like the kits. Years before we tried to make our own kits and that was a huge undertaking to put that together and to have good lessons in it, and it's much more comprehensive now and so I do find that to be a lot easier." When she reflected on the past five years in her 2012 interview, Mary-Ann said, "the use of the kits instigated the change (in my teaching) . . . I used to do traditional stuff where they learned from me and then I tested them to see if they knew what I told them; now they learn for themselves…well, not for themselves. I guide their learning through asking questions to help them think more, investigate more, test more, to express their own thoughts and ideas. The materials have helped." (personal communication, August 1, 2012)

In 2012, Mary-Ann was asked to what she attributed the difference in her teaching from 2007 to 2012. She said that, beyond the kits and the professional development, "in the last few years science has had more importance in our schools." (personal communication, August 1, 2012) She attributes this to the inclusion of the expository writing program and to assessments. She said, "The district is keeping data over time for students. We discuss science at common planning time. We discuss trends and issues; that is healthy part of assessment." She then connected the expository writing to assessment "Writing has helped. Sometimes I thought the kids had to know it and had really learned it because we did it; then I look in their notebooks and I realized they didn't…back to another hands-on lesson…." She also said that the notebooks helped her to make meaning at the end of the lesson. "I used to run out of time, and I would sum it up. Now they are taking time to sum it up themselves and really think about it."

Mary-Ann shared her feelings about the future. She said, "Districts are concentrating so much on testing, testing, testing. It's not kid-friendly. I rather them be doing hands-on learning, especially at the younger years." On reflecting about her own future in regards to her teaching practices Mary-Ann said, "I think change happens in a steady way, although there might be bumps along the way. Good bumps when you are really excited about what you are doing" (personal communication, Mary-Ann, 2012).

Chapter 6

Case III: Hayley

This chapter presents the final case of the three teacher cases. Hayley taught fourth grade through the duration of the study timeline. She was on leave the first year the district joined the university collaborative so she did not start with professional development or have experience using the curriculum until the 2007/ 2008 school year. Her video lesson in 2009 was from the STC Land and Water module in which students observe how slope affects the formation of a river. In 2012 her lesson involved conducting a fair test using rubber band energy and constructed Kinex™ vehicles from the STC Motion and Design module.

The chapter is divided into two major sections: Descriptive Narratives and Change in Inquiry Practices and Beliefs. The Descriptive Narrative section describes the sequence of events that Hayley experienced over the course of five years. It begins with Hayley's professional development and curriculum experiences in science prior to the study timeline. A timeline of Hayley's professional development experiences, curricula experiences, and videotaped lessons for the five years study period provides the reader with a visual account of the events that may have influenced the teacher practices and beliefs. Next, each event is described through rich, detailed, written descriptions. The narrative is organized chronologically as depicted in the timeline.

The videotaped lesson descriptions are partitioned into three parts *engage, explore,* and *explain*. These phases of a science lessons are described by the time usage, Inquiry Component Instruction Code from the EQUIP. Throughout the videotaped lesson description there are factors followed by an alphanumeric combination in parentheses.

For example, the following excerpt is taken from Hayley's 2009 lesson narrative: *Hayley began with a review of the last lesson by asking, "Who remembers what we did on Tuesday with the cups?" (Assessment 1-3). Assessment* refers to the factor, the '1' signifies the first construct in the *Assessment* factor called *Prior Knowledge*, the number after the dash, in this case a '3', identifies the rubric score. So in this example, the description of the first construct in the *Assessment* factor at a level 3 reads, "Teacher assessed student prior knowledge and then partially modified instruction based on this knowledge". Hayley earned a rubric score of 3, Proficient Inquiry, because she asked the students about a previous experiment and the design plan for the current lesson as the students shared their thinking.

The second chapter section, Change in Inquiry Practices and Beliefs, presents the quantitative and qualitative outcome variables, including the composite inquiry scores from the four EQUIP factors over time; the change in scores from constructs in each of the four factors, *Curriculum, Instruction, Discourse,* and *Assessment*; the change in time usage indicators; and the change in the teacher beliefs of teaching inquiry.

Descriptive Narrative

Initial Professional Development Opportunities

Hayley reported having a few college classes when she was in preparation to be a teacher. She had one methods class that "that was combined between math and science." She also took multiple science classes, although she had a hard time recalling them. The transcript of her first interview (2009) showed that when she was asked about her content courses, she stumbled over her words. "Yes, I took biology. I took ecology and I thought--no that's geography. I think that was it--ecology and biology, if I remember.

Ooh, yes I took--I don't know if it was called--I know it had to do with like rock and minerals, but I don't know if that's what the class was called." She did not recall any other professional development before joining the collaborative in 2006.

Hayley was not filmed in 2007. Her own perceptions were that if she had a video of a lesson from 2007 analyzed, she would have scored much lower. She said she had "completely changed the way we taught" for the 2009 video lesson. When she was interviewed in 2009, she was asked "What are some of the elements of an inquiry science lesson that you feel makes it different from other types of science lessons?" she explained how she had recently changed her thinking about inquiry. She said, "Well it's funny because really at this very last follow-up session that I went to, I didn't feel like I knew that much about inquiry science at all. Just this past couple of weeks we started really trying to use inquiry science and I feel it's so much more different because the students have a lot more say in what they're investigating and how it's going to be investigated and I think they internalize the science so much more--rather than us giving them a question, telling them how to set it up. I don't actually think they learn those process skills the same way." (Personal communication, Hayley, December 2, 2009)

Hayley's professional development opportunities 2006 to 2009

Hayley's professional development timeline began in 2007, two years before her first lesson was videotaped for research. In the 2007 school year Hayley attended her first two initial workshop for fourth grade *Full Option Science System* (*FOSS) Magnetism and Electricity* and *Science and Technology for Children (STC) Motion and Design*. She taught the two fourth grade kits in that year. In the school year of 2008-2009 Hayley moved to teach third grade and attended the three initial trainings for the third grade kits, *FOSS Structures of Life*, *FOSS Water*, and *STC Sound*. Experienced teachers facilitated the workshops to help Hayley and her colleagues become familiar with the modules. In the beginning of 2009 Hayley moved back to fourth grade and attended her final initial workshop on the *STC Land and Water* kit. She taught the three fourth grade kits for the second time. In the beginning of Hayley's third year in fourth grade she attended her first follow-up workshop for *STC Motion and Design.* In this workshop she had the opportunity to participate in the lessons from the units, modeled by experienced teachers and to reflect on the content and pedagogy with other professionals. Her total professional development before being filmed in 2009 was 35 hours. All the professional development hours were spent in curriculum-related workshops.

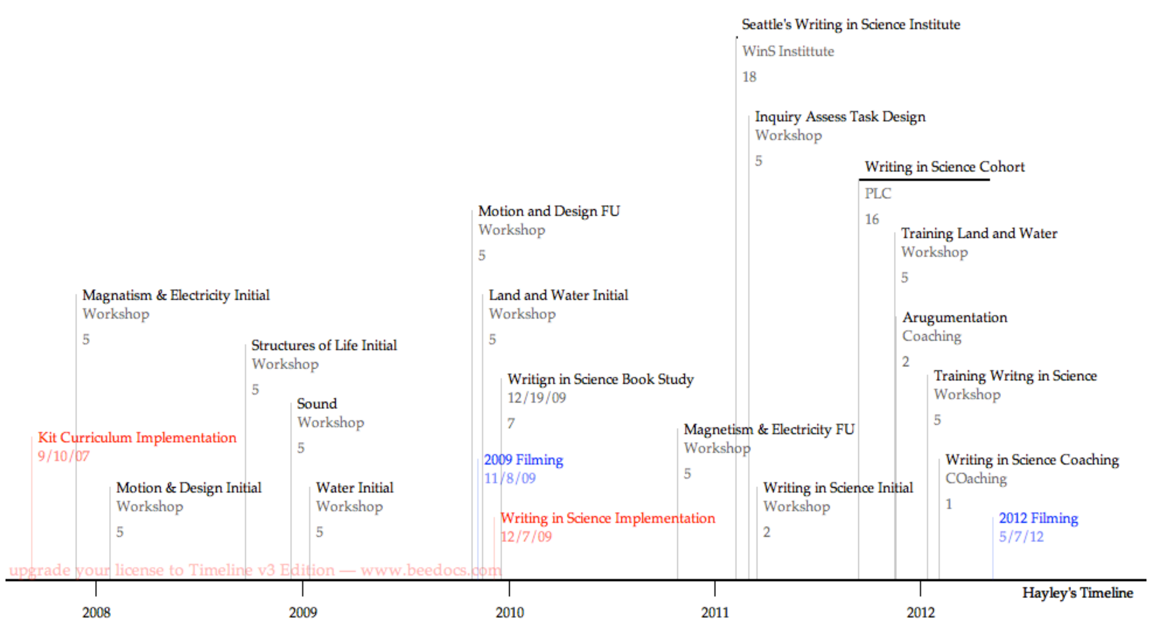

Figure 21. A timeline of professional development experiences and videotaped lessons

Description of Hayley's lesson 2009

The students were seated at the rug in the front of the room. Hayley began with a review of the last lesson by asking, "Who remembers what we did on Tuesday with the cups?" (*Assessment* 1-3). One student responded that when they tried to use the large-hole cup as the source of the river the soil was too dry and a stream didn't form, instead the water remained on top of the land.

Hayley then prompted the students to connect what they observed previously to what they were going to focus on during that day's lesson by asking, "Think about what we noticed in our other lessons about water running down hill. What did you notice?" (*Instruction* 5-3). She encouraged students to think and share. Students reported out different ideas (*Discourse* 3-3). The students clearly stated that water runs faster when it goes downhill. A few children thought that the water might move too fast and not make a deep river. Hayley encouraged the students to think about the word *force* (*Curriculum* 1-3). She allowed students to struggle with their thinking and encouraged the students to critique each other's thinking (*Discourse* 2-3). The following conversation demonstrates how this was done.

Student-"I think the faster it goes the more erosion will happen".

Teacher- "Does anyone agree with Andrew? Give me a 'me too' sign" Some students raise their hand with thumb and little finger extended and shake it back and forth. The teacher comments, "Some agree, some don't".

Student-"I think that I agree with Mason and Andrew but not as much with Andrew because when he said more erosion…I think Mason is right that it will not absorb but if it is going fast enough it might push some land with it."

Hayley then pointed to a chart with 'Today's Objectives' written at the top. Below were two bullet points. She pointed to each bullet and said, "You will learn how slope affects the formation of a stream and the amount of erosion that occurs and you will practice how to control variables and set up a fair test" (*Curriculum* 3-4). She then turned the students' attention to the white board where a question was written. The question was labeled 'Focus Question'. Hayley read the question aloud, "How does the change in the slope of a hill affect the erosion caused by flowing water?" She then engaged the students in the design process of the *explore* part of the lesson (*Curriculum* 2-3). She said, "In order to compare our results when we do this experiment we need to set up a fair test."

Hayley then prompted the students to think about what variable they will change, what variable they will measure, and what variables they will keep the same (*Instruction* 1-3). She persisted with her questioning when the students struggled to develop a fair test plan. The students decided they would measure the width, depth, and length of the delta (*Instruction* 4-3). One student also suggested the class should collect data on the speed of the water. Hayley responded, "How will we measure that? Scientists can't eyeball data but they can make observations" (*Discourse* 5-3).

About 20-minutes into the lesson, Haley visually modeled the set up for materials that the class had developed (with lots of prompting) (*Instruction* 2-3). She let the students know whether they were creating the slope of their stream table with two books, one book, or no books. She instructed one person from each group to create the data collection chart while the other students set up the stream table (*Curriculum* 4-2).

Explore. Students took about six minutes to set up the data collection chart and get their stream table to the standard formation. Hayley rang a bell to get the attention of the class. She informed the students that when everything was set up correctly a teacher would bring a 2-liter bottle of water to the group. Once the water was delivered, the students worked together to actively investigate (*Instruction* 4-3). One student held the bucket to catch the runoff, another student held the source cup steady, and the third student poured the water. The teacher spent most of her time monitoring the students' use of the materials. She corrected the position of the stream tables to ensure they would not slide off the desk, or asked students to raise the bucket up so the mud would not splash out. She commented more than asked questions on the formations in the stream table. For example she said, "Wow, look at that, it is like a canyon" (*Instruction* 2-3). Most groups reacted excitedly to the observations of the river formation and shared their observations openly with each other. Hayley asked a few knowledge level questions like, "What are you measuring?" and "That is not your stream…do you remember how to do this?" (*Assessment* 2-3)

Explain. Hayley rang the bell again to get the students' attention. She said, "I'm noticing some really cool things as I walk around the room. I would like everyone to come to the floor to share their measurements and then we will walk around the room to see everyone's stream tables." At the rug the students shared their data and Hayley recorded it on a class data chart. She then said, "Let's take a minute (to look at our data) because after scientists have a hypothesis and they come up with a plan and they collect their data, then they have to analyze their data and come to a conclusion." (*Curriculum* 3-4) Hayley then facilitated the conversation about the data, through asking questions. Questions she asked made the students connect the process with the content. For example she asked:

“What did someone with three books, notice? And then let’s compare that to what happened with one book,”
“Why do you think our data are all over the place? What could have happened?” and “Which measurement really shows something?” (*Discourse* 2-3).
Hayley led the students to discover that the depth and the width of the stream got bigger as the slope was greater.

She brought the class attention back to the focus question and asked, “What conclusion can we make?” (*Assessment* 5-3). Only a few students raised their hands. One student reported that “The greater the slope, the more erosion,” but did not back up the statement with specific data (*Discourse* 4-2). Hayley also asked why the investigation was a fair test (*Curriculum* 3-4). Hayley had to hint and prompt the students to answer her questions about what was kept constant and what they measured. She then closed the lesson by allowing the students to walk around and look at the different stream tables before they returned to their seats.

Hayley’s professional development experience from October 2009 to May 2012

Hayley was introduced to the science writing approach by her principal around the time of her 2009 videotaped lesson. The principal of her school bought copies of Fulwiler’s *Writing in Science* for every grade level team. The teachers in the school used it for a yearlong ‘book study’ and got together for one hour once a month to discuss a chapter and talk about what they had tried in their classroom.

In the school year of 2010-2011 Hayley attended a variety of professional development sessions. In November, Hayley attended her second Follow Up Curriculum

Workshop for FOSS *Magnetism and Electricity*. In February she went with six other teachers, three principals, and one professional development provider from the collaborative to Seattle's Writing in Science Institute. During the institute the *Writing in Science* program was explained and modeled by the creator and author of the program Betsy Rupp Fulwiler (2007). Hayley spent some time observing Seattle public school teachers who had been using the program. She spent time with Seattle's lead teachers planning her own lessons for when she returned to her school. In March, Hayley attended the Inquiry Task workshop. The intention of the workshop was to offer teacher strategies that teachers could use to help their students become familiar with the format and the terminology on the statewide testing. Later in March the professional development providers visited Hayley's school with a coaching session focused on developing science-writing strategies in the classroom.

In the beginning of 2011-2012 school year Hayley joined a group of over twenty multi-grade level teachers from four different districts in a book study of Betsy Rupp Fulwiler's book, *Writing in Science in Action*. Hayley spent a total of sixteen hours analyzing the text with her colleagues and discussing and sharing new strategies for the classroom. Also in the same school year Hayley became a trainer for two workshops. She planned for and ran an initial workshop for the STC *Land and Water* kit. She also supported the professional development providers in Initial Science Writing Workshop for fourth grade teachers new to the program. Hayley also participated in two coaching sessions. One session involved an hour of classroom coaching that centered on the strategies written in *Writing in Science*. She received feedback on what was working well and what next-step-strategies might help in her classroom. The other session involved a one-hour planning period on incorporating argumentation into science lessons.

Before going into the videotaped lesson in May of 2012, Hayley had received an additional sixty-six hours of professional development. She was immersed in the protocols described in *Writing in Science*. She had already spent time in multiple formats of professional development (i.e., workshops, institute, coaching, and professional learning communities). Going into the 2012 lesson, Hayley had a total of 101 hours of professional development.

Description of Hayley's lesson 2012

The lesson was adapted from lesson seven out of the STC *Motion and Design* module in which the students explore the concepts of stored and potential energy. The students compared the number of times they wrapped rubber band around the axle of the rear wheels and the distance the vehicle rolled. As usual, Hayley co-taught this lesson with the only other 4th grade teacher in the school. The lesson took place in the school gymnasium so that the students would have space to allow their vehicle to travel certain distances. This science lesson was not the first lesson the students conducted in the gym. Hayley had explained previous to the taping of the lesson that the lesson would be conducted differently than normal because they were using this lesson to help the students learn the format of the high stakes inquiry test. Hayley said the biggest difference would be that the students would write their predictions and design their own data collection chart on the next blank page in their science notebooks.

Engage. When the lesson began, forty-eight children filed into the gymnasium and sat on the floor in front of the classroom easel. Hayley asked what the students had observed in the previous lesson during which the students had explored how to use a rubber band to move a *Kinex™* vehicle (*Assessment* 1-3). Students eagerly shared their previous understanding and provided reasoning for their thinking (*Discourse* 2-4). The teacher then directed the students to the lesson's focus question written on chart paper (*Curriculum* 3-4). She read it aloud, "What effect does the number of winds have on the distance the vehicle will travel?" The class spent three minutes dissecting and analyzing the focus question (*Instruction* 5-4). Hayley asked questions like:

"What are our variables? What will we be changing?"

"Who can think of some qualitative words we could use to describe the number of winds?"

"Which is the variable we will measure?" (*Discourse* 1-4).

The teachers then prompted the students to discuss a prediction with justification. Hayley provided the frame "I think..because" and reminded the students to use the variables and the qualitative language they had just discussed (*Assessment* 3-4). The students easily used the *turn and talk* activity to share their thinking with their peers (*Discourse* 4-3). The students then were instructed to write their predictions on the 'test-prep' worksheet (*Curriculum* 4-2).

After the predictions were written, the class together developed a fair test to gather data on the question (*Instruction* 4-4). The plan involved deciding which part of the vehicle to place at the starting point, how many trials they should conduct for each number of winds variable, and how they should measure the distance if the car did not roll in a straight line along the cash register tape (*Curriculum* 3-4). Another *turn and talk* engaged the entire class in problem solving to find the most accurate way to measure the distance the vehicle traveled (*Discourse* 3-4). Hayley told the class that "this lesson is different because" they will not be designing the data collection chart or determining the number of winds because the worksheet provides that for them. Hayley's co-teacher wrote the class-decided procedure on a piece of chart paper and told the students they could refer to it in case they need "help remembering" (*Instruction* 3-4).

Explore. The students worked for 25 minutes. They were spread out across the gym floor in groups of three (*instruction* 4-4). Each group had 16 feet of white cash register tape taped to the floor, three sets of three different colored sticky dots, a measuring tape, and the *Kinex*™ vehicle with a rubber band. They performed three trials by winding the rubber band two times, four times, and eight times around the vehicles' back axles. They placed coordinated colored dot stickers on the cash register tape to represent the distance the car rolled and the students measured and wrote the distance on the sticker (*Assessment* 2-4).

Hayley moved around the gym. She squatted down to check the groups' understanding and asked the students questions. Hayley's questions alternated between monitoring and formative assessment (*Assessment* 4-3). An example of monitoring occurred when three students returned to class from being out of the room with a special educator. Hayley helped them get to their groups and made sure they understood what they needed to do. Other times she used formative assessment techniques while she was talking with the students. For example, she asked many groups what they were noticing about the differences in the distance between each trial with the same number of winds (*Assessment* 2-4). At one point she encouraged the group to think together, "Why don't you have a discussion in your group about (the difference between the distance within a set of trials) I would be interested to hear your thinking about it" (Discourse 3-4; *Assessment* 5-4). These students engaged in a productive evidence-based argument and concluded that the rubber band looses some potential energy each time it is used.

Explain:

The students removed their cash register tape from the floor and taped the strips of paper with the colored dot stickers on it up on the wall. The red, green, and blue data points created an impressive wall of information (*Curriculum* 1-4). Hayley asked the class to look at the data and use qualitative words to answer the focus question. Many hands went up. The first student who was called on accurately summed up a hypothesis: that when there are more winds of the rubber band, then the farther the car moves. Students then actively created a line plot graph by finding the middle number of each of their three trials and record that with another sticky dot on a line plot graph (*Instruction* 2-4; *Curriculum* 3-4). As the students placed their data points on the chart, they realized that eight turns of the rubber bands went farther than Hayley planned for on the graph. The students estimated how far off the graph they should put their stickers. Hayley asked the students to critique her graph design and warned them about the accuracy (*Assessment* 2-4; Discourse 2-4). Hayley had her students look at the line plot graph quantitatively. The students then helped her find the middle number for each of the different number of winds. Then Hayley, using word wall cards attached the words '*only', 'but'*, and '*In fact'* on the graph. The word '*only'* was put over the median (99) and the word '*but'* was put over the 8 winds median (377cm). Hayley asked the class What we should do with the two numbers (subtract) then asked "What will that tell us?"

and “Who can give me a statement using the words only, but, and infact, really scientific like.” (*Instruction* 3-4)

Again, many hands went up. The student called on injected many “ums” as he thought through the complex analysis. He said, “With two winds the car, um, went 99, um, only 99 cm but with 8 winds the car went 377cm. In fact, the car went, um, 179 cm more.” Hayley encouraged the student to add more of his thinking by providing the prompt, “Give me a therefor I think’”. The student said, “Therefore, I think the more winds the farther the car will go.” (*Instruction* 2-4) Teacher followed up with “fabulous scientific thinking.”

Hayley ended saying they will spend more time talking about the reasons why the stored energy and kinetic energy were different in the trials and the students would write a data analysis piece (*Assessment* 1-3).

Change in Inquiry Practices and Beliefs

The overall EQUIP scores from Hayley’s lessons increased from 2009 to 2012, the two points of data available for this participant. In 2009, the mean of all four factors was 2.9 out of 4.00. This score is just within the ‘proficient’ inquiry level on the measure (Marshall et al., 2009). In 2012, Hayley’s lesson increased by .8 to an average of 3.6 out of 4.00 on all the inquiry factors. The rubric score of 3.6 puts Hayley’s 2012 lesson in the ‘exemplary’ inquiry level on the measure.

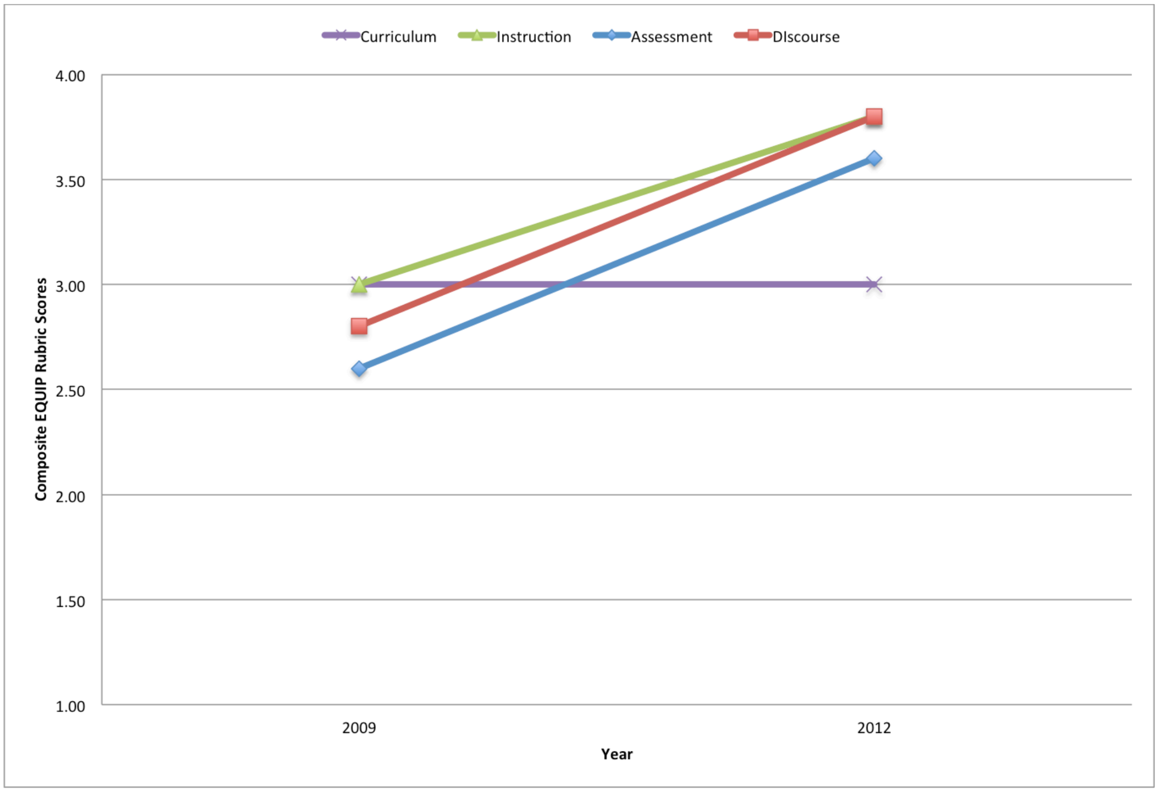

*Figure 22.*Hayley's Composite EQUIP Rubric Scores

The range of all Hayley's factor scores in 2009 was from 2.6 to 3.0, whereas the range of all factor scores in 2012 ranged from 3.0 to 3.8. In 2009, the highest scoring factors were *Instruction* and *Curriculum*, and the lowest scoring factor was *Assessment*. In 2012, the highest scoring factors were *Discourse* and *Instruction*, whereas the lowest scoring factor was *Curriculum*. The factors of *Instruction, Assessment, and Discourse* followed similar rates of increase between 2009 and 2012. The *Curriculum* factor remained the same between the two data collection periods.

The change of *inquiry levels* in each construct across the two data collection periods ranged from no points to a two-point increase. Of the nineteen constructs, one construct increased two points (i.e., *Student Reflection*), twelve constructs increased by one point (i.e. *Conceptual development, Assessment type, Role of Assessing, Questioning Level, Complexity of Questions, Questioning Ecology, Communication Patterns, Classroom Interactions, Order of Instruction, Teacher Role, Student Role, Knowledge Acquisition*), and six constructs remained unchanged (i.e., *Prior Knowledge, Instructional Strategies, Content Depth, Learner Centrality, Integration of Content and Investigation,* and *Organizing & Recording Information*). The construct that demonstrated the greatest change was *Student Reflection*.

Change in *Curriculum*

There are four constructs that constitute the *Curriculum* factors. The constructs *Learner Centrality*, *Integration of Content and Investigation*, *Organizing and Recording Information,* and *Content Depth* did not change between 2009 and 2012. The teacher commented that the construct of *Organizing and Recording Information* would have had a different score if the video lesson had not been on the day it was. Hayley said the students would have worked together to develop a data collection chart and recorded their information on the next blank page in their notebooks. They did not do this because the purpose of the videotaped lesson was to give students practice at responding to the statewide science test questions, as required by the district.

Factor	Construct	2009	2012	Total Change
Curriculum	C1- Content Depth	3.00	3.00	0.00
Curriculum	C2- Learner Centrality	3.00	3.00	0.00
Curriculum	C3- Integration of Content and Investigation	4.00	4.00	0.00
Curriculum	C4- Organizing & Recording Information	2.00	2.00	0.00
Curriculum	Total	12.00	12.00	0.00
Curriculum	Mean	3.00	3.00	0.00

Figure 23 . Hayley's inquiry score on the constructs in the *Curriculum* factor

Change in *Instruction*

The mean of the five constructs in the *Instruction* factor gained .8 points over time and remained one of Hayley's highest scoring factors across both data collection periods. In 2009, all five constructs scored at the 'proficient' inquiry level. In 2012, four of the five constructs increased to the 'exemplary' inquiry level. *Instructional Strategies* remained the same across both videotaped lessons because students were engaged in activities that developed conceptual understanding. The constructs of *Order of Instruction, Teacher Role, Student Role, and Knowledge Acquisition* increased 1 point across the five years of data collection. In both 2009 and 2012, the class actively investigated before the meaning was made. In 2009, the teacher recorded and reported the students' thinking, but in 2012 the students took a more active role in developing the graph and reporting the lesson's content. The teacher in 2012 acted as a facilitator with more consistency and effectiveness. She was more successful in facilitating the conversations that led to the lesson design, she asked questions during the investigation that promoted depth in student thinking and planned for students to participate in the development of graphs during the 'explain' portion of the lesson. The students in 2012 acted more freely, as scientists would. In 2009, the teacher continually prompted the students to plan, investigate, collect data, and evaluate their findings. In 2012, the students got their materials and set up their experiments with little to no prompting from the teacher. They talked openly about their predictions and stayed focused on the experiment throughout the lesson.

Factor	Construct	2009	2012	Total Change
Instruction	I1-Instructional Strategies	3.00	3.00	0.00
Instruction	I2-Order Of Instruction	3.00	4.00	1.00
Instruction	I3-Teacher Role	3.00	4.00	1.00
Instruction	I4- Student Role	3.00	4.00	1.00
Instruction	I5-Knowledge Acquisition	3.00	4.00	1.00
Instruction	Total	15.00	19.00	4.00
Instruction	Mean	3.00	3.80	0.80

Figure 24. Hayley's inquiry scores on the constructs in the *Instruction* factor

Change in *Discourse*

The mean of the five constructs within the *Discourse* factor changed one rubric point from 2009 to 2012. Each of the five constructs increased one rubric point, so that in 2012 the *Discourse* factor had the highest mean score of 3.8 along with the *Instruction* factor. The constructs *Questioning Level, Complexity of Questions, Questioning Ecology,* and *Classroom Interactions* were at a 'proficient' level of inquiry in 2009 and increased to 'exemplary' inquiry in 2012. *Communication Patterns* also increased one point. The lessons started at a 'developing' inquiry level and increased to 'proficient' inquiry. Hayley engaged students in conversation and asked questions in both 2009 and 2012 that required students to justify and explain. In 2012, Hayley was more consistent with engaging students in conversations. Twice during the lesson she used a "turn and talk" strategy that allowed all students to engage in discussions and reflections. Hayley challenged students to critique each other's thinking. For example, four different students reported ideas on how to measure the distance the vehicle traveled. Hayley asked the class to think critically about the solutions and to choose one solution that would yield the most accurate results. Additionally, Hayley asked the class to critique her own thinking. When the line plot chart was not long enough, she challenged the class to critique her design and the possible outcomes of inaccurate results.

Factor	Construct	2009	2012	Total Change
Discourse	D1-Questioning Level	3.00	4.00	1.00
Discourse	D2-Complexity of Questions	3.00	4.00	1.00
Discourse	D3- Questioning Ecology	3.00	4.00	1.00
Discourse	D4- Communication Pattern	2.00	3.00	1.00
Discourse	D5- Classroom Interactions	3.00	4.00	1.00
Discourse	Total	14.00	19.00	5.00
Discourse	Mean	2.80	3.80	1.00

Figure 25. Hayley's inquiry scores on the constructs in the *Discourse* factor

Change in *Assessment*

The mean of the five constructs in the *Assessment* factor increased one point between 2009 and 2012. The construct of *Prior Knowledge* stayed at a 'proficient' inquiry level in both 2009 and 2012. The constructs *Conceptual Development, Assessment Type,* and *Role of Assessing* all increased one point between the two lessons.

In both 2009 and 2012, Hayley used authentic methods to measure student understanding, and expected students to demonstrate evidence of critical thinking and provide explanations for their claims. In Hayley's 2012 lesson, she was more consistent and effective. For example, before the students wrote their predictions she had the class turn and talk through their thinking. She provided them the frame "I think . . . because . . ." which encouraged the students to provide evidence. During the turn and talk, Hayley conversed with a few groups. She challenged them to think differently by asking "But what if" questions. Also, at the end of the lesson, she asked the students who reported to add their own thinking.

Factor	Construct	2009	2012	Total Change
Assessment	A1-Prior Knowledge	3.00	3.00	0.00
Assessment	A2- Conceptual Development	3.00	4.00	1.00
Assessment	A3-Student Reflection	2.00	4.00	2.00
Assessment	A4- Assessment Type	2.00	3.00	1.00
Assessment	A5-Role of Assessing	3.00	4.00	1.00
Assessment	Total	13.00	18.00	5.00
Assessment	Mean	2.60	3.60	1.00

Figure 26. Hayley's inquiry scores on the constructs in the *Assessment* factor

The construct of *Student Reflection* had the greatest increase of all nineteen constructs. In 2009, the construct scored at a 'developing' inquiry level, whereas in 2012, it scored at an 'exemplary' inquiry level. In 2009, Hayley often asked her students to reflect on their learning during the 'explain' portion of the lesson. Hayley asked many questions that might have facilitated students to think beyond the knowledge level, but the students' responses were low. For example, after reviewing the data, Hayley asked, "What conclusion can we make?" Only three hands went up and a student responded with a statement that parroted what Hayley had said earlier, "The greater the slope the more erosion." The student did not provide reasoning for his thinking. In 2012, Hayley encouraged her students to reflect on their learning throughout the lesson. The greatest difference was during the '*explore'* portion of the lesson when Hayley asked the groups questions to make them think about what their data might mean. She asked them to discuss with each other their ideas about why the vehicle traveled different distances with the same number of turns and asked them to predict how far they thought the vehicle would travel if they made more turns.

Change in time-usage indicators

The time usage indicators measure the percentage of time Hayley or her students were engaged in particular characteristics of the lesson. The student *Cognitive* codes assessed the amount of time students spent at different levels of thought. The higher levels of cognitive thought, including 'application' and 'analysis', increased from the 2009 lesson to the 2012 lesson. In fact, in 2012, the students spent half of the lesson verifying, justifying, analyzing, or interpreting information, whereas in 2009, they only spent a third of their lesson at this high level of thinking.

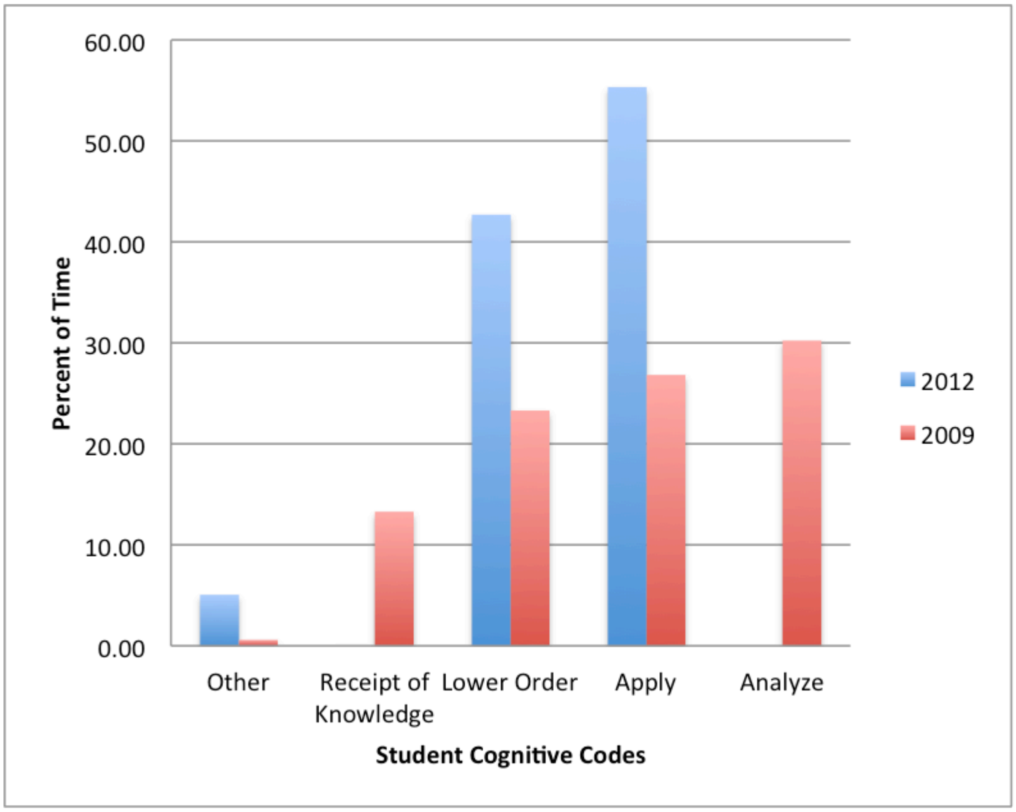

Figure 27. The time students spent at different levels of cognitive thought in Hayley's lessons

Time that Hayley spent using different assessment techniques is shown in Figure 28. In 2009, Hayley spent more time on 'monitoring' than she did in 2012, whereas in 2012, she spent more time on 'formative' and 'summative' assessments than she did in 2009. Therefore, Hayley shifted her use of assessments to decrease the time she spent 'monitoring' the lesson and increase the time she spent assessing students in a formative and summative manner.

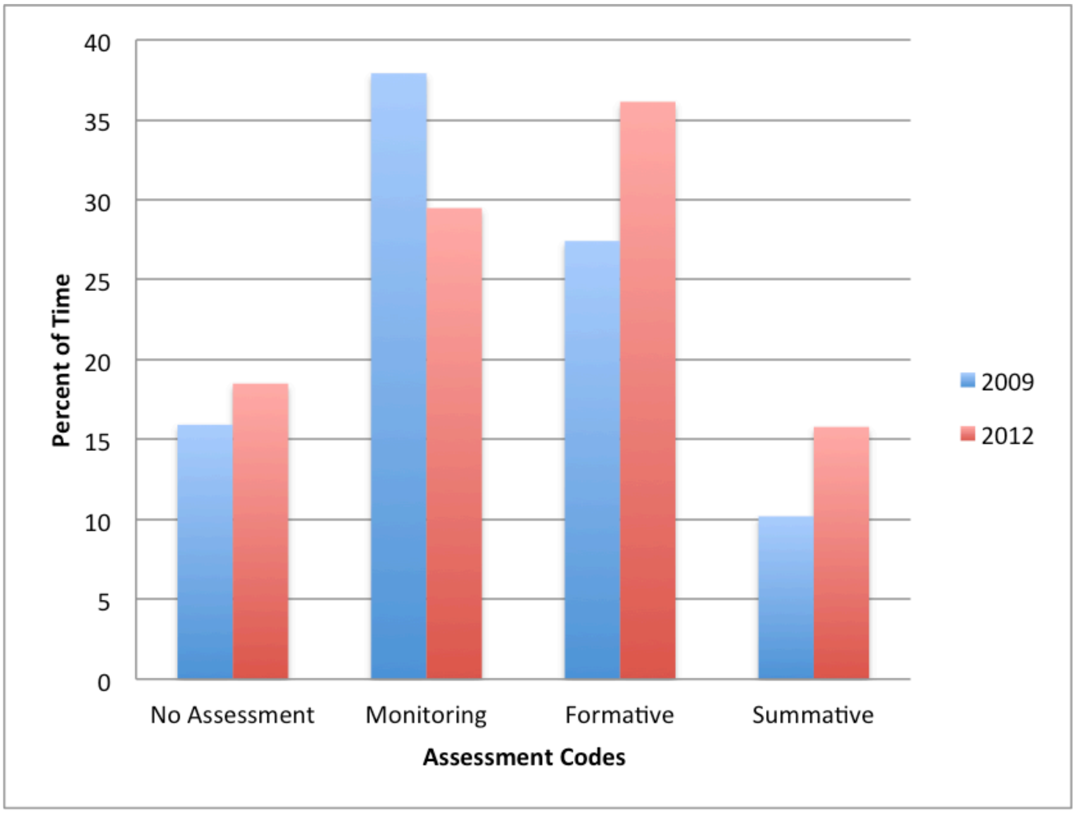

Figure 28. Amount of time Hayley spent using different assessment strategies

The *Inquiry Instruction* codes measured the time each lesson spent in the 'engage', 'explore', and 'explain' portion of the lesson. During the 2009 lesson, Hayley's class spent almost equal time in all three phases of the lesson. In 2012, the class spent more time in the 'engage' portion and less in the 'explain' portion. When Hayley was asked in her 2012 interview what she would have done differently if she could do the lesson again she said, "I would not have spent as much time in the engagement. We could have spent more time at the end. I would have them turn and talk, and we could have come up with more reasoning behind what they discovered. I would have spent more time discussing the data before the graph. Scientists need to understand it." (Hayley, personal communication, August 1, 2012).

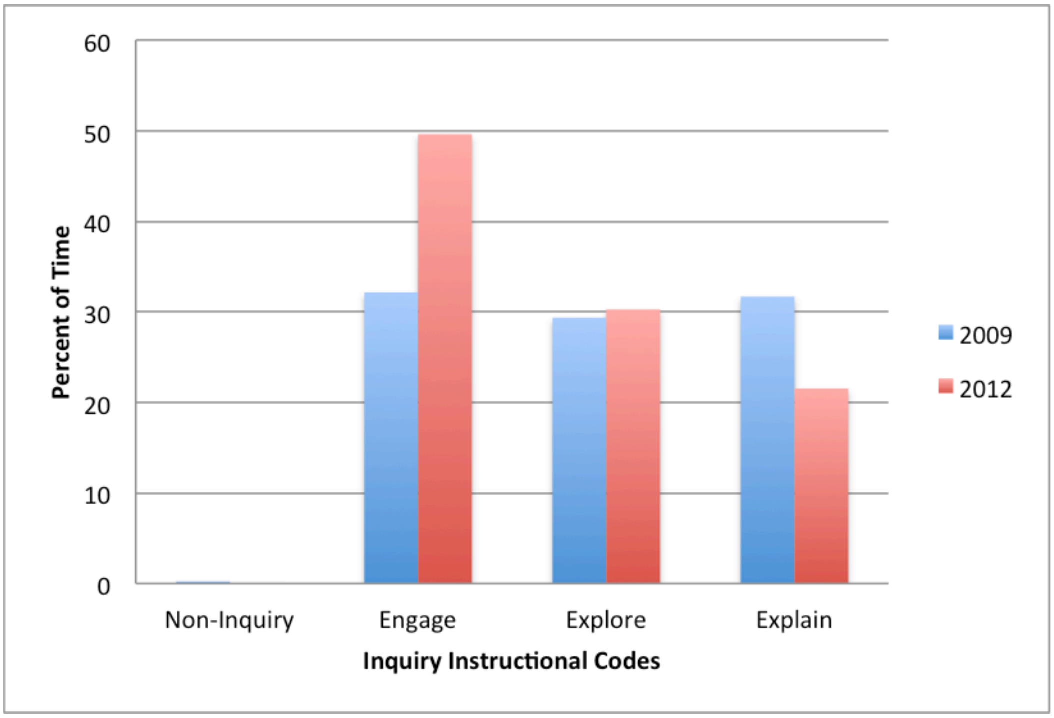

Figure 29. Amount of time Hayley's class spent in different phases of each lesson

Hayley's self-reflection of her change over time

In the 2012 interview, Hayley was asked if she taught science differently today than she did five years ago. Her response was: "Very different. Where shall I start? The time dedicated to science has tripled. In the past, we would teach each lesson as it was written; there was no connection between lesson and no writing in science unless they were answering questions on a worksheet. There was very little data analysis and no deep discussions. We now spend a lot more time planning and teaching science. We give the students a lot more time to think, explore, and write. Something we did not do five years ago." (Hayley, personal communication, August 1, 2012).

Hayley provided specific examples about how her teaching has changed. When she reflected on how she felt about teaching science five years ago, she responded: "I would say that science was hard to teach because I didn't really know what I was doing. When the kits came, they definitely made it easier, but our instruction was not that much better. We were not using the curriculum well. I didn't like it that much. It was just another subject to teach" (Hayley, personal communication, August 1, 2012).

Hayley was then asked to explain what she thought supported her transition to teaching science using exemplary inquiry practices. She reported that the students were the first catalyst in her change process. She said, "When you see the kids get excited though, you can't help but feed off them." Next, she said she had an "Ah Ha moment" in her *Motion and Design* Follow-Up professional development when she was engrossed in thinking through an inquiry lesson using the materials from her unit. After that, she said she was able to reflect thoughtfully on her teaching after she was taped in 2009 for research. She said, "I really wanted to do well. We asked questions [of the PD providers] and thought deeper about how to teach before I was taped and then I got a chance to watch the video tape too." She also commented that her EQUIP score in 2009 was probably inflated because they were trying many of the strategies for the first time. Hayley came out of the videotaping process armed with the knowledge that she wanted to improve her practice. At this time, Hayley's school principal began working with the professional development providers to implement the science-writing program for all the teachers in the school. Hayley was chosen to go to Seattle's Writing in Science Institute, on which Hayley commented, “That was huge (in changing her practice).” She explained, “The goal of *Writing in Science* was to develop the students’ thinking. Before we taught the lesson and asked the kids questions from the guide. Now we really talk about the content. We have more conversations with the students to really push their thinking.” (Hayley, personal communication, August 1, 2012).

Hayley was asked about student learning in regard to the way she teaches science. She responded that she had just been talking with another teacher about the importance of teaching science. She said, “Learning skills is important. If they do well and get excited, it spills over to other subjects. It has helped struggling kids do better in reading, writing, and math. They are seeing why it is important to understand how to graph and why to read. The benefits are far beyond science.” (Hayley, personal communication, August 1, 2012).

She was not content with her teaching and planned to continue to improve her practices, although she admits she is “a little scienced out.” She had confidence in the future development of her science teaching. She attributed this confidence to her building principal who “gets everyone involved,” to her co-teacher who she says she “wouldn’t enjoy it as much if there were not two teachers. It would be more stressful and not as much fun without the support,” and because she has professional development providers whom she can “call up and ask questions” whenever the need arises. Hayley thought her professional growth trajectory looks good, knowing that professional “colleagues to talk to along the way” surround her.

Chapter 7

FINDINGS: CROSS-CASE ANALYSIS

This chapter reports the analysis of the data from observations, interviews, and reflections using case study logical techniques that includes identification of patterns and explanation building (Yin, 2006). Emphasis was placed on looking at events chronologically for each case in order to build explanations regarding teacher learning and implementation of inquiry practices over time. The patterns and trends that could be seen across cases strengthens the developing theory. Where trends and patterns could not be found across cases, theories were discredited and the need for further research became evident.

This chapter will use cross-case analysis based on the evidence collected to answer the three research questions. The data will be used to respond to the propositions for each question. First, how the teachers' practices changed over time will be presented. The changes over time are presented in terms of *Curriculum*, *Instruction*, *Discourse*, and *Assessment* factors, time usage codes, and teacher perceptions. The data will be presented as both supporting and not supporting proposition 1: All inquiry factors (i.e., *Curriculum, Instruction, Discourse, and Assessment)* will increase in each of the data collection periods for each of the teachers. Secondly, the patterns in the evidence are presented to show how the teachers' professional development experiences influenced their change in practice. A correlation of the hours of teachers' professional development and the change in teachers' inquiry scores on the EQUIP are reported, and patterns are highlighted from the teacher interviews. The evidence is provided in relation to proposition 2: Teachers who receive the greatest amount of professional development during the data collection period will have greater increases in the use of inquiry practices. Finally, patterns are presented from the teachers' interviews to show how the *Curriculum* choices influenced the teachers' practices. The final portion of the chapter provides data in relation to proposition 3: After the implementation of an expository science-writing program, the factors of *Curriculum* and *Discourse* will show a more rapid adoption of inquiry practices.

How have individual teachers shifted their inquiry science practices over a five-year time frame?

All three teachers made changes in their practices over time. The changes were qualitatively observed in the actions and words of the teachers while teaching their videotaped lessons. The changes were also quantified use the EQUIP rubric. The teachers total score of Inquiry Practices from the EQUIP over the three data collection periods are presented in Figure 30. All three teachers moved from developing inquiry in 2007 to being at or above the exemplary inquiry line in 2012.

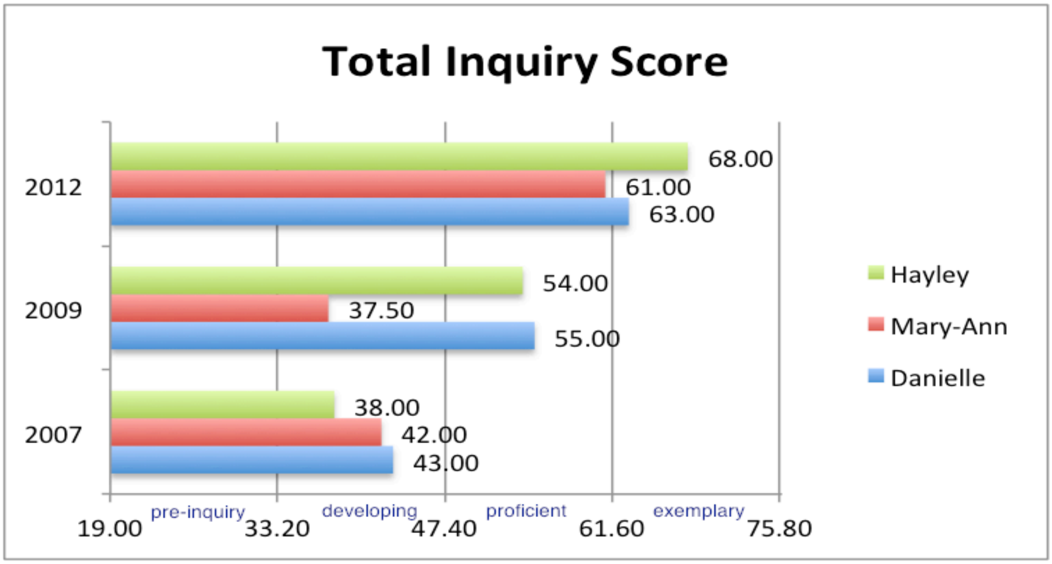

Figure 30. The teachers total inquiry scores over all three data collection periods

All three teachers had a different learning development trajectory. Danielle increased all four constructs between each data collection period. Her rate of increase was fairly consistent across time. Mary-Ann did not increase at every data collection period. She had a slight decrease between 2007 and 2009 in *Instruction, Discourse,* and *Assessment* but a slight increase in *Curriculum*. She then had a rapid growth rate for all factors between 2009 and 2012. Hayley perceived an increase between 2007 and 2009, but the researcher was not able to measure her inquiry scores in 2007. Between 2009 and 2012, Hayley had an increase of scores on *Instruction, Discourse,* and *Assessment*, whereas, *Curriculum* remained the same in both years.

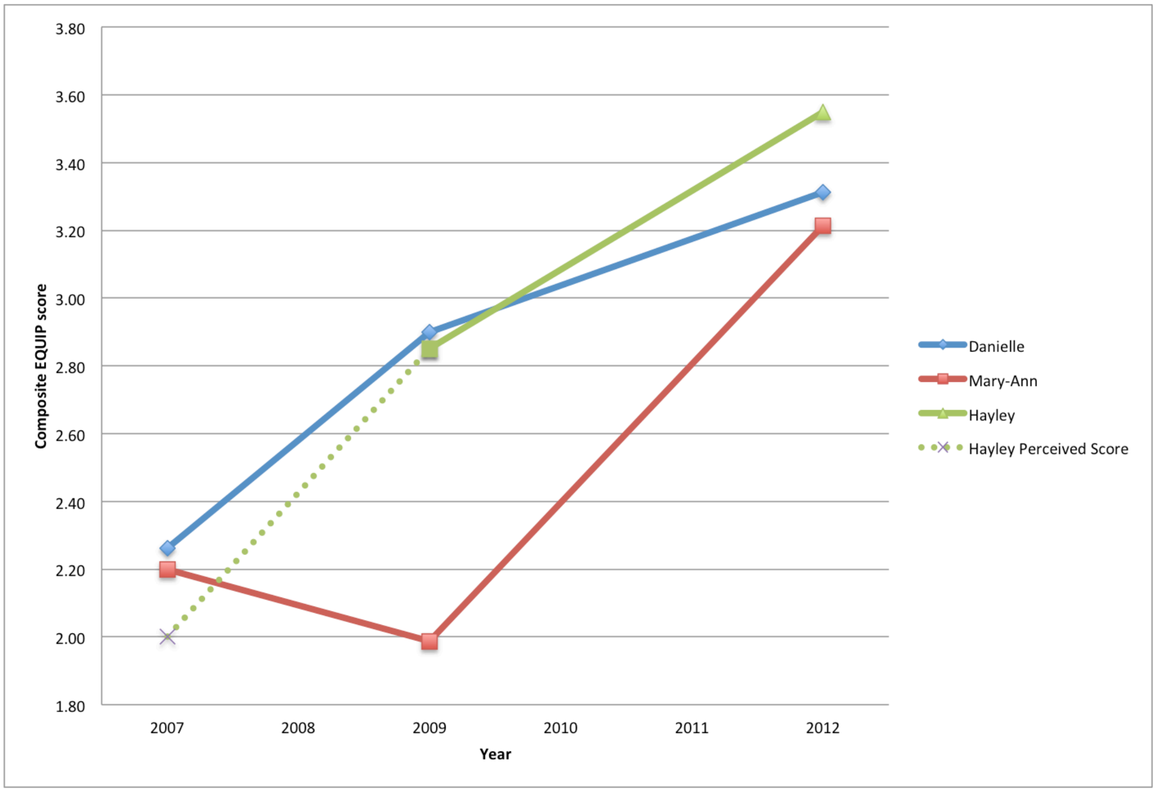

Figure 31. Three teachers composite inquiry scores over three data collection periods in five years

The data collected in this research did not support the proposition that all inquiry factors increased in each of the data collection periods for every teacher. The proposition was only supported by the data collected in Danielle's case. Mary-Ann and Hayley's cases, on the other hand, showed that some factors did not increase between data collection periods. The data collected from the interviews provides evidence that other intervening variables might have contributed to the lack of increase in certain factors for certain lessons. Three examples of 'other intervening variables' that influenced the lesson outcomes are provided below.

There was a decrease in the level of inquiry use in Mary-Ann's 2009 video lesson. Only the *Curriculum* factor increased whereas the other three factors decreased. In Mary-Ann's case, her 2009 lesson involved second graders learning about the abstract relationships between the sun, earth, and moon, whereas her 2007 and 2012 lessons included the concrete observations of insects. Research and theorists have agreed that young children build knowledge through concrete experiences (Dewey, 1938; Duckworth, 1987; Piaget and Inhelder, 1969; Vygotsky, 1978). The researchers, teachers, and scientists who collaborated on best practices for the Next Generation Science Standards Frameworks (NRC, 2011) decided that learning about the phases of the moon should occur by the end of the fifth grade band. It is logical that teachers' practices would change if the lesson content were inappropriate for the grade level taught. Further information would be needed to understand how grade level content appropriateness affects teacher practices.

Mary-Ann perceived the reason for the drop in her inquiry score to be because of a glitch in technology. After reviewing the data from her lessons she commented, "I had to change the lesson last minute. I planned to show the students a computer-imaging model of the phases of the moon. I pulled up a model on the computer the morning of the lesson and it didn't work" (personal communication, August 1, 2012). This is a concern for multiple reasons. First, new curricula are being developed that rely on technology that neither schools or teachers have the capacity to use (Harris, Mishra, & Koehler, 2009). Secondly, it is possible that Mary-Ann was counting on the computer modeling to do some of the content teaching for her. When it did not work Mary-Ann was not prepared to teach the content. This resulted in inaccurate information being presented to the students. For example, the class decided that there were eight full moons in the month of October, instead of a more accurate response of one full moon. If reform investments are used to purchase technology without developing teachers' practices then it is likely that lessons will fail to support student learning.

The factor of *Curriculum* for Hayley's lesson did not change between 2009 and 2012. The intervening variable for Hayley's 2012 lesson might have been the "test prep" nature of the lesson. Before filming her 2012 lesson, Hayley informed the researcher that the lesson was going to be slightly altered from the way she normally teaches because the students would be practicing the format of the upcoming high-stakes testing. The lesson was the "next lesson" in the curriculum unit. Hayley had taught the lesson as it was intended but altered the way the class organized and reported the data so that it would mirror the statewide high-stakes test. Research has indicated that more time is being spent in schools on test-preparation activities (Dee, Jacob, Hoxby, & Ladd, 2010). Preparing for high stakes tests affects the time teachers have to develop inquiry practices (Darling-Hammond & Richardson 2009). More research could help us understand how different types of test preparation lessons affect different aspects of inquiry practices.

How has ongoing professional development influenced teachers' inquiry-based practices?

Professional development influenced all three teachers' use of inquiry practices. Each teacher spent different number of hours in professional development sessions, participated in different formats of professional development, and attended different content focuses of professional development. All three reported that the professional development sessions offered by the university-district collaborative were key to the development of their practices.

Number of Hours in Professional Development

The number of hours of professional development influenced the teachers' use of inquiry practices. A Pearson R test was computed to assess the relationship between the hours teachers spent in professional development and the outcome of their inquiry scores on the EQUIP. The Excel program was used to calculate that the two variables had a strong positive correlation, with a Pearson R-value of 0.87. Danielle commented that the number of hours of professional development has allowed her to feel confident in using inquiry practices. She said, "I like teaching science because it is hands-on. I probably am more comfortable with science now than any other subject because I have had so much training" (Danielle, personal communication, August 1, 2012).

Professional Development Content

The content of the professional development also influenced the teachers' use of inquiry practices. The professional development sessions were sorted into two "content" categories. The first category was classroom-specific curriculum professional development. The professional development sessions that were placed in this category modeled grade level-specific lessons that the teachers could use in the classroom to teach the reform-based skills and content. The other category was labeled 'leadership professional development'. The professional development sessions in this group often combined teachers from multiple grade levels in the building of school leadership and in work sessions connecting curriculum to standards and testing. There was a very strong correlation between curriculum-specific professional development and the teachers' use of inquiry as measured by EQUIP. The Pearson R value for the correlation between curriculum-based professional development and the use of inquiry practices was 0.91, whereas the Pearson R value for the correlation between leadership-based professional development and the use of inquiry practices was only 0.65. These numbers strengthen the developing knowledge from research that, in order for professional development to change teacher practice, it must include experiences for teachers that they will actually use in the classroom (Penuel et al., 2007). Hayley pointed out, "The GEMS-Net training in science is the only useful training we have gotten. It supports the lessons we do in the classroom" (personal communication, August 1, 2012).

Professional Development Format

The format of professional development also influenced teachers' practices. All three teachers received the majority of their professional development hours from multiple one-day workshops. All three teachers also participated in classroom coaching and professional learning communities. Hayley participated in workshops, classroom coaching, professional learning communities, and attended a four-day institute. Hayley had the greatest variety of professional development experiences and scored the highest level of inquiry on the EQUIP rubric. Hayley admitted that the institute was a "huge" factor in how she teaches. Reflecting on the institute's professional development she said, "Getting to focus and immerse in thinking about one thing is rare for a teacher. I think differently about teaching science now" (personal communication, Hayley, August 2012).

The findings from this research support proposition 2 because the teacher who received the greatest amount and various types of professional development had the greatest increase in the use of inquiry practices. More specifically, there was a very strong relationship between curriculum-specific professional development and the quality of that teacher's inquiry teaching. The strongest relationship is shown through data points for Hayley who had the greatest change in inquiry teaching as measured by the EQUIP between 2009 and 2012. During this time, she received 66 hours of professional development in four different formats. The smallest change across all data points was actually a slight decrease between the years of 2007 and 2009 for Mary-Ann. During this time she received only five hours of curriculum-based professional development.

How has the addition of an expository writing program to an existing kit-based curriculum influenced teachers' inquiry science practices?

All three teachers stated that both the kit-based curriculum and the expository writing program were influential in achieving higher levels of inquiry. Although the EQUIP data did not support the researcher's proposition that *Curriculum* and *Discourse* factors would increase after the addition of the expository writing program, the participants' comments did. All three teachers were introduced to the science writing approach between 2009 and 2012. According to EQUIP data points, there were no specific patterns across cases in *Curriculum* or *Discourse*. Yet during the 2012 interviews, all teachers mentioned that *both* the introduction of the kit-based curriculum and the science-writing program had major impacts on their teaching practices.

Kit-Based Curriculum

By 2012, all three teachers agreed that the kit-based curriculum benefitted their ability to teach through inquiry. Danielle stated, "If I didn't have the kits, I would not have as much of an inquiry classroom. I don't know what we would do if we didn't have the kits" (personal communication, Dec 2, 2009). Mary-Ann commented that the kit-based curriculum "instigated" the change in her teaching. She said that even though she and her colleagues tried to build their own "kits" they were not as comprehensive. She explained, "I used to do traditional stuff where they learned from me and then I tested them to see if they knew what I told them. Now they learn for themselves . . . well not for themselves. I guide their learning through asking questions to help them think more, investigate more, test more what their own thoughts and ideas are. The materials have helped" (personal communication, August 1, 2012). The research shows that teachers need materials that match their sequence of lessons (Erickson, 2006; Pine et al., 2006; Schneider & Krajcik, 2002). Reforms such as the NGSS are asking the students to act like scientists, but without appropriate materials this will not happen (NRC, 1996; NRC, 2011).

The kits alone may not be enough to change practice. In 2007, both Danielle and Mary-Ann were using a kit curriculum and still did not reach a proficient level of inquiry as scored on the EQUIP. In 2007, when Mary-Ann was asked what makes it hard to teach inquiry she said, "Sometimes reading the kits. It's not that easy or fast to find what you want." A change in curriculum materials does not automatically change teachers' practice (Hall & Hord, 2001; Sahlberg, 2006). Time with the materials and developing teachers' practices on sense-making are needed for teachers to use the kit curriculum to their fullest potential (Sullivan-Watts et al., 2012). Hayley reflected on this, "When the kits came, they definitely made it easier but our instruction was not that much better. We were not using it well. I didn't like it that much. It was just another subject to teach."

Writing in Science

All three teachers reported that the addition of the science-writing program to the kit-based curriculum supported their use of inquiry in science. The common themes were found in the transcripts of their 2012 interviews. The first theme was that *Writing in Science* helped the teachers make more thorough meaning of the science lessons. Second, the program helped the teachers to be more mindful in planning the structure of their science lessons. Lastly, all the teachers commented that they were better able to assess what their students knew. These three effects of the science-writing program on the teacher's use of inquiry practices are discussed in the following paragraphs.

Researchers have criticized the kit-based curricula because it has been often wrongly portrayed as "activity for activity's sake" without the structures for developing students' conceptual knowledge (Anderson, 2007; Erickson, 2006; Geier et al., 2008; Schneider & Krajcik, 2002). The science-writing program provides teachers with the structures to help students make meaning from the kit-based activities. Mary-Ann said, "The science notebooks have been a big shift. I used to run out of time and I would sum it up. Now they are taking more time to sum it up themselves"(personal communication, August 1, 2012). Mary-Ann's perceptions support the claim that Sullivan-Watts et al. (2012) made in their research. These researchers found that teachers using kit-based curriculum incorporated many inquiry practices into their lessons, but even in these classrooms teachers were falling short in "making sense of data." The researchers suggested that the incorporation of *Writing in Science* could support the teachers in their meaning-making efforts.

Fulwiler's (2007) *Writing in Science* use of protocols encourages scientific thinking and deepens conceptual understanding via an expository writing program that provides a number of structured prompts and processes that focus the kit-based student investigations on the key conceptual ideas. The concept that the science-writing program has supported students' conceptual development can be witnessed in Hayley's reflection of her own content knowledge. Hayley said, "*Writing in Science* has helped me realize that I needed more content knowledge. The kids are coming to us in fourth grade with more knowledge because of the program, and now I need to up my knowledge too." She admitted that she only began reading the "background content for the teacher" section of her kit-based curriculum after she started using the science writing approach. She said, "I don't know why I didn't read it before, but now I want to even more" (personal communication, August 1, 2012).

When the science-writing program was added to the established kit-based curriculum, the teachers reported that they spent more time planning for science. The teachers all mentioned the time spent planning with their colleagues, writing focus questions, or developing the scaffolding for the notebook entries. Hayley commented on the changes in her teaching before and after she began using the science approach: "In the past we would teach each lesson as it was written, there was no connection between lessons and no writing unless the students were answering questions on a worksheet. There was very little data analysis or discussion. We now spend a lot more time planning and teaching science and we give the students a lot more time to think explore and write" (personal communication, August 1, 2012). The time spent on planning supports the teachers' use of inquiry practices by making what they do in each lesson more intentional. The teachers think about how to connect to previous lessons, what questions they will ask, and how they will facilitate student discussions.

The science-writing program has allowed the teachers to see into the minds of the students. The EQUIP states that part of teaching through inquiry involves adjusting your instruction to match what the students need. Mary-Ann clearly stated how the writing program helped her to understand what her students had learned or not learned: "Writing has really helped me know what individual kids are thinking. I used to assume that they understood through group discussion and now I know if students have a certain level of understanding. Sometimes, I thought the kids had really learned it, then I looked in their notebooks and I realize they didn't. It always surprises me, but at least I can clearly see what each child knows, and I am not just guessing" (personal communication, August 1, 2012).

The research questions in case study research help to set the parameters of what data are analyzed. While looking at the interview data, other common themes were found across cases. First, all three teachers mentioned that the kids love to learn science. Mary-Ann said, "You hear them [the students] say 'Oh, Science, Yeah!' They are deeply involved in the content of the kit. They are interested. They want to learn and connect it to their world. They bring in specimens from home or the schoolyard. They clip out weather reports to share with the class. They can connect to their learning." Hayley added another common sentiment. She said "When you see the kids get excited through you, you can't help but feed off them" (personal communication, December 2, 2009).

The teachers all explicitly mentioned the time it takes to get good at teaching something as complex as inquiry science. When Mary-Ann reflected on her content knowledge she said, "…you learn something new every year or get another perspective on things." Danielle added, "The more you are exposed to the kits, the more you think about how it connects to the real world."

Conclusion

The teacher's inquiry scores on the EQUIP and the data from teacher interviews show that teachers do adjust their instruction when they are supported by curriculum and professional development. Of the three propositions in this study, only the proposition that more time in professional development would increase teacher's inquiry scores was supported across all three cases. The other two propositions were supported in some cases, but not all. The variation in the data demonstrates that educational change processes are not "one size fits all."   At any given point in a teacher's day there are multiple variables that support or act against developing teachers' practices. More observations of each teacher, as well as, the observations of additional teachers, would provide an even more detailed vision of the time and supports involved in reforming teaching in elementary science classrooms.

Chapter 8
DISCUSSION AND IMPLICATIONS

Another reform, by its nature, will call for changes in science education. A report brief for the Next Generation Science Standards Frameworks (NGSS, 2011) claimed:

> The time is ripe for a new framework for K-12 science education not only because of weakness in the current approaches, but also because new knowledge in both the sciences and the teaching and learning of science has accumulated in the last 15 years. (para. 3)

The NGSS report brief provides hope that a new reform will have different results than past reforms. The document claims that the new set of standards will not be lists of unconnected concepts; instead it will promote depth in content, practices, and thinking. The authors of the Frameworks readily admit that, while they have analyzed the research available, there is a need for more information as to how teachers learn to use practices over time and what kind of supports enable teachers to develop the skills associated with reform-based teaching.

The evidence collected from the three teachers who participated in this research provides guidance for those who wish to make the type of change that is effective and lasting. This chapter begins by providing three theories developed from the results of this research. Each theory is created with the assumption that teachers need support as they learn to use the complex practices associated with inquiry teaching. The description of each theory will end with a recommendation. The recommendations are intended for classroom-, school-, or district-level decision makers as they react to the pressures associated with the distribution of a new set of standards. It will then provide the limitations associated with case study research. Finally, questions that arose throughout the study will offer a platform of suggestions for future research.

Discussion Point 1: 'Teacher Change' takes time. Teachers need time and experience to develop their practices.

If teachers are to develop their practices, they need time and consistency with curriculum to do so. When the teachers were asked in their interviews in 2009 what made it difficult to plan and teach inquiry lessons, they all responded, "time". The lack of time to plan and implement inquiry practices has been identified by research as a crippling factor in the process of learning to use inquiry effectively (Dorph et al., 2011). It might be that current expectations of what "time" means needs to be broadened to extend across years rather than the narrow view of minutes in a school day.

Every time a new curriculum replaces an old one, teachers return to working through the mechanics of teaching before they are able to reflect on their practices and use the curriculum well (Ball & Cohen, 1999). In elementary school, lessons are only taught once a year. Lessons particular to science, such as learning to teach children how to build an electromagnet, takes a particular understanding of how electromagnets work and how to support students to think about the content and design process. Most fourth grade teachers do not enter teaching with the knowledge, the confidence, or the experience to teach such lessons (Saad & BouJaoude, 2012). Therefore to become confident in the content and processes of the lesson will take many years. Timeframes set for implementation and learning ought to consider how teachers' experience builds slowly over years. Most curricula are removed from the classroom before teachers can build confidence and experience with the lessons and reflect and make changes to their teaching (Sahlberg, 2006). Both Hayley and Mary-Ann reflected on this process, saying that when they started using the kit-based curriculum they were just going through the motions, now they consider the individual students and how the curriculum affects them. Hayley clearly said that when she had time and consistency with her curriculum, she changed her practice: "In the past we would teach each lesson as it was written, there was no connection between lessons and no writing in science unless they were answering questions on a worksheet. There was very little data analysis or discussion. We now spend a lot more time planning and teaching science, and we give the students a lot more time to think explore and write" (Hayley, personal communication, August 2012).

The data from this research showed that, even after two years of curriculum experience and professional development, the teachers were only just approaching a proficient level of inquiry. Findings from data on the level of inquiry of the teachers in this study in 2009 were consistent with other research performed by the authors of the EQUIP tool (Marshal et al., 2010). Reaching a basic level of proficiency should not be the end goal of educational reform. Additionally, since many professional and personal factors affect teachers' abilities to change, some teachers will take longer then other teachers to change their practice.

Berliner (2001) found that it takes teachers at least five years to move from novice to expert. The teachers in this research showed that within five years they had moved from developing inquiry practices through levels of proficiency toward exemplary use of inquiry practices. It is possible that when teachers can depend on the supports offered to them they are more willing to become life long learners. It was clear in the video lessons and the interview transcripts that the teachers were building confidence in their teaching over time. However, even by the end of the research, the teachers were not content. Mary-Ann commented "I'm more comfortable teaching science now, but you learn something new every year or get another perspective on things" (personal communication, August, 1, 2012). Danielle asked the university district partnership for professional development that related to the areas of inquiry she scored lowest on. Hayley mentioned that, because her whole school was teaching science so well, the students were coming to her class with more knowledge and skills. She was concerned that she needed to increase her own knowledge level to continue to challenge the students. None of the teachers received the highest possible score on the EQUIP and all the teachers perceived a need to continue to improve. Therefore, learning to teach inquiry science is not achieved in a particular time frame, instead it is a career-long journey.

Recommendation 1: Provide teachers with time and experience to develop practices. Curriculum should not be changed without considerable thought for a long-term investment and commitment. Reform resources should focus on developing teachers' practices rather than making superficial changes.

Discussion Point 2: 'Teacher Change' is complex. Teachers need comprehensive support systems to develop their practices.

Multiple intervening factors constantly affect the teachers' practices. This research found that ongoing professional development and educative curricula supported the teachers' growth but factors such as lesson's content appropriateness, test preparation, technology glitches, and lack of time impeded the development of practices. For example, Mary-Ann was asked about what made it difficult to plan and teach inquiry science, she responded about the demands of other curriculum on her time: "I do have some time constraints. This particular year we've blocked off a reading block, a math block, and that has pushed science and social studies to the afternoon--which is fine because for the young children they can move around and that works well for science, except that I do have a special (music, art, library, or physical education class) right in the middle of that time. So most of the time we have to start something, take a break, and return to it afterwards, and so that can be difficult. And just being an elementary school teacher, there's so many different subjects that you have to consider" (Mary-Ann, personal communication, December 2, 2009). In addition to these constraints, research has identified many other intervening variables that teachers face every day, including but not limited to, students' home life, teachers' previous experiences, school climate, leadership support, other curricular implementation, and many other factors too numerous to name (Abel, 2007).

Simplistic intervention strategies are not going to 'change' all teachers' practices. Similarly, multiple intervention strategies that are unconnected will not be effective in changing practice. Instead a comprehensive but flexible support system needs to be developed that includes professional development, curriculum, and attention to the specific needs of the individual teachers, schools, and districts.

The evidence collected in this research confirms the need for a comprehensive approach to supporting teacher growth. The connection between professional development and curriculum was exposed by the strong correlation between the hours spent in professional development based on the teachers' curriculum and the growth in the EQUIP scores that measured levels of teachers' inquiry practices. In addition, the professional development providers' knowledge of the teachers' previous learning experiences is reflected in Danielle's (personal communication, 2012) comment, "I like going to the university, you are treated like a professional and you get verification of what you are doing and then be able to take the next specific step."

Many companies that develop and sell curriculum also provide professional development for the teachers when the curriculum is purchased. But the professional development that comes with curriculum is rarely ongoing and does not cater to the individual needs and continuous changes in the teachers' classrooms. It might be more logical to provide professional development through a local outside source, such as a university-district partnership, which would be in a position to analyze and consider individual teachers' practices more holistically. Miller (2001) explains this partnership as benefitting the schools, the university, and the community. He says the partnership responds "to emergent issues, concerns, and needs of the members as well as to the demands of the context" but is "firm in its values of participation, reciprocity, democracy, and collaborative inquiry" (p. 104).

Recommendation 2: Comprehensive support systems, such as university-district partnerships, should be developed to support the development of teacher practices. These support systems should dynamically link the individual teacher needs, the curriculum, and the professional development.

Discussion Point 3: Professional development is more effective when it is structured on what teachers do in the classroom rather than what they need to know.

Inquiry teaching is complicated. Many of the practices associated with inquiry teaching are linked together. This research found that when one factor of inquiry increased, other factors did also. This makes sense in terms of the reality of the classroom. For example, if the teacher becomes proficient in asking questions that challenge students to explain, reason, and justify, then the teacher is better equipped to assess the students' understanding of a concept or to help students reflect on their thinking. Educational researchers and theorists pull apart the practices involved in inquiry teaching to be able to study them academically, yet the practices are not separate in the classroom. Wynne Harlen (1997) describes how the practices involved in inquiry are interconnected:

> Process skills are described in various ways, all of which suffer from the problem of trying to draw boundaries round things which are not separable from each other. For when we describe an example of 'observing' there is some 'hypothesizing' going on as well, and even some degree of 'investigating'. It will soon become apparent that the aspects of practice, which we call process skills, are not single skills but conglomerates of coherent skills. It is for convenience only that we refer to each as individual skills. (p. 26)

Teachers' lack of time to plan and implement inquiry lessons makes it hard for them to translate professional development based on a specific skill into their own classroom practice. Hayley commented that the professional development she received in science was the "only useful" professional development she received. She explained that it was different from other professional development sessions because it taught "the lessons we do in the classroom" (personal communication, Hayley, 2012). The "usefulness" of professional development that was based on classroom curriculum was validated by the strong correlation between the hours of this type of professional development and teachers' growth of inquiry practices in the classroom.

Many professional development sessions that focus on what teachers should know, such as 'studying the standards', fall short of affecting classroom practice. When learning is contextual it is more likely to develop multiple practices and be more "useful" to teachers. Rather than offering professional development sessions that are based on learning specific skills such as developing questioning strategies, teachers would be better served 'practicing' the lessons they actually do in the classroom and then reflecting on the skills they are developing.

Recommendation 3: Professional development should make use of classroom teachers' curriculum lessons to develop pedagogical content knowledge. Professional development should provide teachers with models and practice of what they will do in their own classroom. Both the lack of time and the multiple intervening variables discussed previously may negatively affect teachers' abilities to translate learning from professional development into practice. Professional development that is contextualized in classroom experiences is more likely to change practice.

Limitations

The results of a case study cannot be generalized to a larger population because of the uniqueness of the selected cases within a specific context; instead, the results can be generalized to theory development (Creswell, 2003). The broad implications are based on empirically studied and observed evidence. Larger sample sizes and/or more data points would be needed to predict the results of this study to be true for other teachers.

This study was bound by the primary examination of inquiry practices through isolated lessons. With the multitude of variables in the context of the classroom, these discrete moments only provide a snapshot for the researcher to study empirically. These observations do not necessarily represent the entirety of the teachers' skills. The researchers deductions are based on the assumptions that the isolated data points for each videotaped lesson are representative of the teachers' practices at that point in time and that the lessons in-between would fall into a particular range of the teachers' skills.

Due to the nature of qualitative research, the data within this study may be subject to different interpretations by different readers. Detailed data is provided to invite readers to analyze and interpret the data. In addition, there is a potential for bias in the qualitative results interpretation because the researcher is a professional development provider for the participants. However, the researcher took efforts to minimize bias. Yin (2009) suggested that reporting your findings while in the data collection process to a few "critical colleagues" and asking them to present "alternative explanations and suggestions for data collection" can help the researcher to avoid personal bias (Chapter 3 para. 23). The data and the data collection process were shared with colleagues and discussions helped the researcher to think about the data from different perspectives.

In addition, it is especially important for the researcher to be open and conscientious in finding the "truths" of teacher change. Flyvbjerg (2006) in his description of the misunderstanding of case-study research wrote:

> We understand why the researcher who conducts a case study often ends up by casting off preconceived notions and theories. Such activity is quite simply a central element in learning and in the achievement of new insight. More simple forms of understanding must yield to more complex ones as one moves from beginner to expert. (p. 429)

The researcher's desire to better understand the complex phenomena of teacher growth initiated the research; therefore, the discussion points intend to highlight the discovered truths of the teacher development process.

Implications for future research

This research is based on a theory that singular factors never work alone in affecting teacher change. For that reason suggestions for future research should consider how the factors in question interact with one another to change teachers' practices over time. The following factors together were possible influences on teacher use of inquiry practices: the grade level the teacher taught, the type and level of the lesson's content, the nature of the lesson in terms of test preparation, the specific school environment, the time spent in different formats of professional development, the types and experience with a specific curriculum, and the teachers' belief system and ability to make change. Research has already been conducted on how these factors influence teacher practices. Now research should look into how the factors influence each other to affect teacher practices and how teachers' practices evolve as teachers' ability to teach with inquiry increases over longer periods of time.

Some of the future questions from this study seem overwhelmingly challenging to address. The three teachers all changed their instruction over multiple years. Would that be the case for all teachers, particularly those teachers less likely to participate in research? What would happen to the teachers' practices if professional development were removed? Would teachers retain the inquiry practices they had acquired or would they fall back on traditional strategies that might be easier or more comfortable to teach? Can teachers transmit their knowledge of teaching from one curriculum to another or do they begin again at a ‘developing inquiry’ level of instruction when their curriculum changes? If supportive professional development continues and teachers have consistency with educative curriculum will their practices continue to develop over time or will they ‘level off,’ as research suggests?

Creative research strategies should be considered to investigate these complex questions. There is a promising future for longitudinal research because of new technologies. Case-tracking studies may become more common because of accumulating computerized databases. With the ability to track teachers over longer periods of time researchers can continue to explore how teachers’ learning trajectories develop and the knowledge developed from these studies can help inform reformers about the time and supports that teachers need to develop exemplary skills in teaching.

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