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Elementary teachers' ideas about, planning for, and implementation of learner-directed and teacher-directed inquiry: a mixed methods study

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ELEMENTARY TEACHERS' IDEAS ABOUT, PLANNING FOR AND IMPLEMENTATION OF LEARNER-DIRECTED AND TEACHER-DIRECTED INQUIRY: A MIXED METHODS STUDY

by

Mandy Sue Biggers

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Science Education in
the Graduate College of
The University of Iowa

May 2013

Thesis Supervisor: Assistant Professor Cory T. Forbes

ABSTRACT

Using a framework for variations of classroom inquiry (National Research Council [NRC], 2000, p. 29), this study explored 40 inservice elementary teachers' planning, modification, and enactment of kit-based science curriculum materials. As part of the study, a new observation protocol was modified from an existing protocol (Practices of Science Observation Protocol [P-SOP]) to measure the amount of teacher direction in science inquiry lessons (Practices of Science Observation Protocol + Directedness [P-SOP^d]). An embedded mixed methods design was employed to investigate four questions:

1. How valid and reliable is the P-SOP^d?
2. In what ways do inservice elementary teachers adapt existing elementary science curriculum materials across the inquiry continuum?
3. What is the relationship between the overall quality of inquiry and variations of inquiry in elementary teachers' enacted science instruction?
4. How do inservice elementary teachers' ideas about the inquiry continuum influence their adaptation of elementary science curriculum materials?

Each teacher chose three lessons from a science unit for video-recorded observation, and submitted lesson plans for the three lessons. Lesson plans and videos were scored using the P-SOP^d. The scores were also compared between the two protocols to determine if a correlation existed between the level of inquiry (measured on the P-SOP) and the amount of teacher direction (measured on the P-SOP^d). Findings indicated no significant differences between planned and enacted lessons for the amount of teacher direction, but a correlation existed between the level of inquiry and the amount of teacher direction. In effect, the elementary teachers taught their science curriculum materials with a high level of fidelity for both the features of inquiry and the amount of teacher direction. A smaller group of three case study teachers were followed for the school year to give a more in-depth explanation of the quantitative findings. Case study findings revealed that the teachers' science instruction was teacher-directed while their conceptions of inquiry were student-directed. This study contributes to existing research on preservice teachers' learning about the continuum (Biggers & Forbes, 2012) and inservice teachers' ideas about the five features of inquiry (Biggers & Forbes, in press).

Abstract Approved: ______________________
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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D thesis of

Mandy Sue Biggers

has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
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To Palmer, Harrison, & Annabelle for being my constant sources of inspiration and motivation.

If we knew what it was we were doing, it would not be called research, would it?

Albert Einstein

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Two people who influenced my decision to become a science educator deserve a special thank you here. Mr. Swift – you taught me that it was okay to be a girl who likes science and opened my eyes to the amazing world of what I thought was a boring subject until I started 7th grade science with you. I can remember like it was yesterday sitting around your classroom as you told us stories about your adventures collecting specimens and traveling the world. You are the reason I decided to become a science teacher, and the rest is history. Thanks for impressing on a tiny 7th grader that the world was big enough for my dreams and not to settle for what others thought I should be. And to Myrna Parsons – I am so grateful that I got to be in your classroom for my student teaching experience. You have been an amazing mentor and inspiration to me since then. I still ask myself, "What would Myrna do?" Your passion and dedication to the field of science education marks the high standard I measure myself against daily.

To my parents (all four of you!) – thank you for putting up with this crazy dream, for allowing us to take your grandchildren a thousand miles away from you, and for supporting us throughout the entire process. Thanks for sending us goodies in the mail, for gladly making the trip to Iowa time after time, for keeping us supplied with Zigenbock, and especially for the graduation gift of my doctoral regalia. To Palmer, Harrison, and Annabelle – thank you for being such amazing kids. You are the reason I chased this dream. I hope you know that you can do *anything* you can put your mind to. Hard work really does pay off whether it is piano lessons, math homework, spelling practice, or going to college. I believe you can do anything you want to do and can be anything you want to be! I truly can't wait to see what all you accomplish in your lives.

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CHAPTER I

INTRODUCTION

This study addressed how inservice elementary teachers adapted existing kit-based science curriculum materials across the continuum of teacher-directed to learner-directed inquiry. A mixed method embedded design was used in which a multiple case study of three inservice elementary teachers was nested within a quantitative study of 40 teachers. The quantitative strand investigated *if* and *to what extent* teachers modified their elementary science curriculum materials to be more or less teacher-directed. The case study qualitatively explored in depth *how* three inservice elementary teachers modified their curriculum materials along the inquiry continuum, and how their reasoning for doing so explained findings from the quantitative phase of the study. Data sources included video-recorded classroom observations of three enacted science lessons, associated lesson plans, and semi-structured interviews for a smaller, select group of teachers. Lesson plans and enactments were scored on three observation protocols, one of which was developed and tested for validity and reliability as part of this study. The newly developed protocol is a modified version of an existing instrument, the Practices of Science Observation Protocol (P-SOP). The P-SOP measures the level of inquiry in science lessons and lesson plans. The new modified protocol developed and tested as part of this study measures the amount of teacher direction in science lessons as well as science lesson plans, and is called the Practices of Science Observation Protocol + Directedness (P-SOP^d).

Statement of Problem

The current state of science education reform emphasizes eight scientific practices (a) asking questions, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) constructing explanations, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information (National Research Council [NRC], 2012). These scientific practices should be emphasized at all grade levels, beginning with very early learners (NRC, 2007). Early impressions of science content and science processes build an important foundation for future scientific learning. Elementary learners need to engage with these essential scientific practices in order to understand how the process of science works, and in effect, how the world works (NRC, 2000). Students need to experience these practices, not just read about them or hear about them from a teacher. In order to support students to engage in these scientific practices, elementary teachers need to afford students these opportunities. For this to occur, elementary teachers should understand (1) the importance of the scientific practices and (2) how to engage students in those practices during instruction. Elementary teachers, however, have been shown to have weak science content knowledge and low self-efficacy for teaching science-as-inquiry (Abell, 2007). These obstacles make it difficult to afford students opportunities to engage in essential scientific practices.

One way that science educators can better foster students' engagement in these practices is through encouraging the use of varying amounts of teacher direction in inquiry lessons, as emphasized in the inquiry continuum presented by the NRC's *Inquiry and the National Science Education Standards* (2000). This continuum (shown in Appendix D) presents a spectrum of five inquiry features ranging from very teacher-directed styles (sometimes referred to as 'guided inquiry') to very learner-directed styles (or 'open' inquiry). While some scholars argue that we should aim for student-directed inquiry as the 'gold standard' (i.e. Johnston, 2007), others contend that the inquiry continuum should be used to help teachers adapt their curriculum materials to meet the needs of their learners (Settlage, 2007). If elementary students need more structure and scaffolding, as the literature suggests (e.g. Lehrer & Schauble, 2004; Metz, 2004, 2008), teachers can slowly introduce the practices of science through more teacher-directed inquiry instruction. As students become more comfortable with scientific ways of thinking, scaffolds can be removed as teachers move their instruction towards more student-directed forms of inquiry.

The true 'gold standard' for classroom inquiry, however, should be matched to the needs of the students rather than to a fixed matrix. Teachers need support to learn how to adapt their curriculum materials across this continuum, and this study was a first attempt to look at inservice elementary teachers' ideas about the inquiry continuum and how they adapted their curriculum materials across it during the baseline year of a multi-year professional development study. This study was grounded in a set of prior research studies concerning preservice teachers' learning about the inquiry continuum (Biggers & Forbes, 2012; Biggers, Forbes, & Zangori, in press; Zangori, Forbes, & Biggers, submitted), and also broader research on preservice and inservice teachers' ideas about the five essential features of inquiry (e.g. Beyer & Davis, 2008; Davis, 2006; Davis & Smithey, 2009; Forbes, 2011; Forbes, Biggers, & Zangori, 2013; Haefner & Zembal-Saul, 2004). The complexities involved in the associated research questions required a mixed methods approach in order to explore both general trends across a large group of practicing elementary teachers and also in-depth pedagogical reasoning from a smaller group of teachers.

Purpose of the Study

No Child Left Behind requires states to report yearly progress for students in grades three through eight (and at least once in high school) in reading and math in order to quality for federal funding (Marx & Harris, 2006). In effect this means that schools are held accountable for literacy and math progress, but there is no requirement in the legislation for reporting science progress (Center on Educational Policy, 2006). This lack of accountability has caused science to be de-emphasized in U.S. elementary schools in order to spend more time on reading and math (Abell, 2007; Beyer & Davis, 2008;

Forbes & Davis, 2008; Hall, 1998; Marx & Harris, 2006; Pratt, 1981; Spillane, Diamond, Walker, Halverson, & Jita, 2001). In addition, elementary teachers often have limited science content knowledge (Abell & McDonald, 2004; Beyer & Davis, 2008; Davis, Petish, & Smithey, 2006; Eshach, 2003; Tilgner, 1990). These two factors cause elementary teachers to rely heavily on their science curriculum materials (Abell & McDonald, 2004). While science education reform documents advocate teaching science as inquiry at all age levels (e.g. American Association for the Advancement of Science [AAAS], 1993; NRC, 2000, 2007, 2012), few elementary classroom teachers actually enact all aspects of science as inquiry (Forbes, et al., 2013 [see figure 1]; Tilgner, 1990).

Even within the field of science education, definitions of 'inquiry' are varied and sometimes contradictory. These contradictory definitions are most likely confusing for classroom teachers who attempt to enact inquiry lessons with their learners (e.g. NRC, 2000, 2012). The inquiry continuum (NRC, 2000, see appendix D) is a spectrum ranging from completely student-directed science instruction (open inquiry), to more teacher-directed inquiry instruction (guided inquiry).

This embedded mixed methods study addresses how inservice elementary teachers adapt existing kit-based science curriculum materials across the inquiry continuum of teacher-directed to student-directed (NRC, 2000). The quantitative phase of this study included data from 40 inservice elementary teachers. It was used to investigate *if* and *to what extent* teachers modified their curriculum materials to be more or less teacher-directed. The multiple-case study embedded within this quantitative phase explored *how* a subset of the teachers modified their curriculum materials along the inquiry continuum.

This study was the culmination of research over the past three years. In a recently published study (Biggers & Forbes, 2012) investigating preservice elementary teachers' ideas about inquiry based on the five essential features of inquiry (NRC, 2000), I found that preservice teachers entered their science methods courses with very student-directed ideas about inquiry (see also Settlage, 2007). When they attempted to enact student-directed inquiry lessons, however, they encountered various obstacles in the classroom. These obstacles caused their ideas to shift to accept more teacher-directed forms of inquiry which they had been exposed to during their science methods course (Forbes, 2011) and in effect, broadened their definitions of inquiry.

In a similar study, I investigated inservice elementary teachers' ideas about one of the five features of inquiry (Biggers, et al., in press). The inservice teachers had similar ideals of student-directed inquiry during interviews but their classroom enactments fell on the teacher-directed side of the inquiry continuum. I also found that the inservice teachers taught their existing science curriculum materials with relatively high levels of fidelity (Century, Rudnick & Freeman, 2010; O'Donnell, 2008; Shulte, Easton & Parker, 2009). There are not enough studies that focus on the fidelity of implementation as a central aspect of the success of an intervention (i.e. O'Donnell, 2008). A trend from both of these studies (preservice and inservice) and other published literature (Hmelo-Silver, Duncan, & Chinn, 2006) is that that when attempting more student-directed forms of inquiry, the teachers failed to scaffold their students to be successful in scientific practices. The combination of these lines of research led me to the topic for this dissertation study.

Research Questions

The research questions that guided this study were:

1. How valid and reliable is the P-SOP^d?
2. In what ways do inservice elementary teachers adapt existing elementary science curriculum materials across the inquiry continuum?
3. What is the relationship between the overall quality of inquiry and variations of inquiry in elementary teachers' enacted science instruction?

4. How do inservice elementary teachers' ideas about the inquiry continuum influence their adaptation of elementary science curriculum materials?

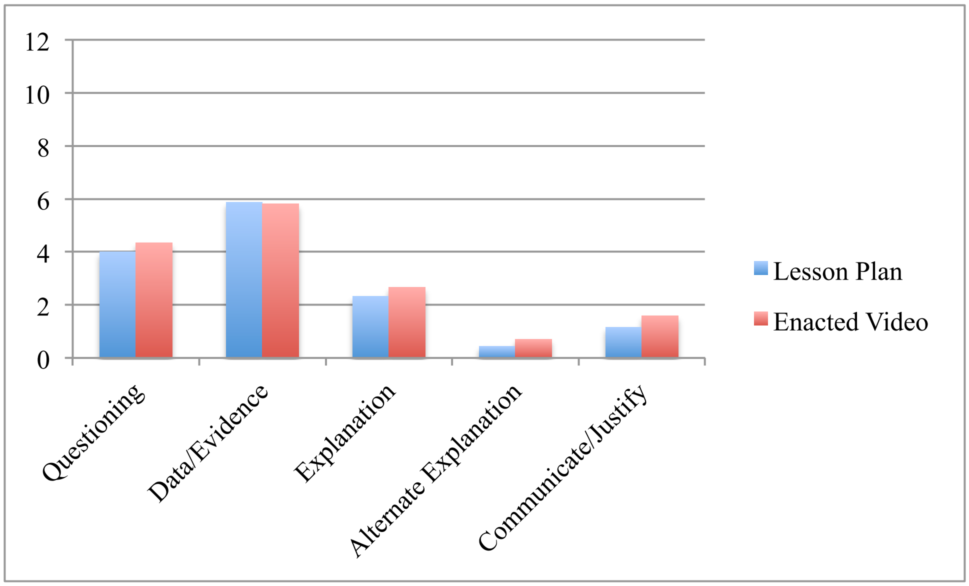

Figure 1. Mean scores of the Practices of Science Observation Protocol [P-SOP] for both enacted lessons and lesson plans of the five essential features of inquiry in elementary science (n=124) (Forbes, Biggers, & Zangori, 2013)

Significance of the Study

This study is timely with the recent release of the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and the *Next Generation Science Standards* ([NGSS] NRC, 2013). It is unique in its look at elementary inservice teachers' adaptation and enactment of science curriculum materials across the inquiry continuum. Davis and Miyake (2004) state that, "scaffolding implies that given appropriate assistance, a learner can attain a goal or engage in a practice otherwise out of reach… with this support very young children attained higher levels of performance than they could alone" (p. 266). The inquiry continuum is a tool teachers can use to scaffold their students' engagement in scientific practices. In order to support inservice teachers to scaffold their students across the continuum of teacher-directed to student-directed inquiry, researchers, curriculum designers, and professional developers need research, such as this study, to inform their efforts to support effective, reform-based, science teaching and learning.

The majority of the literature around student-directed and teacher-directed inquiry has focused on student learning outcomes rather than how teachers implement the variations (Hug & McNeill, 2008; van der Valk & de Jong, 2009). Most research on teachers' adaptations of science curriculum has been done at the secondary level (Enyedy & Goldberg, 2004; Fogleman, McNeill, & Krajcik, 2010; Penuel, McWilliams, McAuliffe, Benbow, Mably, & Hayden, 2009; Roehrig & Kruse, 2005; Schneider, Krajcik, & Blumenfeld, 2005) and with preservice elementary teachers (Beyer & Davis, 2009-a, 2009-b; Davis, 2006; Forbes, 2011; 2013; Forbes & Davis, 2010; Schwarz et al., 2008). There is very little existing literature on inservice elementary teachers' use of science curriculum materials, and this study will begin to fill that gap.

Findings from this study are significant in three main ways. First, this is a unique look at how teachers adapt and modify their science curriculum materials. No other research has investigated how elementary teachers adapt their curriculum materials. Second, the P-SOP^d is an important addition to the field of science education. No other instrument that measures the amount of teacher direction in inquiry lessons has been validated in elementary settings. Third, curriculum developers benefit from this research by seeing how elementary teachers adapt and modify kit-based science curriculum materials across the inquiry continuum. Their adaptations and the reasoning behind the adaptations inform curriculum research and design in how to best meet the needs of the teachers enacting their curriculum materials in elementary classrooms.

CHAPTER II

LITERATURE REVIEW

Theoretical Framework

The theoretical framing for this study involved four inter-related strands. First, I present theory on student and teacher learning involving conceptual change. Second, I present the difficulty of defining the term ‘inquiry’ in the elementary science classroom. Third, I discuss the idea of scaffolding across the continuum of scientific practices, and finally I discuss the relationship between teachers and their curriculum materials (see figure 2). These four strands make up the theoretical framework of this study because of the nature of the inquiry continuum. In order for teachers to modify their curriculum materials across the inquiry continuum, they must elicit students’ ideas about scientific practices and scaffold them appropriately in their attempts to engage in inquiry in the elementary classroom. Each of the four strands of the framework is discussed in the following section.

Learning Theory

Learning theory involving conceptual change informs us of why this engaging students in science-as-inquiry with the appropriate amount of teacher direction is critical (Duit & Treagust, 2003; Osborne & Freyberg, 1985; Posner, Strike, Hewson, & Gertzog 1982). Students are much more than “blank slates” and actively generate their own learning (Osborne & Wittrock, 1983). Conceptual change occurs when learners develop new ideas in addition to or in place of existing ideas (Driver & Oldham, 1986). Children form explanations about how the world works long before they are formally taught (Driver & Oldham, 1986). Often, these explanations are in direct contradiction to currently accepted scientific knowledge. Research in the Piagetian tradition supports the idea that learners construct their own knowledge and make their own meaning based on direct experience with the physical world and informal social interactions (Driver &

Oldham, 1986).

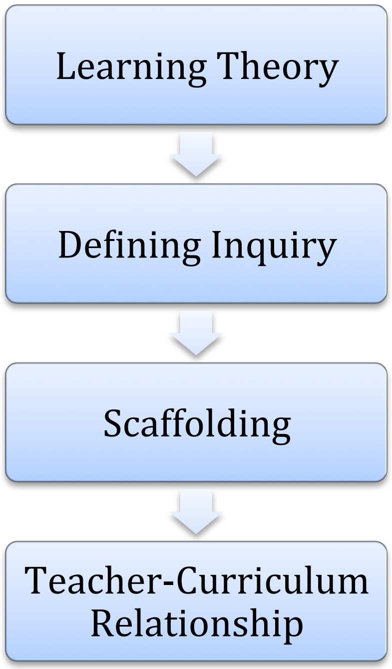

Figure 2. Theoretical framework flow of ideas

Although the term 'constructivism' has been defined in many ways, Collins (2002) proposes some recognized features of constructivist learning:

- Learning is active
- Learning is the interaction of ideas and processes
- New knowledge is built on prior knowledge
- Learning is enhanced when situated in contexts that students find familiar and meaningful
- Complex problems that have multiple solutions enhance learning

- Learning is augmented when students engage in discussions of the ideas and processes involved (p. 9).

The consequences of this type of constructivist learning are articulated by Bransford, Brown & Cocking (1999) in the following way:

> Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information they are taught, or they may learn them for purposes of a test but revert to their preconceptions outside of the classroom (p. 14).

In order for students to construct new knowledge, they must first become dissatisfied with their own understanding of a concept (Posner et al., 1982). A teacher simply telling a student that their understanding is incorrect is not nearly enough motivation for change (Osborne & Wittrock, 1983). Dissatisfaction must come from within the learner (Osborne & Wittrock, 1983); however, dissatisfaction itself does not lead to conceptual change (Posner, et al. 1982). In order to replace or modify their existing explanation, students need opportunities to be exposed to different (alternative) explanations so they may judge for themselves which explanation is most plausible, sensible, intelligible, and feasible (Posner et al, 1982). Once an alternative explanation has been shown to meet these factors, students may either assimilate or accommodate the new knowledge into their existing framework (assuming they are initially dissatisfied with their current explanation). Assimilation is defined as “using existing concepts to deal with new phenomena” whereas the more radical accommodation is defined as “replacing or reorganizing central concepts” (Posner et al, 1982, p. 212).

The term “conceptual change” is somewhat overused in the existing literature to refer to either assimilation or accommodation, when true conceptual change aligns more closely with the definition of accommodation. Assimilation could be referred to as "conceptual growth" rather than conceptual change as it is a less radical version of constructing new knowledge. In order for true conceptual change (or accommodation) to occur, the learner must undergo a paradigm shift (Kuhn, 1970), and therefore true conceptual change is extremely rare (Posner et al, 1982). Changing one's ideas is not easy by any means, nor does it happen quickly (Chinn & Brewer, 1993; Posner et al, 1982). A radical change in one's knowledge construction is typically a gradual outcome over time, with small steps laying the groundwork for a major reconstruction of a central concept (Posner et al, 1982) including both epistemological and ontological shifts (Duit & Treagust, 2003).

Interestingly, teachers themselves must undergo conceptual change in order to embrace a science-as-inquiry orientation to teaching and learning. Metz (2009) investigated teacher thinking over time while implementing a rigorous inquiry curriculum in elementary classrooms and discovered that teachers openness and willingness to try a lesson, even if they believed it to be beyond their students' current capabilities, ended up being a pathway to belief transformation. This type of true conceptual change (as mentioned above) is neither abrupt nor easy (Osborne & Wittrock, 1983), and studies have shown that it takes great amounts of time and professional development to change teacher belief structures (Guskey, 1985).

In order to achieve this goal of students' undergoing conceptual change in the classroom, teachers must take on new and unfamiliar roles to help students develop new conceptions (Crawford, 2000; Posner et al., 1982) A few of these roles include (a) clarifier of ideas, (b) presenter of information, (c) adversary in the sense of Socratic tutor, (d) model of scientific thinking, (e) motivator, (f) diagnostician, (g) guide, (h) innovator, (i) experimenter, (j) researcher, (k) mentor, (l) collaborator, and (m) learner. While the first two roles (clarifier and presenter) have been the typical roles teachers have taken in classrooms, others (i.e. mentor and collaborator) offer a new perspective on how teachers can help students achieve true conceptual change.

Teachers need support to help students externalize and modify their own knowledge in order to cause conceptual change (Wandersee et al, 1994). Teachers can employ several research-based strategies in order to achieve this goal. Some of these strategies include: clinical interviews, concept maps, open-ended or multiple-choice response items, problem sets, computer simulations, sorting and word association tasks, classroom discussions, cooperative learning, and journal writing (Wandersee, et al., 1994). Of all of the strategies listed, clinical interviews and concept maps seems to be the most common in the literature (Wandersee et al, 1994). This type of classroom activity usually is classified as formative assessment, which is a way of probing student understandings before mapping out the path for how to teach the concept to students (Abell & Volkman, 2006; Long et al., 2008; Shavelson et al., 2008; Wiggins, 1998; Wiliam, 2008).

These strategies help learners externalize their explanations so teachers have some place to start in their teaching of the concept. Choosing a strategy (or several strategies) to use is only part of the issue, however, and will in itself not make the difference. The true shift must be in responsibility and control of learning, from teacher to student responsibility (Baird, 1986; Wandersee, et al. 1994). “When students feel that they, rather than their teachers, parents, other people, or other factors cause their success or failure in school, their motivation to learn and their effort to learn often increase” (Osborne & Wittrock, 1983, p. 494). Teachers must elicit student ideas for both content and scientific practices in order to know how much scaffolding they require for each scientific practice. This requires a substantial change in how teachers teach science (Osborne & Wittrock, 1983).

Defining Inquiry

The field of science education does not have a single, agreed-upon definition of what inquiry looks like in the classroom. Teachers, researchers, and science educators may each have very different definitions of inquiry (Crawford, 2007). When asked to define inquiry, teachers offered ideas such as (a) engaging students in higher level thinking and learning, (b) applying knowledge, (c) doing fun or self-interest activities, (d) allowing diverse methods or answers, (e) dealing with real-world problems, (f) dealing with topics that are relevant to students, and (g) providing students with opportunities to express their understanding (Kang et al., 2008).

Science education reform documents advocate teaching science as inquiry at all age levels (e.g. AAAS, 1993; NRC, 2000, 2007, 2012). Because of conflicting results from empirical studies on the effectiveness of inquiry (e.g. Furtak, Seidel, Iverson, & Briggs 2012; Kirchner, et al, 2006), it is more important than ever that science educators pay close attention to how inquiry is defined in these and future studies. For example, Kirchner and colleagues (2006) define inquiry as “minimal guidance during instruction” (p. 75). Similarly, Johnston (2008) claims, “open inquiry should be the central learning goal in all that we do” (p. 12). Minner, Levy, and Century (2010), in their meta-analysis of literature on inquiry, show that of nine studies empirically testing the amount of student-direction in inquiry, six studies claimed that student participation in open inquiry leads to greater learning gains than more teacher-directed forms (p. 19).

There are numerous models and definitions in the literature representing different facets of inquiry. One such model, based on the learning cycle (Karplus & Their, 1967) incorporates the “5Es” of Engagement, Exploration, Explanation, Elaboration (sometimes refered to as Extension) and Evaluation (Bybee, et al., 2006). While there is quite a bit of research on the 1960’s learning cycle’s effectiveness (e.g. Ates, 2005; Balci, Cakiroglu, & Tekkaya, 2006; Billings, 2001; Ebrahim, 2004; Odom & Kelly, 2001), there is very little empirical research on the 5E model of inquiry. It does seem, however, to be familiar to most science school teachers, and is therefore reported by Bybee et al. (2006) to be the chosen inquiry model used in certain districts (e.g. Grand Rapids, Michigan; Jennings, Missouri), state standards (e.g. Connecticut and Texas), preservice teacher training programs (e.g. North Carolina State University, University of Alabama, and Texas A&M University), informal science education centers (e.g. American Institute of Physics and Miami Museum of Science) as well as countless textbooks and curricula across the United States (e.g. BSCS, NIH, MSST, NESCent) as well as over 235,000 lesson plans on the World Wide Web.

Another inquiry model is inquiry through model-based learning (Harrison & Treagust, 2000; NRC, 2007; Stewart, Cartier, & Passmore, 2005; Schwarz et al., 2009; Windschitl, Thompson & Braaten, 2008). Figure 3 presents an inquiry cycle including modeling. There are other models of inquiry as well. One is implementing inquiry through argumentation (Berland & Reiser, 2009; NRC, 2007; Norris, Phillips, & Osborne, 2008; Osborne, Erduran, & Simon, 2004; Polmon, 2004; Wells & Arauz, 2006) using frameworks such as (a) claim, (b) evidence, and (c) reasoning (McNeill & Krajcik, 2007) or (a) question, (b) claims, and (c) evidence (Norton-Meier, Hand, Hockenberry, & Wise, 2008). A model of implementing argumentation was suggested by Zembal-Saul (2009) and is shown in figure 4.

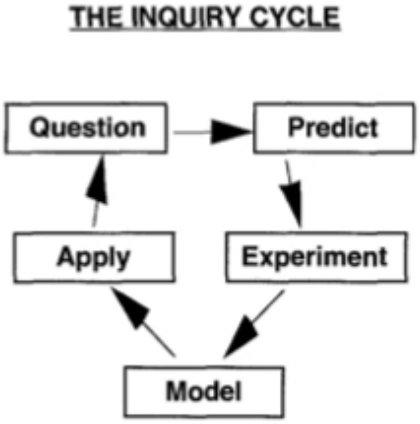

Figure 3. The inquiry cycle using modeling (White & Fredriksen, 1998).

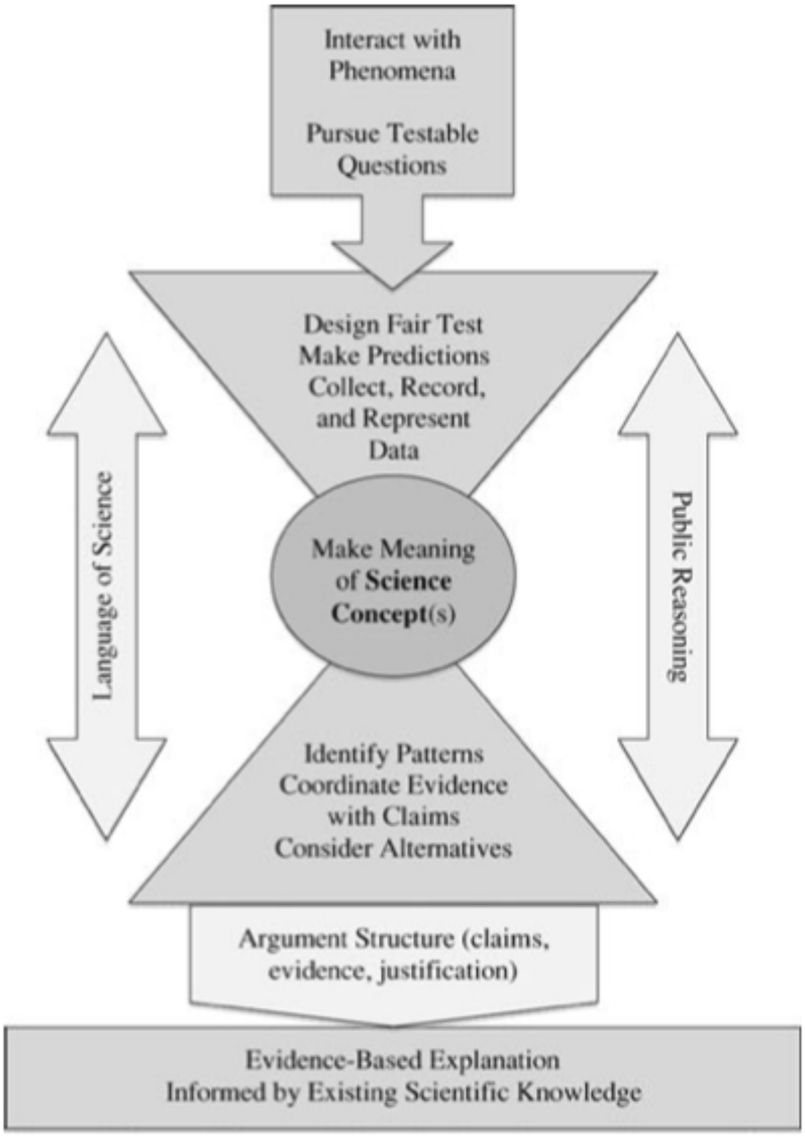

Figure 4. Teaching science as argument framework (Zembal-Saul, 2009).

The NRC (2000) defines inquiry along a continuum of teacher guidance from very teacher-directed inquiry to student-directed (see appendix D). Their report claims that, "students should have opportunities to participate in all types of inquiries in the course of their science learning" (p. 30). The authors reinforce the idea that students rarely have the skills necessary to begin at the completely open-inquiry end of the continuum. In his 2007 position paper, Settlage argued that, "holding open inquiry as the purest form of classroom inquiry and suggesting it is an ideal for which science teachers should strive is a myth" (p. 464). He pointed out that if we perpetuate this 'myth' of open inquiry to preservice teachers, we are setting them up for failure. And just as they reported empirical studies supporting more student-directed forms of inquiry, Minner and colleagues (2010) also reported studies that showed no statistical difference between student-directed or teacher-directed forms. Some studies even showed the reverse. Students in more structured teacher-directed groups had higher learning gains than students in open inquiry groups (Furtak et al., 2012; Sturm & Bogner, 2008). These contradictory findings simply add to the confusion around the inquiry continuum, and whether one form of inquiry is 'better' than another.

My purpose in this study is not to show that teacher-directed inquiry or student-directed inquiry is 'better' in terms of measureable student outcomes, but rather to investigate *if* and *how* teachers adapt their existing curriculum materials across the continuum and *why* they make these instructional choices. Inquiry can be taught as teacher-directed or student-directed, but what exactly does inquiry look like in the classroom? The NRC (2000) document defines inquiry in terms of 5 essential features, which include engaging in scientifically-oriented questions, giving priority to evidence, formulating explanations from evidence, evaluating explanations in light of alternative explanations, and communicating and justifying explanations.

At first glance it is immediately clear that these essential features give a heavy emphasis on explanation building as a critical piece of inquiry. This focus on explanation building is what separates science-as-inquiry from the typical activity based science classroom or traditional lecture-based science teaching, as the "central aim of science is to provide *explanations* for natural phenomena" (Driver, Leach, Millar, & Scott, 1996). Inquiry allows students to engage in their own learning and aligns with constructivist, student-centered learning theory (Driver et al., 1994, 1996). A teacher cannot transmit knowledge to students; they must build it on their own through exposure to authentic science practices and through learning how (and participating in how) scientific knowledge is generated, debated, and communicated (Driver & Oldham, 1986; Duit & Treagust, 2003; Duschl, 2008; Posner, et al., 1982; Windschitl, 2002). This is not a comfortable position for most teachers, and most especially for elementary teachers. In order to engage learners in inquiry practices teachers must first assume their students are capable of such thinking, which is not a common assumption (Metz, 2009).

Inquiry attempts to mimic the process of science in the classroom, though engaging students in authentic practice (Duschl & Grandy, 2008; Roth & Roychoudhury, 1993). No classroom inquiry, however, is a perfect representation of the true scientific community and is "inevitably partial and incomplete" (Kelly, 2008, p.121). Classroom teachers in general do not aim to form content experts, but they want their students to attain and understand the current scientific understanding of the concepts of their discipline (Wandersee et al., 1994).

Cutting across these 5 features of inquiry is a matrix allowing for variations in the amount of learner-direction and teacher-direction (see Appendix D). Surprisingly, even though this document has been in publication for over a decade, there is very little published research based upon these essential features (Davis et al., 2006). Further, a majority of elementary teachers are not familiar with the document. 70 percent of teachers in grades K-2 and 58 percent of teachers in grades 3-5 had not been exposed to this document (Weiss et al., 2001).

In light of the recently released framework, which will drive the new science education standards, these features are still "essential" to engaging students in scientific practices (NRC, 2012). The new framework states that,

> 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. (p. 19).

The new NRC framework (2012) introduces eight scientific practices as the aim of science education. It also emphasizes the integration of science and engineering practices because of the nationwide trend toward science, technology, engineering, and math (STEM). These scientific practices include (NRC, 2012, p. 42):

1. Asking questions (for science) and defining problems (for engineering),
2. Developing and using models,
3. Planning and carrying out investigations,
4. Analyzing and interpreting data,
5. Using mathematics and computational thinking,
6. Constructing explanations (for science) and designing solutions (for engineering),
7. Engaging in argument from evidence, and
8. Obtaining, evaluating, and communicating information.

These scientific practices use new and updated language to more explicitly encourage science teachers to engage students in the practices of science. The language, while updated and more explicit (i.e. drawing out modeling and computational thinking separately), is parallel with the aims of the five essential features (NRC, 2000). These five features are still ‘essential’ for classroom teachers to engage students in when teaching science as inquiry.

Scaffolding

At the heart of notions of the inquiry continuum is the idea that students need scaffolding in order to progress from more teacher-directed[1] forms of inquiry to more student-directed forms. Students need training in the processes of science, and teachers need to provide the correct amount of scaffolding to their students. It would be inappropriate and unsuccessful to expect learners at any level, especially elementary school, to step immediately into an open-inquiry experience from day one of the school year. Inquiry lessons should be structured to challenge students with, not only the content, but also with the amount of autonomy they are provided in designing and conducting the investigation. As students become more proficient at more teacher-directed forms of inquiry, teachers can progress to more student-directed forms of inquiry as appropriate. This requires new roles for teachers and students alike (van der Valk & de Jong, 2009).

The amount of teacher guidance during this type of progression of science investigations decreases as students advance to the more open versions of inquiry. The goal should not be to teach every single lesson as complete, open-inquiry, as this is impractical. Rather, teachers can wean students off of how much structure they provide as they become proficient with scientific practices such as questioning, collecting and analyzing data, etc. van der Valk and de Jong (2009) provide a theoretical framework that guided this study and provided a lens through which I analyzed existing literature.

Teacher-directed forms of inquiry require *guiding by prescribing*, where the main role of students is to carry out prescribed steps (some literature refers to this type of lesson as 'cookbook' investigations: - Clark, Clough, & Berg, 2000). When students are

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[1] Note: The literature in this area uses different terms for representing different variations of inquiry (i.e. learner-guided, student-guided, student-led, student-directed, teacher-led, teacher-guided, teacher-directed, open inquiry, guided inquiry, full inquiry, etc). For purposes of this study, I will use the terms learner-directed and student-directed interchangeably.

ready for more autonomy, the teacher provides *guiding by modeling*, providing examples of how to analyze data and reach conclusions. *Guiding by scaffolding* helps students transition into even more autonomous variations of inquiry by helping them learn to fill the autonomous roles. At the most autonomous level, teachers provide *guiding by laisser-faire*, or ‘full space to organize their own activities’ (van der Valk & de Jong, 2009, p. 832). Importantly, these authors made no judgment as to which type of scaffolding is ‘better’. The goal for teachers should be providing the correct amount of scaffolding their students need at that moment in time.

Scaffolding research ties back to the ideas of Vygotsky (1962), whose concept of the “zone of proximal development” (ZPD) influenced how much scaffolding a particular student needs in order to be successful. The idea of the ZPD has typically been applied to individual learners, but Guk and Kellogg (2007) have applied it to whole-class situations. This model affords an interesting way for teachers to scaffold their learners’ abilities within the class’s ZPD across the continuum of inquiry experiences. If a class needs more scaffolding to engage in the scientific practices of inquiry, the teacher could start at the more teacher-directed side of the continuum and scaffold students toward more learner-directed forms of inquiry over a series of many investigations.

On the other hand, if students are successful at more teacher-directed forms of inquiry, their teacher might begin removing scaffolding from their curriculum materials (e.g. premade worksheets) and transitioning students toward more learner-directed forms of scientific practice. Often, students need significant scaffolding in order to do so, which makes the inquiry continuum a tool the elementary science teacher can use to adapt existing science curriculum materials to meet the needs of early learners. Science curriculum materials (lesson plans, teacher guides, student worksheets, and other curricular resources) are important resources that can support elementary teachers to engage students in inquiry-based science.

Teacher – Curriculum Relationship.

Teacher knowledge of curriculum (see figure 5) is an essential component of teacher pedagogical reasoning (Abell, 2007; Peterson & Treagust, 1998). For example, knowledge of curriculum is one aspect of the complex web of teacher pedagogical content knowledge (Grossman, 1990; Magnusson, Krajcik, & Borko, 1999).

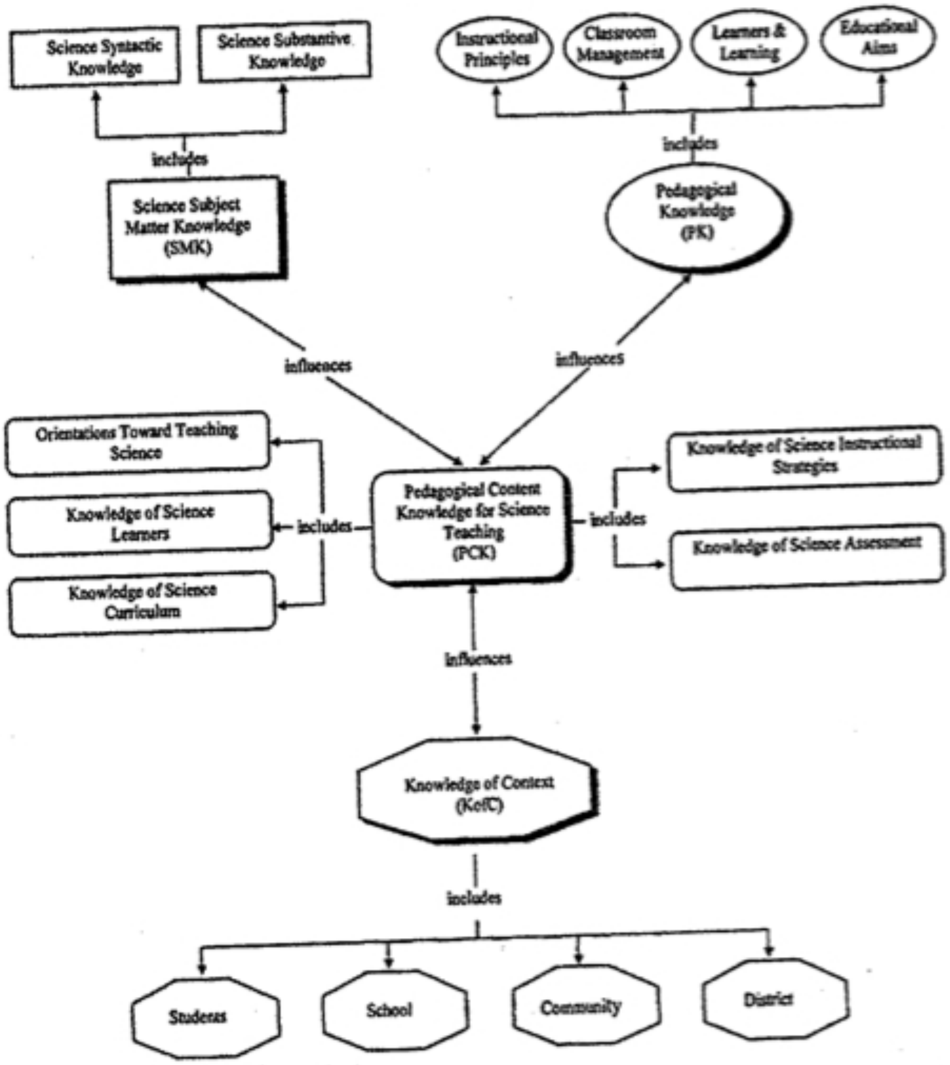

Figure 5. A model of science teacher knowledge (from Abell, 2007; Grossman, 1990; and Magnusson, Krajcik, & Borko).

There is also research that looks at the differences between curriculum materials teaching *to* teachers, rather than aiming (as traditional, historic curricula has done) at teach *through* teachers (Remillard, 1999). These curricula are called "educative curriculum materials" (Ball & Cohen, 1996; Beyer & Davis, 2009-a, 2009-b; Davis & Krajcik, 2005; Schneider & Krajcik, 2002). This shift is an important one, as the teacher becomes much more actively involved with their science curriculum materials, rather than a passive curriculum user. There is a dynamic relationship between teachers, students, and curriculum materials as evidenced in Remillard's model (2005) (see Figure 6).

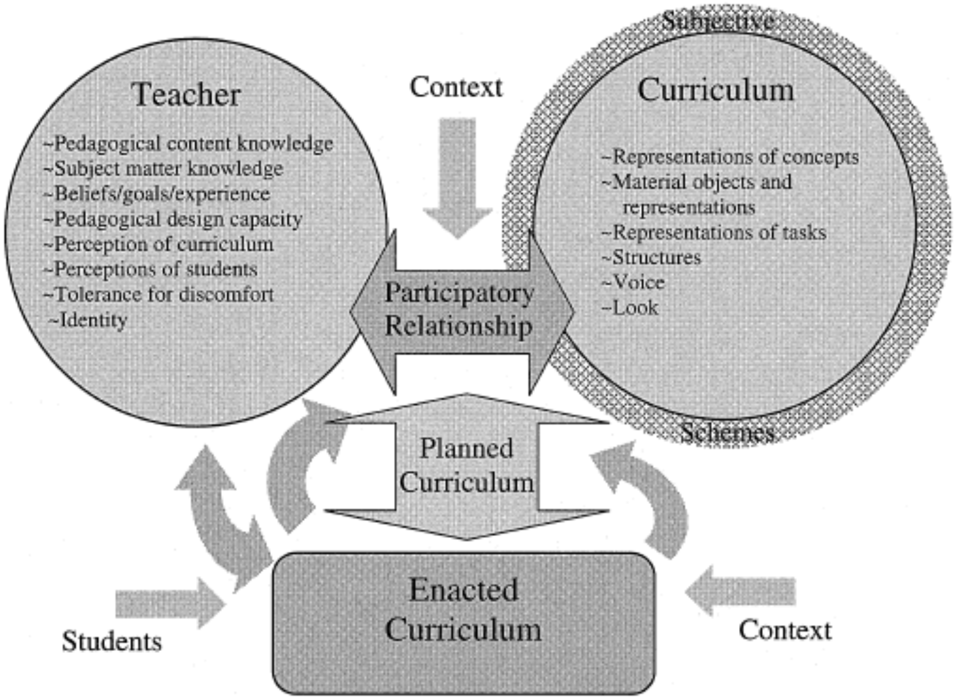

Figure 6. Elements of the teacher-curriculum relationship (Remillard, 2005, p. 235)

Teachers use curriculum materials at varying levels, but new teachers tend to rely on their curriculum materials especially heavily in their first years of teaching (Abell & McDonald, 2004; Century et al., 2010; Kauffman et al, 2002). Many times, curriculum developers fail to take account of the teacher in designing curriculum materials for the classroom (Ball & Cohen, 1996) opting for "teacher-proof" (Barab & Luehmann, 2003) curriculum materials, which could be taught by anyone without much training at all (Brown, 2009). At the elementary level, especially, teachers rely heavily on their curriculum materials because of their lack of science content knowledge and low self-efficacy for teaching science. The following authors captured the dichotomy of how curriculum materials are often enacted in elementary schools:

> Elementary school classrooms are experiencing a paradox in curriculum and instruction. On the one hand, teachers are driven by high-stakes testing to enact a *curriculum of reproduction*, where the focus is on low-level facts, algorithms, and right answers… On the other hand, in this era of standards-based reform, we find the vision to be that of a *curriculum of inquiry*. (Abell & McDonald, 2004, p. 259 [emphasis added])

The difference between a curriculum of reproduction and a curriculum of inquiry is dependent on whether a teacher adapts their curriculum materials, and also dependent on how structured (teacher-directed) the existing curriculum materials are. In light of the differences between curricula of reproduction and curricula of inquiry, it is important to explore how teachers modify their curriculum materials as they implement their science lessons. Teachers enact curriculum materials across a range of possibilities (Schneider et al., 2005). There are a myriad of factors that affect curriculum enactment, which, in part, makes it difficult to study. Ball and Cohen (1996) offer five domains that affect how curriculum materials are enacted:

- What teachers think about their students
- Teachers' own understanding of the material
- How teachers fashion the material (adaptation)

- Intellectual and social environment
- Community and policy contexts

This study was mostly concerned with the third domain, which concerns how teachers adapt their curriculum materials. Curriculum materials can be enacted "as-is," they can be adapted (although the quality of the adaptations varies (Roehrig, Kruse, & Kern, 2007; Schneider et al, 2005)), or they can serve as an inspiration for something entirely different than intended (Davis & Smithey, 2009). Many teachers do not recognize that adapting curriculum materials is "allowed" or even a part of their job (Bullough, 1992; Davis & Smithey, 2009; Eisenhart, Shrum, Harding, &, Cuthbert, 1988).

Review of Relevant Literature

In this section I show how this study fits in with the existing literature. I begin broadly with why elementary science is important and what the research says about how it is typically enacted. Included in this section is an overview of the many existing definitions of inquiry and why this creates confusion for practicing teachers. I then discuss the importance of curriculum materials to elementary classroom teachers and how they need to be scaffolded to adapt the curriculum materials to meet the conditions of teaching science as inquiry. These sections tie together to represent the importance of how elementary teachers adapt their curriculum materials around the inquiry continuum. Figure 7 represents how the literature review is structured.

Elementary Science

While inquiry is important across all grade levels, it is critically important in the elementary science classroom. Even though its importance is well documented (e.g.

AAAS 1993; NRC, 2000, 2007, 2012), elementary science has been cited as the weak point in science education (Appleton & Kindt, 2002; Eshach, 2003; Gardner & Cochran, 1993). These early formative years should be a time when science is an extension of early learners' natural curiosity. Instead, science often gets pushed aside for other subjects such as math and reading because of state standards and No Child Left Behind legislation requiring states to assess math and reading every year. For example,

> Individuals associated with science education were beginning to feel the negative impact of NCLB's emphasis on math and reading was having on science education as science educators were being forced to defend their discipline against district who wanted to spend more time on math and language arts. (Vasquez, Teferi, & Schicht, 2003, p. 39)

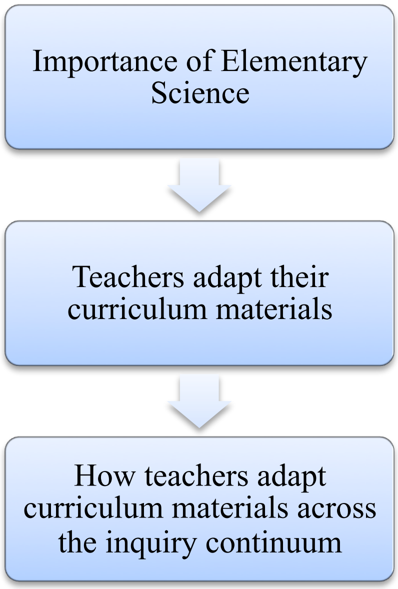

Figure 7. Literature review flow of ideas

In 2007 No Child Left Behind began requiring schools to assess some form of science in grades three through five, although these numbers are not required to be reported as part of the school's Annual Yearly Progress in order to qualify for federal funding (Marx & Harris, 2005). The National Survey of Science and Mathematics Education reported the percentages of time spent on the main elementary subjects. (Table 1).

Elementary teachers face immense challenges in teaching science as inquiry in their classrooms (Abell & McDonald, 2004; Davis, et al, 2006; Davis & Smithey, 2009). These challenges include (1) limited training in science for generalist elementary teaching degrees, (2) limitations of elementary curriculum materials in supporting teachers to enact science-as-inquiry, (3) the mismatch between traditional assessment techniques and inquiry, (4) issues associated with classroom management, and (5) difficulties in teaching inquiry to early learners. The next section looks at each of these five challenges.

Table 1

Percentage of time per subject in third grade classrooms (National Institute of Child Health and Human Development, 2005)

	Literacy	Math	Science
Percentage	56%	29%	6%

Limited content knowledge. First, elementary teachers are typically trained as generalists, and, therefore, often have limited content knowledge in science (i.e. Abell, 2007; Anderson & Mitchener, 1994). This could be partially due to the fact that few college courses are required for their elementary education degrees (Appleton & Kindt, 2002; Davis et al., 2006). In the most recent national survey on the status of elementary science, the most recent coursework in science for nearly 60% of elementary teachers occurred more than a decade ago, and only 5% of elementary teachers reported having a college or graduate degree in science, science education, or engineering (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013). This lack of science content knowledge directly influences elementary teachers' confidence in teaching science (Abell, Bryan & Anderson, 1998; Davis et al., 2006; Howes, 2002). It often results in textbook-driven lessons attempting to directly transmit information from teacher to student. Fewer than three in 10 elementary science teachers reported feeling 'well qualified' to teach science, whereas seven in 10 indicated they felt 'well qualified' to teach reading/language arts (Weiss, Banilower, McMahon, & Smith, 2001).

Elementary teachers have also been shown to have limited knowledge and experience with science as inquiry (Davis & Smithey, 2009; Keys & Bryan, 2001). Some studies claim this occurs because they did not learn science as inquiry in their formal schooling years, and so do not know how to teach it in their classrooms. "Science was something teachers took in college, but it was not something they experienced as a process of inquiry" (Welch, Klopfer, Aikenhead, & Robinson, 1981). These limitations of knowledge of science cause some elementary teachers to avoid teaching science altogether (Davis & Smithey, 2009).

Curriculum limitations. Second, much of the existing elementary science curriculum materials do not support teachers in enacting inquiry in their classrooms. Only 5% of elementary teachers report being able to choose their own textbook or curriculum modules (Banilower, et al, 2013). Most of these decisions are made at the district level. Research from the PIESC[3] project (Promoting Inquiry-based Elementary Science through Collaborative Curriculum Co-construction), as shown in Figure 1 (above), showed that elementary curriculum materials scored very low on their inclusion of the five essential features of inquiry (Forbes, Biggers, & Zangori, in press; NRC, 2000). The three sense-making features scored the lowest of the five, significantly lower than the first two features (questioning and evidence). Elementary science typically takes on one of two orientations (Abell & McDonald, 2004), either a typical didactic transfer of information, or an 'activitymania' orientation with a string of disconnected activities. The first orientation of teaching science through a traditional, didactic method, i.e. learning facts from a textbook, focuses on the content of science but ignores the processes of science (Schmidt, McKnight, & Raizen, 1997; Tobin, Briscoe, & Holman, 1990). For instance,

> Many elementary teachers believe that inquiry approaches present a developmentally appropriate, concrete, and less abstract mode of interactive learning that allows students to construct their knowledge about science is compatible with elementary students' physical, intellectual, and emotional development. They frequently describe the inquiry as free play, messing around with objects and ideas, or discovery learning. Unfortunately, many teachers overemphasize the importance of sensory experiences, placing primary emphasis on activities and physical engagement leading to 'activitymania.' The emphasis on the activities and not on the debate/argument around the experiences, evidence and claims and the cognitive scaffolding required in the meaning-making process. (Abrams, Southerland, & Silva, 2008)

This type of teaching focuses on a transfer of information from teacher to pupil (Enyedy, Goldberg, & Welsh, 2005), which does not conform to constructivist teaching ideals.

The other common orientation to teaching elementary science, through what has been deemed "activitymania" (Abell & Roth, 2004), engages students in the processes of science usually devoid of content. "Activitymania is one way science has entered elementary classrooms. It is a step away from teacher-directed, textbook-centered elementary science" (Moscovici & Nelson, 1998, p. 40). Activitymania strings together activity after activity, which is good for giving students hands-on experience with materials, but does not develop their ideas and explanations about the phenomenon being studied. Neither of these orientations (didactic teaching or activitymania) support teaching science as inquiry. Although hands-on experience with science is important, it is not enough. A growing body of research suggests that elementary teachers leave out the sense-making activities that should be associated with the hands-on activities.

Assessment. The third challenge elementary teachers face when attempting to implement science as inquiry in their classrooms is the mismatch of current assessment practices with the goals and products of inquiry lessons. Abell and McDonald (2004) claim, “in the present climate of high stakes testing, elementary teachers also have serious concerns about how they will assess student learning” (p. 258). Teachers in their study worried that their students weren’t covering as much content as classrooms teaching science with a more traditional, didactic orientation and, therefore, would not be prepared for the end of year assessments.

Although some studies have shown that students who are taught in inquiry-oriented science classrooms score higher on standardized tests (e.g. Geier et al., 2008; Hmelo-Silver et al., 2007), there are also studies with the opposite result (Kirschner, Sweller, & Clark, 2006; Pine et al, 2006). No Child Left Behind (U.S. Department of Education, 2002) gives substantial monetary incentives to states that measure student performance against a standard to show school, teacher, and student success or failure. This type of standardized testing can never be a true measure of what students are learning in inquiry-oriented science classrooms (Blanchard, Southerland, & Granger, 2008; Shaver, Cuevas, Lee, & Avalos, 2007; Southerland, Abrams, & Hunter, 2007; Whitford & Jones, 2000). A standardized test cannot accurately demonstrate the skills students learn or represent their understanding of the authentic process of science (Pine et al, 2006).

Teachers need to focus on formative assessment to meet their students where they are and drive their instruction accordingly (Ascherbacher & Alonzo, 2006; Ayala et al., 2008; Bell & Cowie, 2001; Bybee et al., 1989; Cronin-Jones, 1991; Harms & Yeager, 1981; Lee & Houseal, 2003; Otero, 2006; Welch, et al, 1981; Wiliam, 2011). Formative assessment is defined as:

> An assessment functions formatively to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have made in the absence of that evidence. (Wiliam, 2011, p. 43)

Formative assessment strategies are key to (a) knowing what prior knowledge students bring to the classroom, and (b) developing instruction to clear up misconceptions and teach new content. Formative assessment is also key to adapting curriculum materials across the inquiry continuum, because a teacher needs to be aware of what his/her students are capable of achieving successfully and how to adapt their curriculum materials to meet those needs (Black & Wiliam, 2009).

Logistical challenges. Fourth, elementary teachers face several logistical challenges in implementing science as inquiry in their classrooms. These challenges include (a) materials, (b) time, and (c) safety (Abell & Roth, 1992; Appleton, 2003; Lee & Houseal, 2003; Tobin, et al, 1990). First, science is a materials-rich subject, and in order for students to experience science, they need materials and equipment in order to do so. Teachers face the challenge of locating, setting up, cleaning up, and storing materials and equipment used for science (Appleton, 2003). Science-as-inquiry requires students to explore scientific topics directly, through hands-on investigations (NRC, 1996). This could take many forms, i.e. doing an experiment, designing a way to test a problem, manipulating a model, or using a database of already-existing data to answer a research question (e.g., Duschl, 2008). Each of these opportunities requires some kind of classroom materials, which are sometimes scarce in elementary schools (Appleton & Kindt, 2002; Abell & McDonald, 2004), and poses challenges for classroom management (Keys & Kennedy, 1999). Teachers are often fearful to implement inquiry because they are afraid it will be chaotic (Brickhouse & Bodner, 1992).

The second logistical challenge elementary teachers face is the fact that science lessons take extended amounts of time, more specifically, the *perception* by elementary teachers that they take extended amounts of time (Richardson, 1997). Teachers must make science a priority during the school day to devote enough time to completing activities and sense making to engage students in inquiry practices. 71% of school districts surveyed for a report from the Center on Educational Policy indicated that they had reduced instructional time for other subjects (including science) to make more time for NCLB-assessed subjects (Center on Educational Policy, 2006). Teachers in the national survey of the status of elementary science reported that only 20% of elementary students receive science instruction every day, as opposed to 99% of elementary students receiving math instruction every day (Banilower et al., 2013). The same elementary teachers reported an overall average of 19 minutes per day spent on science versus an average of 89 minutes per day spent on Language Arts instruction.

Teachers are under time constraints no matter which type of teaching they do, but teaching science-as-inquiry involves in-depth lessons with a focus on allowing students to make mistakes, make changes, do external research, and build explanations rather than simply telling them the “right” answer (NRC, 2007). American science curriculum materials, especially, have been characterized as being “an inch deep and a mile wide” (Duschl, 2008) which directly opposes the purposes and aims of science-as-inquiry. Time is also needed for both planning and enacting the science lessons. This challenge links back to the first point about science being de-emphasized in the elementary classroom in favor of more time for literacy and math (Appleton, 2003). Finally, teachers must always consider the issue of safety when students are working with science materials and equipment (Abell & McDonald, 2004; Keys & Kennedy, 1999). Most other subjects do not have safety concerns in daily activities.

Early learners. The fifth challenge associated with teaching science as inquiry in the elementary classroom deals with teaching science to especially early learners who may not be able to read and/or write yet, or who are beginning readers and/or writers. Elementary teachers must be creative in their requirements for how students represent their ideas in these instances. There is a growing body of research, as mentioned earlier, showing that early learners are capable of engaging in sophisticated science practices (Lehrer, Carpenter, Schauble, & Putz, 2000; Lehrer & Schauble, 2004; Lehrer, Schauble, & Petrosino, 2001). This is an extremely important line of research, which supports the importance of engaging students, especially early learners, in these essential scientific practices. Elementary teachers need to learn how to scaffold their lessons to better meet their students' needs in order to offer opportunities to engage in the process of science.

Curriculum Materials

Research is lacking on inservice elementary teachers' views of inquiry, and specifically of this 'inquiry continuum'. This research is especially absent at the elementary level when students are forming critical ideas about science content and processes. Ball and Cohen (1996) claim that teacher ideas, beliefs, and understandings all affect the enactment of their science curriculum materials. Teachers also often struggle to translate their ideas into practice (Forbes & Davis, 2010), but one resource they rely on is their curriculum materials. Even when relying heavily on curriculum materials, teachers make adaptations to them, though the quality of the adaptations varies greatly (Schneider et al., 2005). However, teachers need a great deal of support in order to learn how to effectively and appropriately modify their curriculum materials in ways that make them more inquiry-oriented. Further research is needed on teacher ideas about inquiry and how those ideas influence their teaching practice. This study helps to fill this gap that exists in the literature by exploring elementary teachers' ideas about the inquiry continuum and how they influence the planning and enactment of science as inquiry lessons.

The broad and varying definitions of inquiry within the literature mentioned above provide little guidance to teachers for how to actually plan, enact, and assess science lessons within a teacher's classroom (Keys & Kennedy, 1999). Science curriculum materials (lesson plans, teacher guides, student worksheets, and other curricular resources) are important resources that can support elementary teachers to engage students in inquiry-based science. However, science curriculum materials available to teachers often vary in quality (Forbes & Davis, 2010; Beyer, Delgado, Davis & Krajcik, 2009; Kesidou & Roseman, 2002). In addition to quality, they also vary in specificity, rigidity, and standardization (Kauffman, Johnson, Kardos, Liu, & Peske, 2002).

Fidelity of implementation. One body of research focuses on how closely a teacher's implementation of curriculum matches the intentions of the curriculum developers. Some studies suggest that the closer a teacher teaches the curriculum to the way the developers intended it (i.e. high fidelity) the higher the level of inquiry-based teaching and learning in the classroom (Bybee, 1997; Coulson, 2002). Of course, this can only be true if the curriculum is written to support inquiry-based teaching and learning. Others contend that implementing the curriculum "as-is" is exhausting for teachers (Davis, 2003), and takes away their creativity. Still other studies show a link between teacher belief and their implementation of curriculum. If classified as "reform-based", teachers may be more apt to teaching a reform-based curriculum (Roehrig & Kruse, 2005). This idea of "fidelity of implementation" is a relatively un-researched idea with respect to elementary science curriculum material implementation. A gap in the existing research is whether high levels of fidelity of implementation of curriculum increase student learning.

Curricular adaptations. In order to engage students in inquiry practices, then, elementary teachers must learn to productively modify and adapt the science curriculum materials they use (e.g., Remillard, 2005). Teachers must, therefore, be supported to learn to adapt science curriculum materials effectively. Recent studies researching this phenomenon have provided promising findings (e.g., Forbes & Davis, 2007, 2008, Forbes, 2011; Beyer & Davis, 2009-a, 2009-b; Davis, 2006; Schwarz et al., 2008). These studies show that elementary science preservice teachers are capable of modifying existing science curriculum materials to better engage students in the practices of science. The work presented here builds on this body of preservice research to begin to explore an area yet to be addressed; practicing elementary teachers' learning to use science curriculum materials to plan for and engage in inquiry-based science teaching across the inquiry continuum.

Summary

Science is typically de-emphasized in elementary classrooms for a variety of reasons, including elementary teachers' lack of preparation in science coursework, limitations of elementary curriculum materials, lack of alignment of current assessment practices and science education reform ideals, classroom management issues associated with teaching science as inquiry, and the difficulty of teaching early learners (who may not be able to read or write) how to represent scientific ideas. In addition to these challenges, an agreed-upon definition of inquiry does not exist within the science education community. This leads to confusion and frustration on the part of elementary science teachers. Inquiry can be defined across a continuum of teacher-directed to student-directed within five 'essential features' defined by the NRC, but teachers need to value all types of inquiry across this continuum and scaffold their students accordingly. This usually means they need to adapt their curriculum materials to meet the needs of their learners. This study investigated how inservice elementary teachers adapted their curriculum materials across this inquiry continuum.

CHAPTER III

METHODS

In this section I present a general overview of mixed methods research and how I conducted the study to answer my four research questions. Second, I introduce the participants, both the large group and the smaller, select group of case-study teachers; and I describe in detail the methods utilized for this dissertation study. Finally, I describe how I collected and analyzed the data using both quantitative and qualitative methods for analysis.

Characteristics of Mixed Methods Research

Mixed methods research is defined by Tashakkori and Teddlie (1998) as the combination of "qualitative and quantitative approaches in the methodology of a single study or multi-phased study" (p. 18). Mixed methods research can be thought of as a continuum (see figure 8).

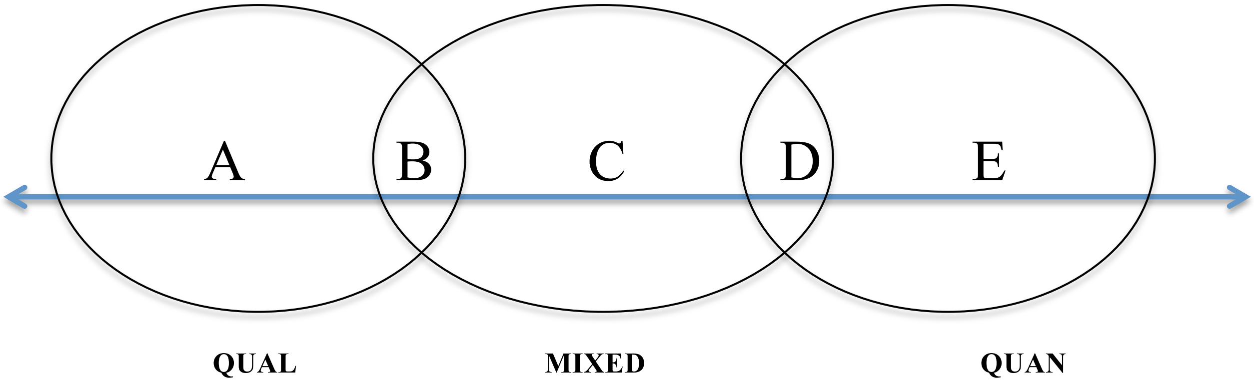

Figure 8. Continuum of mixed methods research (from Teddlie &Yu, 2007, p. 79)

This Venn diagram depicts the continuum of research methodologies ranging from completely qualitative (such as the letter ‘A’ from figure 8) to completely quantitative (such as those depicted by letter ‘E’ in figure 8). Some studies might emphasize qualitative analysis (such as the letter ‘B’) while others emphasize quantitative analysis methods (such as letter ‘D’ above) depending on what the author’s research questions are and which method or methods match best to answer them. Many research questions today are complex and need multiple forms of evidence in order to answer them completely.

Many researchers support the idea of not trying to characterize research into an either/or dichotomy between quantitative or qualitative methods. This allows researchers to have more freedom to answer research questions using the method(s) that best fit rather than designing a research study to fit a certain method. The comparisons presented by Teddlie and Tashakori are very helpful in looking at the differences regarding causal relations and the possibility of generalizations for the continuum of these methodologies and paradigms. This type of research cannot be done in a laboratory or from the library. It is a research paradigm that encourages the researcher to get to know their subjects in the study and live their experience as closely as possible. I approached this study with a pragmatist paradigmatic orientation (Johnson & Onwuegbuzie, 2006; Morgan, 2007), in order to combine the qualitative and quantitative methodologies rather than treating them as purely separate entities. Pragmatism has been defined by Johnson and Ongeugbuzie (2004) as:

> A very broad and inclusive ontological realism where virtually everything a qualitative or quantitative researcher deems to be real can be considered, in some sense, to be real, including subjective realism, intersubjective realism, and objective realism. (p. 54)

Pragmatism is useful in mixed methods research as it moves beyond looking at qualitative versus quantitative and accepts a broader worldview.

My purpose in using mixed methods is complementarity (Greene, Caracelli, & Graham, 1989); specifically to explore the reasoning behind the findings of the quantitative phase of the study (which involved the entire study sample) by exploring in detail a smaller group of teachers' curriculum material adaptations and their pedagogical reasoning around these adaptations. Greene et al. (1989) define complementarity as a purpose for mixed methods research which “seeks elaboration, enhancement, illustration, clarification of the results from one method with the results from the other method” (p. 260).

Research Design

This mixed methods study was situated in a larger quasi-experimental research study (IRB# 201004754), and investigated how inservice elementary teachers adapted and enacted their existing science curriculum materials across the inquiry continuum. A concurrent nested design was used (Creswell, Plano Clark, Gutmann, & Hanson, 2003) in which a qualitative multiple case study was nested within a quantitative exploratory study. The data from the quantitative was used to determine *if* and *how* the teachers adapt their curriculum materials across the inquiry continuum, and the qualitative case-study phase took a more in-depth look at explaining *how* and *to what extent* the teachers made the adaptations they made to their existing curriculum materials.

The data collection occurred during 2010-2011 (see timeline in Table 2). The qualitative and quantitative strands occurred concurrently (Creswell & Plano Clark, 2011). The research design is shown in figure 9. By using a mixed methods approach, I drew ‘meta-inferences’ (Creswell & Plano Clark, 2011, p. 212; Teddlie & Tashakkori, 2009, p. 300) combining both types of analysis (see Appendix J for joint data display).

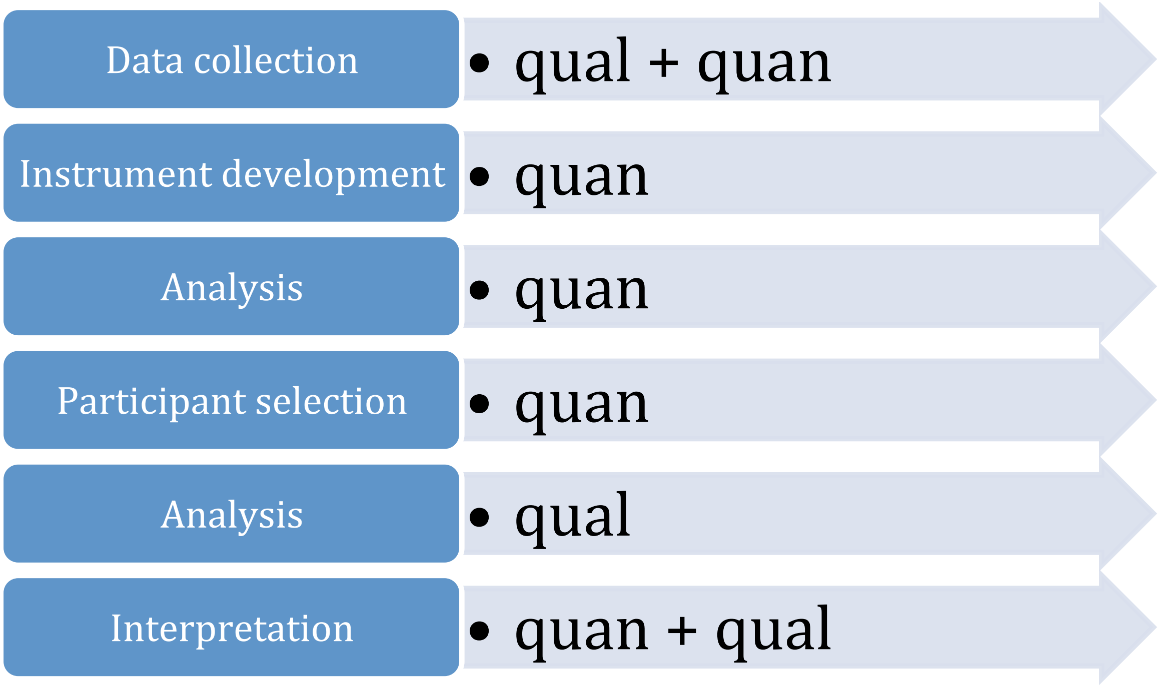

Figure 9. Design model of the proposed mixed methods study

Research Context and Participants

The teachers in this study were recruited for volunteer participation (a type of convenience sampling [Teddlie & Yu, 2007]) in the PIESC^3 project, a multi-year professional development grant through the University of Iowa. The PIESC^3 project's purpose was to investigate if and how inservice elementary teachers adapted their existing curriculum materials to be more inquiry oriented according to the five essential features of inquiry (NRC, 2000). Data for the present study came from the first year of the PIESC^3 project, and was collected during the 2010-2011 school year. Approximately half of the teachers participated in a professional development program as part of their participation in the larger project, but the data used for this study came from the first year 'baseline' data of the project, so the professional development was not considered an influencing factor since it occurred during the summer after the data was collected.

Table 2

Timeline of data collection

2010-2011	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
Whole Group	Recruiting, LPE		3 Lessons + lesson plans collected							
Case Study		Initial Interviews				Lessons videoed + Lesson Plans collected + Pre/Post interviews			Final Interviews	

The teachers were mainly recruited from the Douglas Community School District[2] (DCSD) in the Midwest. DCSD is one of the largest in the state, and considered

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[2] District names are pseudonyms

an urban, high-needs district. The district has a total of 19 elementary schools where recruiting efforts were focused. A recruiting email was sent to all of the elementary teachers in DCSD (650+ teachers) announcing the project and asking for interested volunteers (see appendix I for the recruiting email flyer). From this email, 50 teachers volunteered to participate in the PIESC[3] project. Since the project goal was 60 teachers (30 for the professional development and 30 for the control group), we turned to surrounding districts for additional control group participants.

Using the same email template, additional teachers were recruited from districts within regions served by Area Education Agency 1[3] (AEA1) and Area Education Agency (AEA2), central facilities serving schools in their surrounding areas. AEA1 serves 40 school districts, and AEA2 serves 46 school districts. Seven teachers volunteered from the AEA2, four from four schools within the area including one private school. AEA2 recruiting effort yielded additional teachers, one from each of eight districts and 11 from a larger district (International Community School District, ICSD)[4].

Over the course of the school year, 18 teachers from the original 50 DCSD recruits dropped out of the study, citing various reasons (e.g. health reasons, lack of time, maternity leave, and retirement). Four of the ICSD teachers dropped out, as well as the individual teachers from three of the AEA2 schools. Additionally, there were several teachers who never submitted classroom observation videos, and were subsequently removed from the participant list. Three of the volunteer teachers from DCSD were middle school teachers (7th and 8th grade) who asked to participate. Their data is not included as part of this proposed study because I focused only on elementary inservice

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[3] Pseudonym

[4] Pseudonym

teachers (K-6). This left a total of 40 inservice elementary teacher participants, mainly from DCSD as shown in Table 3.

Table 3

Breakdown of schools and teachers represented in the study

	District	Total # Students	% Free or Reduced Lunch	# Schools represented in this study	# Teachers represented in this study
DCSD	Douglas Community School District	16, 594	57.8%	12	28
	Area Education Agency 1				
AEA1	School 1	1753	44.4%	2	4
	School 2	1945	62%	1	1
	School 3	1442	45.5%	1	1
	School 4		NR[5]	1	1
	Area Education Agency 2				
AEA2	School 5	12,405	29.7%	2	3
	School 6	16728	42.7%	1	1
	School 7	1755	20.9%	1	1

The quantitative phase involved the 40 elementary teachers described above. The voluntary nature of the study did not lend itself to random sampling or assignment, but

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[2] Private Schools are not required to report percentages of Free/Reduced lunch.

encompassed a variety of teachers, grade levels, and schools. The resulting 40 teachers taught grades Kindergarten through 6th grade, with a majority of teachers in the study representing upper-elementary grade levels. One of the teachers was from a private school; all others represented public schools in the state. In this Midwestern state, it is a common practice for buildings to have blended classrooms between two grade levels. The participant teachers' grade levels are represented in Table 4.

Table 4

Breakdown of grade levels the teachers in this study represent

Grade Level	Number of Teachers from PIESC[3]
Kindergarten	2
1st Grade	3
2nd grade	3
2nd/3rd Grades	1
3rd Grade	7
3rd/4th Grades	3
4th Grade	8
4th/5th Grades	1
5th Grade	10
6th Grade	1
Intervention Specialist (K-6)	1
Total	40

Data Sources and Collection

The following table (Table 5) summarizes the data sources collected as part of this study, the purpose of collecting each type of data, and which appendix applies to each data source. Data sources for this study included data collected for the entire group of teachers (n=40) and additional data collected from the subsample of case-study teachers (n=3). Data from all teachers included three classroom observations (videos) and matching lesson plans from a self-selected science unit. Case-study teachers were interviewed nine times over the course of the school year and provided two additional documents. Finally, each data source is presented in detail, including a description of how it was collected and implemented, and how it helped answer one or more of the research questions.

Lesson Plans

Each of the 40 teachers in the study selected a science unit they currently taught and chose three lessons from the unit to focus on during the PIESC^3 project. For each of the three chosen lessons, teachers submitted lessons plans to show what they planned to teach. Most of the submitted lesson plans were copied straight out of the Full Option Science System (FOSS) Teacher's Guide. FOSS is the main source of the district adopted elementary science curriculum materials. Occasionally, the teachers found lesson plans online at popular websites (such as www.sciencenetlinks.com) or from other curriculum sources. Some teachers made notes on the lesson plans such as marking out certain sections or drawing a line to indicate how far they planned to go during the lesson. I considered their markings as part of their planned lesson when scoring the lesson plans, and only scored the parts the teachers planned to enact. If no marks were made, everything the teacher submitted was scored.

These lesson plans were a crucial data source in this study, for, by comparing the scores of the lesson plans to the scores of the enacted lessons, I determined whether the teachers modified their curriculum materials during instruction to be more or less teacher-directed.

Table 5

Data sources for both entire sample and case-study teachers

	Data Sources	Description	Purpose	Associated Research Question(s)	Appendix
Entire Sample (n=40)	Classroom Observations (Videos)	Each teacher videoed three enacted lessons from a self-selected elementary science unit.	To assess how teachers enacted the inquiry continuum.	1 2 3 4	Appendix A & C (rubrics for scoring the videos)
	Lesson Plans	Lesson plans matched the videotaped lessons (i.e. copies from the FOSS Teacher's Guide)	To assess how teachers modified their curriculum materials across the inquiry continuum.	1 2 3 4	Appendix A & C (rubrics for scoring the lesson plans)
	Lesson Plan Evaluation (LPE)	Each teacher evaluated a provided lesson about magnets based on the inquiry matrix	To assess teachers' definitions of inquiry, the five essential features, and the inquiry continuum; and to assess whether they recognized the features in a provided lesson.	2 4	Appendix H
Case-study teachers (n=3)	Lesson Plan Rationale (LPR)	Teachers documented the adaptations they plan to make when enacting the existing curriculum materials	To explore teachers' curriculum material adaptations and their pedagogical reasoning.	4	Appendix G
	Formal Interviews	Semi-structured interviews at the beginning and end of the	To assess elementary teachers' ideas about inquiry, the	4	Appendix E

	semester exploring teachers' definitions of inquiry, each of the five features, and the inquiry continuum	five essential features, and the inquiry continuum.		
Pre- and Post-Enactment Interviews	Semi-structured interviews before and after each videorecorded observation.	To investigate teachers ideas about, planning for, and implementation of the inquiry continuum.	2 4	Appendix F

Lesson Enactments.

From their self-selected unit, the teachers selected three lessons which they videorecorded. We provided the teachers with three SD memory cards to use for recording each of their lessons. Video cameras were provided to the district science coordinator to check out to teachers on an as-needed basis. The teachers in the study checked out a video camera, recorded the lessons on their own SD cards, and then mailed the SD cards back to the project office in a postage paid envelope. Case-study teachers, however, were videorecorded in person by the author or by Laura Zangori (another PIESC[3] researcher). The videos, once received, were uploaded to a secure server in the College of Education which was password protected to ensure the confidentiality of the teachers in the study.

The first year of data yielded 120 matched pairs of enacted lessons (videos) and lesson plans (documents) from the 40 teachers. The videorecorded lessons ranged from approximately 25 minutes to over one and a half hours in length with an average lesson lasting 42 minutes. The topics of the lessons varied according to the district's scope and sequence by grade level, and were self-selected by each teacher. A great majority of the lessons (64.8%) were Full Option Science System (FOSS) lessons, with the remaining few scattered between STC (9.3%), SNOOPS (2%), and lessons found online (23.9%).

The classroom observations served as the basis of this study. The videotaped enacted lessons served as a way to measure how teacher-directed or student-directed a teacher's enactment of their science curriculum materials were. If a difference existed between the lesson plan score and the enactment score on the P-SOP[d], I claimed the teacher adapted the curriculum materials to be either more teacher-directed or student-directed (depending upon the direction of the score change).

Lesson Plan Evaluation

The Lesson Plan Evaluation ([LPE] see appendix H), developed by the PIESC[3] research team, consisted of a lesson plan (based on the topic of magnets), student pages, and a form for the teacher to fill out. The LPE asked the case-study teachers to first define each of the five features of inquiry and then identify where it is represented in the provided magnets lesson plan. The lesson provided to the teachers was a lesson based on an open-access AAAS lesson freely available online and based on magnets: (http://sciencenetlinks.com/lessons/magnets-2-how-strong-is-your-magnet/). The magnets lesson was modified to exhibit the highest level of each of the five features on the P-SOP rubric, therefore exhibiting the highest score possible for an inquiry-based lesson (Zangori, Forbes, & Biggers, 2012). The magnets lesson varied by feature of inquiry the amount of teacher direction.

The purpose of this document was two-fold. First, it asked the case-study teachers to explicitly define each of the five features of inquiry, which was useful in establishing their initial ideas of the features before beginning the three observations. Second, it helped determine if the teachers could recognize the features of inquiry within a given lesson plan. This information was helpful in investigating the teachers' ideas about the features and how they modified their curriculum materials around the features of inquiry.

Semi-Structured Interviews

The three case-study teachers were interviewed (using a semi-structured interview protocol, see appendices E and F) nine times over the course of the school year. These nine interviews can be categorized into three main types; (a) formal interviews, (b) pre- and post-enactment interviews, and (c) reflection interview. I describe each type in the following paragraphs.

Formal interviews. First, I conducted formal entrance interviews (approximately September, 2010) with the three case-study teachers to explore their initial definitions of inquiry and of each of the five essential features of inquiry, as well as their ideas about the inquiry continuum. Paired with this entrance interview (using the same interview protocol) was an exit interview at the end of the school year (approximately late April to early May, 2011). The formal protocol asks questions to get a sense of the teacher's definition of inquiry, the inquiry continuum, and definitions of each of the five essential features of inquiry. In addition, questions targeted how teachers envisioned engaging students in each of the five features of inquiry in their own classrooms.

Pre- and post-lesson interviews. Second, I conducted pre- and post-enactment interviews for each of the teacher's three observed lessons. These interviews explored how the particular lesson met each of the five features of inquiry and where it fell along the inquiry continuum. Before the lesson, the pre-enactment interviews explored how the teacher planned for the lesson and if/how they modified their existing curriculum materials. After the lesson, the post-enactment interviews focused on how the teachers interpreted the actual enactment of the lesson and what they might do differently when they taught it the next time.

Teacher reflection interviews. Finally, I conducted follow-up interviews with the teachers about their answers to the LPE of the magnets lesson (described above). After the teachers turned in their LPE, I interviewed them based on their responses to get a more in-depth picture of their ideas about inquiry. The LPE asked the teachers to define each feature and identify where it was represented in the provided magnets lesson. The goal of this interview was to dig deeper into each case-study teacher's definition of each of the five features and where they recognize each feature within the provided magnets lesson.

The case-study teachers' interviews were a critical piece of the qualitative phase of this study. They served a two-fold purpose. First, the interviews gave an in-depth perspective into the teachers' ideas about inquiry and the inquiry continuum. Second, they allowed for further insight into the teachers' reasoning behind their curriculum material modification along the inquiry continuum.

Lesson Plan Rationale

In addition to their lesson observations and artifacts, case-study teachers also provided Lesson Plan Rationales ([LPR] see Appendix G), for each of their three observed lessons which asked them to justify any changes they made to their original lesson plan when planning for instruction. This document asked them to rate the inquiry-orientation of the original lesson on a Likert scale of 'very inquiry oriented,' 'somewhat inquiry-oriented,' 'not very inquiry oriented,' or 'not at all inquiry oriented' and to justify their rating.

This document was helpful in my analysis of the teachers' pedagogical reasoning behind their curricular adaptations. This rating feature and subsequent explanation was helpful in seeing how the teachers rated their existing curriculum materials as to how inquiry-oriented it was and how the teachers adapted the existing curriculum materials to make them more inquiry-oriented.

Instruments and Instrument Development

P-SOP

Description. The P-SOP is an observation protocol that measures the level of inquiry in a science lesson based explicitly on the NRC's (2000) five essential features of inquiry: (a) questioning, (b) data/evidence, (c) explanations, (d) alternate explanations, and (e) communication/justification. The P-SOP can be used to score both enacted lessons and lesson plans, which makes it unique among other inquiry observation protocols such as the Science Teacher Inquiry Rubric (STIR -- Bodzin & Beerer, 2003), the Reformed Teaching Observation Protocol (RTOP -- Sawada et al., 2002), and the Extended Inquiry Observational Rubric (EIOR -- Luft, 1999). It has been shown to be a valid and reliable instrument among elementary science lessons (Forbes et al., 2013).

The P-SOP instrument (Forbes, et al., 2013) measures each of the five features of inquiry on a 12-point scale (see appendix A). Each of the five features is broken down into four submeasures aligned with the NRC (2000) definition of the features of inquiry and each submeasure is measured on a scale of 0-3 with 0 meaning the submeasure was not present and 3 being the highest form of enactment for that submeasure. These scores lend a total possible score per feature score of 12, and a total possible aggregate score (across all five features) of 60. The P-SOP was intentionally worded to allow for *all* variations of inquiry across the inquiry continuum, rather than emphasize one variation of inquiry over another. Directly contrasting this, however, is the RTOP protocol (Sawada et al., 2002), which values “student-centered” (p. 245) variations of inquiry.

Scoring. The scoring of the lesson plans and videos on the P-SOP and RTOP rubrics took place as part of previous PIESC[3] work. Many of the teachers’ lessons scored zero on one or more of the features of inquiry on the P-SOP. If, for example, a teacher scored a zero on the P-SOP on the first feature of inquiry (questioning) because there was not an investigation question present in the enacted lesson, the P-SOP^d score for that feature would automatically be zero because the feature was not present in the lesson. There cannot be any amount of teacher-directed or student-directed inquiry if the feature of inquiry is not present in the lesson in the first place. The original data set from the P-SOP scores included zeroes on individual features of inquiry (see Table 6). No lesson scored zeroes on all five features of inquiry, but many lessons had at least one feature scoring a zero. The number of zeroes per feature ranged from one to 90 (out of the possible 120 lessons), depending on the feature. This gives an indication of how infrequently some of the features of inquiry were represented in both the planned lessons and the enacted lessons from the original P-SOP study (Forbes, et al., 2013). These zero scores reduced the total number of valid cases of analysis for comparing video and lesson plan scores across the P-SOP and P-SOP^d rubrics.

Table 6

Number of zero scores on P-SOP broken down by feature; both planned and enacted lessons

Feature of Inquiry	Enacted Lesson Zero Scores	Planned Lesson Zero Scores
Questioning	51 (42.5%)	53 (44.2%)
Data/Evidence	1 (0.83%)	3 (2.5%)
Explanations	23 (19.2%)	45 (37.5%)
Alternate Explanations	87 (72.5%)	90 (75%)
Communicate/Justify	18 (15%)	37 (30.8%)

RTOP

The Reformed Teaching Observation Protocol ([RTOP] Sawada et al., 2002, see Appendix B) is a 25-item classroom observation instrument that measures “reform practices in math and science” (p. 245). It is a commonly used observation protocol in science education, and has been validated for secondary and post-secondary science lessons in various studies (Sawada et al., 2002). The RTOP’s 25 items are divided into five submeasures: (a) lesson design and implementation, (b) propositional knowledge, (c) procedural knowledge, (d) communicative interactions, and (e) student/teacher relationships. Each submeasure includes five items which each are scored on a scale of 0-4 with 0 meaning "never occurred" and 4 meaning "very descriptive". The five submeasures on the RTOP do not correlate with the five essential features of inquiry submeasures on the P-SOP or the P-SOP^d, so the submeasures were not individually correlated. The overall aggregate scores of the instruments were correlated to see if they measured the same constructs.

The authors claim that it is "(a) standards based, (b) inquiry oriented, and (c) student-centered" (p. 245). This third claim of being student-centered is why it was used in the current study. The P-SOP instrument was created to allow for all variations of inquiry, both teacher-directed and student-directed. The RTOP, however, claims to emphasize student-centered science. This comparison made an interesting contrast. The RTOP has also only been validated with enacted lessons, not with lesson plans. Therefore, it was only used to compare to the enacted lessons in the current study.

P-SOP^d

Description. A major piece of this study (representing the first research question) was the modification of the P-SOP instrument (Forbes, et al., 2013) to create a version that accounts for how teacher-directed or student-directed an inquiry lesson is. This new instrument, the Practices of Science Observation Protocol + Directedness [P-SOP^d] was developed using the NRC (2000) matrix (see appendix D) of teacher-directed to student-directed inquiry as a basis for describing and defining how each of the five essential features of inquiry could be enacted at each of the levels from teacher-directed (guided inquiry) to student-directed (open inquiry). One unique aspect of the P-SOP and P-SOP^d rubrics is that they can be used to score lesson plans, whereas other published inquiry observation rubrics (such as the Reformed Teaching Observation Protocol [RTOP] - Sawada et al., 2002) were only designed and validated for enacted lessons. The P-SOP^d, developed as part of this dissertation study, is a tool that will allow researchers to measure the amount of teacher direction in both enacted lessons and lesson plans in an effort to continue this important line of research.

The P-SOP^d does not break down each feature on the four sub-measures as the P-SOP does. Rather, it scores at the feature level (questioning, data/evidence, explanation, alternate explanation, and communication) on a scale of 0-4 with 0 meaning the feature of inquiry was not present in the lesson, 1 meaning the feature was the most student-directed version possible, and 4 meaning the feature was the most teacher-directed form possible. It is important to note, however, that a higher score does not mean a better score. In this case, teacher-directed or student-directed inquiry was simply being measured. No value or judgment was placed on the score. I chose not to modify each of the sub-measures across the inquiry continuum, although this could eventually be an extension of this study in future research. In reducing the number of new descriptors, the P-SOP^d instrument will have higher inter-rater reliability and will give a strong picture of how inquiry lessons are being taught across the continuum of teacher-directed to student-directed.

In order to develop the descriptors for the amount of teacher-direction vs. student-direction for the P-SOP^d, I began by using the exact language presented in the NRC (2000) matrix (p. 29; see appendix D). The purpose was to stay as true to the NRC descriptions as possible while making the descriptors as clear and explicit as possible. Some of the wording from the original NRC document was not useful when looking at either a lesson plan or an enacted lesson. For example, the second feature “learner gives priority to evidence in responding to questions” describes the following four variations (from most student-directed to most teacher-directed):

1. Learner determines what constitutes evidence and collects it
2. Learner directed to collect certain data
3. Learner given data and asked to analyze

4. Learner given data and told how to analyze

There were two main issues with the wording of these variations. First, the two most student-directed versions did not address the analysis of the data, only the collection of data. Second, it was difficult to empirically measure the difference between levels 3 and 4 whether students were "asked to analyze" or "told how to analyze" the data they were given between the two more teacher-directed variations. To accomplish that, I worded the variations on the P-SOP^d as follows:

1. Learner decides what to collect as data
2. Learner selects among possibilities of what to collect as data
3. Learner directed to collect certain data
4. Learner given data

In these descriptors, the focus was shifted to how the data was collected rather than how it was analyzed. These changes made the variations more explicitly clear so that it was easier to analyze both lesson plans and enacted lessons, between teacher-directed and student-directed. These changes occurred for each of the five features and their variations in order to create a rubric that would be valid and reliable for measuring the amount of teacher direction in inquiry lessons.

Scoring. Once the descriptors distinguishing student-directed from teacher-directed inquiry were in place for each feature, the following four steps were followed to establish the validity and reliability of the P-SOP^d. First, I conducted rater training. Two raters (myself included as one of the raters) scored a small subsample (n=3) of videos together in a collaborative environment. These video scores were not included in the validity/reliability reporting. The purpose of scoring the first three videos collaboratively was to engage discussion around possible coding issues and to help decision-making become less subjective and as clear as possible to both raters. By the end of the rater training, we achieved 100% agreement on our P-SOP^d scores.

Second, the two raters independently scored 40 videos (1/3 of the entire sample) in order to establish inter-rater reliability (IRR) for the P-SOP^d. Both raters' complete sets of scores were imported into SPSS for analysis. Third, the correlation coefficients and Cohen's kappa values were calculated to determine how reliable the two raters' sets of scores were to each other. Fourth, the internal reliability of the instrument was measuring using Cronbach's $\boldsymbol{\alpha}$ values between both the P-SOP and the P-SOP^d.

For the validation of the P-SOP^d, I focused on (a) *construct validity*, "whether the instrument measures what it is intended to measure" (p. 210), and (b) *content validity,* "how judges assess whether the items or questions are representative of possible items" (Creswell & Plano Clark, 2011, p. 210). These two types of validity were chosen from the possible types of validity listed in figure 10 by Johnson and Onwuegbuzie (2006).

First, to establish and maximize construct validity (making sure the instrument measures the amount of teacher- or student-directedness), I conducted a search of existing literature in science education journals searching for (a) how the construct has been defined, and (b) instruments that measured this construct of teacher-directedness of inquiry lessons. In a meta-synthesis of empirical inquiry studies, Minner, Levy, and Century (2010) found mixed results concerning the amount of 'student responsibility for learning' (p. 18). They surveyed nine studies that compared in some way the amount of student- vs. teacher-direction. Six of the nine "found a statistically significant increase in student conceptual learning when there was more student responsibility in the instruction… compared with instruction where there was more teacher-directed learning goals and activities" (p. 19). There were also three studies that "did not find a statistically significant effect of increased student-directedness in the instruction on conceptual learning" (p. 19).

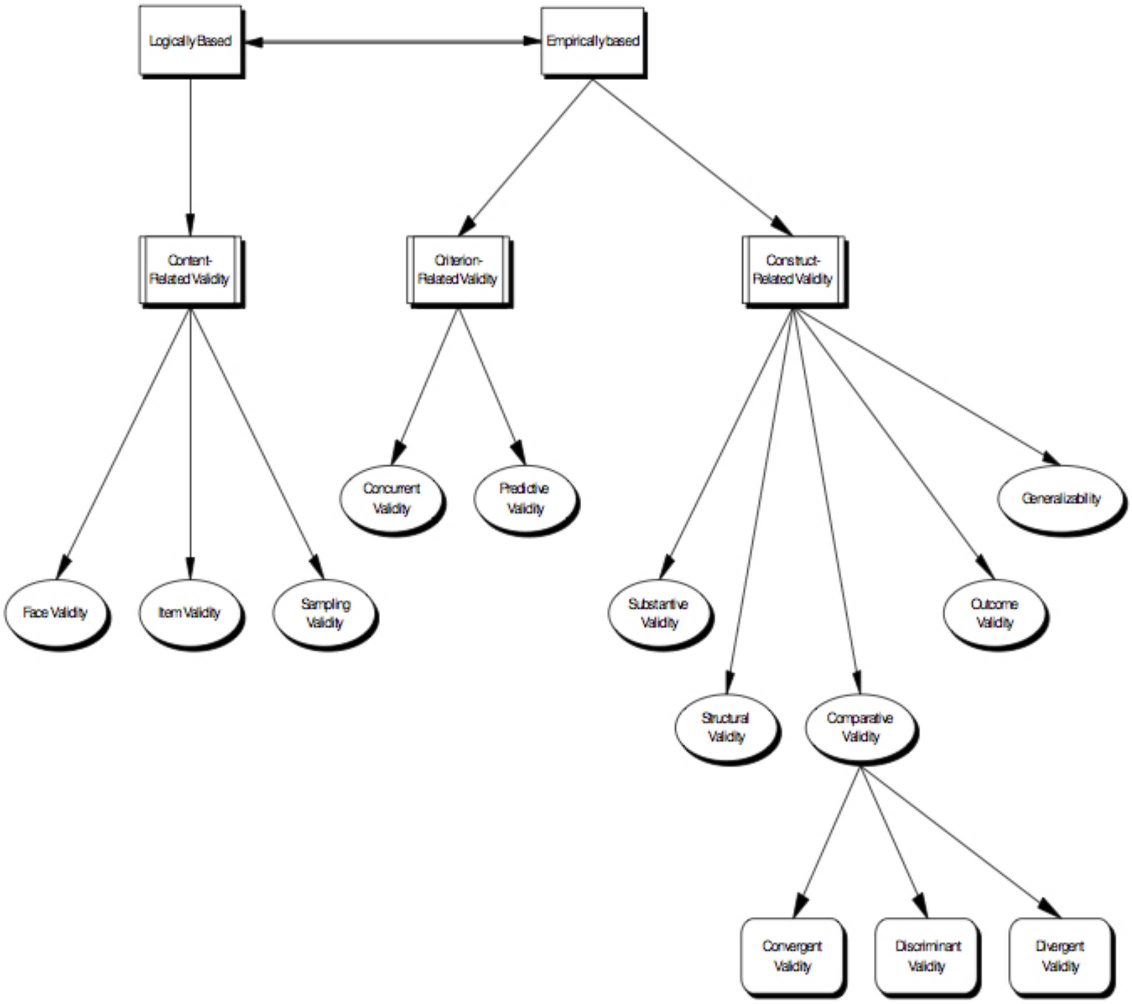

Figure 10. Schematic representation of various instrument score validities (Johnson & Onwuegbuzie, 2006, p. 51)

More recently, Furtak, Seidel, Iverson, and Briggs (2012) published results of a meta-analysis of 37 inquiry studies. Twenty-two of those 37 studies investigated how the amount of teacher-direction in an inquiry lesson affected student learning outcomes. Their results cite an effect size of 0.40 larger for studies involving teacher-led activities than for those with student-led conditions. Sturm and Bogner's (2008) smaller study found an interesting dichotomy. The students in their student-led conditions had higher motivation scores, but those in the teacher-led conditions had higher learning gains. Each of these studies, however, presents how the amount of teacher-direction affected the student learning outcomes. No studies have reported inservice elementary teachers' ideas about the inquiry continuum.

The only instrument that measured the construct was the Science Teaching Inquiry Rubric ([STIR] Bodzin & Beerer, 2003). I chose not to use the STIR for my study for several reasons. While the STIR measured this construct on a continuum of teacher-directed (guided inquiry) to student-directed (open inquiry) across the five essential features, its' reliability and validity was reported using only 10 observed lessons, and it was not validated for elementary science lessons. The STIR also separates the feature of data/evidence into two separate constructs (gathering evidence and analyzing evidence), which does not explicitly align with the NRC's original framework (2000). I also found only a handful of published studies using the STIR instrument since its publication in 2003 (see Blanchard, et al., 2009; Leonard, Barnes-Johnson, Dantley, & Kimber, 2010; Leonard, Boakes, & Moore, 2009). One of these only used the rubric for its features of inquiry rather than the amount of teacher or student direction (Leonard, et al., 2010). To typically establish construct validity, the new instrument scores would be compared to an established instrument's scores to establish that the new rubric measures what it is intended to measure. In this case, that was not a possibility.

Second, to assess content validity, I sent the P-SOP^{d} to several subject matter experts for review. The selected experts were asked to comment on the instrument in general, and also took an online survey using the university's survey software (Qualtrics) that randomized the P-SOP^{d} descriptor items for each feature. The survey then asked them to rank the items from the most teacher-directed to the most student-directed. These experts' suggestions and Qualtrics results were taken into consideration in the wording of the items to be made in order to be explicitly clear about the four divisions between teacher-directed and student-directed inquiry for each essential feature.

These experts' suggestions caused a few minor changes in the wording of the items to be made in order to be more explicitly clear about the divisions between teacher-directed and student-directed inquiry for each essential feature. With the exception of one case where two adjacent items for feature 1 were exchanged, all experts ranked the items in the same order as the instrument. The wording of those two items was modified to be even more explicitly clear.

Case Study

The qualitative aspect of this study fell under the umbrella of case-study design, and was a holistic, multiple-case design, with an emphasis on both individual case reports and cross-case analysis (Merriam, 2009; Yin, 2009), and focused on the case-study teachers' planning and enactment of their three self-selected science lessons. Eight teachers from the Douglas district were asked to participate as case-study teachers in the PIESC^3 project for in-depth qualitative cases (see Table 7). The district science coordinator purposefully selected teachers to invite as case-study participants who had shown a prior interest in teaching science. As with the large group, these teachers also volunteered for which level of the project they wanted to participate (professional development or non-professional development). The difference in requirements for each level mainly included attending the PIESC^3 professional development during the summer, and monthly professional development workshops taught by the district science coordinator (see Appendix I for the requirements at each level of participation as well as compensation provided). The teachers involved at the professional development level were compensated at a higher rate because of the extra time invested in the project.

For this study, I chose to include three out of the possible eight case-study teachers (see Table 7). The difference in sample sizes between the quantitative phase and qualitative phase was intentional. I could not use three teachers to find statistical trends for this study, nor could I qualitatively analyze the data from each of 40 teachers. The quantitative phase provided a large sample to draw statistical inferences about this group, and the three case-study teachers provided enough saturation of the data to find patterns and trends across the teachers' ideas about the inquiry continuum. I chose the three teachers for my study because they represented three differing points on the continuum of teacher-directed to student-directed inquiry in both their ideas and their classroom enactments. Yin (2009) refers to this reasoning for selecting cases as "theoretical replications" which aim to "predict contrasting results for anticipatable reasons" (p. 54). I used three methods to establish which of the eight case-study teachers would be included in this study.

Table 7

Case-study teachers' demographic information

	Grace	Emily	Janet
Grade level	3rd	3rd	3rd
Focus unit	Structures of Life	Structures of Life	Structures of Life
Years teaching	35	17	8
Highest Degree	MS reading	MS leadership	BA education
Gender	F	F	F

First, I averaged the case-study teachers' P-SOP^d scores on both their lesson plans and enacted lessons. When I subtracted the difference between the teachers' video scores from their lesson plan scores (see Table 8), I found a range of values. Although the difference in the numbers is slight, when represented on a continuum from most teacher-directed to most student-directed, I noticed that three of the case-study teachers who taught their three lessons from the same FOSS investigation (Structures of Life, Investigation 1) varied in their score differentials. Grace modified her enacted lessons to be more teacher-directed than her lesson plans, Emily modified her enacted lessons in a more student-directed way than her lesson plans, and Janet showed almost no modification between her enacted lessons and her lesson plans. Although they did not represent the most extreme cases (i.e. one other case-study teacher had a more extreme teacher-directed score differential than Grace), the unifying feature of these three teachers teaching their lessons from the same FOSS investigation outweighed the fact that they were not the most extreme cases on the continuum.

Table 8

Case-study teachers' differences across the inquiry continuum

	Averaged P-SOP[d] Differential Score (Video – Lesson Plan)	LPE Curriculum Ranking
Grace	0.104	Somewhat inquiry-oriented
Emily	-0.650	Not very inquiry oriented
Janet	0.068	Very inquiry oriented

Second, I looked at the teachers' LPE data, particularly how they ranked the lesson on the provided scale of 'very' inquiry oriented, 'somewhat' inquiry oriented, 'not very' inquiry oriented, or 'not at all' inquiry oriented. Even though the lesson provided as part of the LPE was of a different context than the lessons the teachers chose to teach for their observations, their rankings of the curriculum materials matched their rankings from their averaged P-SOP^d scores.

Finally, I used the teachers' interview data to get a general sense of their ideas about the inquiry continuum. I found that their ideas differed on how inquiry-oriented they thought their FOSS curriculum materials were according to the continuum, and how they modified their curriculum materials accordingly. These three methods (P-SOP^d differential scores, LPE curriculum ranking, and interview ideas) were how I chose the three teachers for the case-study portion of this study. Their main connecting feature, however, was the fact that they each taught their lessons from the first investigation of the same FOSS unit (Structures of Life).

Structures of Life Lessons

The main reason the three case-study teachers were identified out of the possible eight for this study was the fact that they taught the same series of three self-selected lessons. In order to better understand the lessons (and later the modifications from the original curriculum materials), a description of the series of lessons is provided here. The three teachers in this multiple case study each taught their three videotaped lessons from the FOSS unit, "Structures of Life" (SOL). The lessons are from the first investigation (out of five). Investigation one is titled "Origins of Seeds" and aims to help students meet the following learning goals:

- Explore common fruits to find seeds
- Observe and compare properties of seeds and fruits
- Organize and communicate information about seeds
- Set up a seed sprouter and maintain a watering schedule for a week
- Monitor and record changes in seeds over days

- Investigate the effect of water on seeds
- Compare the mass of dry seeds and those soaked in water
- Use scientific thinking processes to conduct investigations and build explanations: observing, communicating, comparing, and organizing (SOL Investigation 1 p.1).

The unit was designed for third or fourth grade students, and all three teachers in this study taught third grade. The science content objectives of the investigation are:

- Seeds are found in the plant part called a fruit
- Different kinds of fruits have different kinds and numbers of seeds
- Seeds have a variety of properties
- Seeds undergo changes in the presence of water
- A seed is a living organism, a living thing
- Seeds store food and provide protection for the young plant (SOL Investigation 1 p. 1).

Investigation one is divided into three lesson parts: Part one, “Seed Search”, part two, “The Sprouting Seed”, and part three, “Seed Soak”. Here, I will describe each of the three lessons as they appear in the original FOSS curriculum materials.

Part one of investigation one is titled “Seed Search”. The lesson begins by asking teachers to hold a discussion with students about properties of a fruit. The teacher holds up a familiar fruit such as an apple and asks students to describe the fruit. These properties are listed on the board. The term ‘property’ is defined specifically as “something you can observe about an object… include[ing] size, shape, color, texture, smell, and other features” (SOL Investigation 1, p. 13). The teacher then introduces a bean pod to the class and asks them to describe it just as they did the apple. Again, their observations are listed on the board. Plastic knives are now distributed to the groups of students and they are asked to “carefully open the pods and find out what is inside” (p. 13). The beans (or peas) are identified as seeds of the plant, located in the fruit. Teachers indicate that the scientific term for fruit is different than the everyday definition of fruit, say at the supermarket.

The students then describe the properties of the bean seeds. These observations are added to the list on the board from the previous descriptions. Students count how many beans their pod held, and they graph these numbers on a class histogram. Once all the student data is added to the class histogram, teachers use the histogram to ask what the most common number of seeds per pod was in their class, and ask students to predict if they opened one more pod how many seeds they think it will have.

A pre-prepared data sheet is then passed out to each student. Students record the name of the fruit they have observed (bean pod), the number of seeds their bean pod included, several properties of the bean seeds, and draw a picture of the seed. The data sheet has room for them to record more fruits, which is the next step in the lesson. Each group of students is given two plates and several fruits to explore. Students are asked to open the fruits, find the seeds, and record their observations just as they did for the bean pods. For fruits, such as kiwi, with too many seeds to count individually, students are introduced to the term “estimate” to figure out an approximate number of seeds. The seeds are then sorted by property. The lesson ends with students adding their newest vocabulary words to a word bank and summarizing what they have learned on a content/inquiry chart. The final piece of the lesson is a reading from their science story reader titled, “Seeds are Everywhere”.

Part two, “The Sprouting Seed,” begins with students in collaborative groups. Each group is given a container with four different types of seeds (bean seeds, corn seeds, sunflower seeds, and pea seeds). Students sort seeds by type and make observations of each type of seed. The teacher asks, “If we wanted to grow these seeds, what would we need?" (Investigation 1, p. 22). After students make their suggestions, the teacher asks, "What do you think would happen if we just watered the seeds instead of planting them in soil?" Students are given a pre-prepared data sheet to record their observations of the dry seeds, with each student in the group selecting a different type of seed to write about. Students glue one dry seed of each type on their data sheet.

The teacher introduces the mini-sprouters the class will be using. These include a ¼ liter clear container with lid and a coffee filter. The seeds are placed in the mini-sprouter and watered (and then drained) with a weak bleach water solution (to prevent mold). The students water and drain their mini-sprouters each day for one week and record observations on their data sheet. The class also sets up a larger class sprouter in addition to their mini-sprouters. After the week of observations, the students each receive a response sheet titled "Origins of Seeds" to complete. This lesson ends with adding vocabulary to the word bank and adding to the content/inquiry chart as they did with the first part of the investigation.

Part three, "Seed Soak", overlaps with the mini-sprouter investigation from part two. Students begin by sharing their observations of the seeds in their mini-sprouters. Their observations are listed on the board. Teachers mention that an important part of science is asking questions about things we observe and designing investigations to answer those questions. The teacher asks "What could be causing the seeds to appear swollen?", and "If the seeds are soaking up water, how can we find out how much water the seed are holding?" (Investigation 1, p. 30).

Teachers draw on student ideas to design a procedure that includes weighing dry seeds and soaked seeds to measure how much water the seeds absorb. Students use a balance and gram pieces to measure the mass of the dry seeds. They share their results with the class, and if differences occur, the teacher asks, "Does it make a difference where the beans or the gram pieces are placed in the cups?" (Investigation 1, p. 31). The importance of a standard procedure is reinforced, and students once again weigh their dry beans using the established procedure. They record the mass on their data sheet. Water is added to the beans in a cup so the beans can soak up water overnight. The following day, students predict how much they think the beans have swelled after soaking, and then weigh their soaked beans and compare the dry and the soaked bean weights. Students have to figure out that the amount of absorbed water can be measured by subtracting the two weights. They share their results with the rest of the class, and then the cut open a soaked bean to observe it. The students identify seed parts, such as they seed coat, embryo, and cotyledon. As in the first two parts of the investigation, students add words to their word bank, summarize what they have learned on the content/inquiry chart, and read the coordinating science story from their readers.

Data Analysis Procedures

The data analysis occurred during the 2011-2012 school year. Table 9 shows a breakdown of when the analysis occurred by month, but overall the quantitative phase was analyzed first and then the three case study teachers were chosen based on their quantitative scores. Following participant selection, the qualitative data was analyzed.

Table 9

Timeline of data analysis procedures (2011-2012)

Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
• P-SOP^{d} developed, • Rater training	IRR; Videos & lesson plans scored on P-SOP^{d}		Quant results written		Participants selected for case study	Qualitative coding (2 iterations)	Qual results written		

The qualitative and quantitative data were also jointly analyzed in order to draw mixed methods meta-inferences (see Appendix J for joint data display).

Video Scoring

Each lesson was scored according to the P-SOP^d rubric on both the existing lesson plan (document), and the enacted lesson (video) to measure how learner-directed or teacher-directed the teachers' lesson plans and enacted lessons were for each of the five features of inquiry (NRC, 2000). Then, the two scores were compared to see if the teachers adapted the curriculum materials to be more or less teacher-directed than the original lesson plan. Two raters independently completed the scoring of 40 out of the 120 videos (1/3 of the sample) in order to establish inter-rater reliability (IRR) for the instrument.

Quantitative Analyses

Both raters' complete sets of scores for the P-SOP^d were entered into Excel. After a careful overview checking for key entry errors, the data was imported into SPSS for analysis. To address research question one, *How valid and reliable is the P-SOP^d*, four analyses were conducted. Reliability was calculated for both inter-rater reliability and test-retest reliability, and validity was assessed for both construct validity and content validity.

If a difference existed between the lesson plan and enacted video scores, I made the claim that the teacher made a modification to the lesson from the planned version to the enacted version. The teachers could modify their curriculum materials to be more or less inquiry-oriented (based on the P-SOP rubric) and/or more or less teacher-directed (based on the P-SOP^d). I then compared the two rubric scores to see if there existed any relationship between how inquiry-oriented the lessons are (based on the P-SOP) and how teacher/student-directed the lessons are (based on the P-SOP^d).

Reliability. First, I calculated the correlation coefficients and Cohen's kappa (see Equation 1) values overall and for each feature to determine how reliable the two sets of scores (n=40) were to each other.

Equation 1

$$(\mathrm{K} = (\Pr(\alpha) - \Pr(e))/(1 - \Pr(e)))^{6}$$

Since the overall average Cohen's kappa was at least 0.70 (considered 'substantial' by Landis & Koch (1977) and 'good' by Fleiss (1981)), a single rater scored the remaining 80 videos. I also reported the correlation coefficient between the two raters' scores for each feature of inquiry since this value is so widely accepted and understood, and to further demonstrate the reliability of the modified instrument.

Second, in order to assess teacher effects, I measured the intra-class correlation coefficient (ICC) across the three lessons submitted by each teacher. Since each teacher submitted three videos, the data is nested within teachers. In order to determine the degree to which teachers are consistent across different lessons, the intra-class correlation was used. If no teacher effect existed, the lesson was justified as the unit of analysis rather than the teacher's set of three lessons.

Validity. In order to analyze the content validity of the P-SOP^{d} I reported the results of how the subject matter experts ranked the items on an online Qualtrics survey,

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[6] Where $\Pr(a)$ is the relative observed agreement among raters and $\Pr(e)$ is the hypothetical probability of chance agreement

and how these results affected the ordering of the items on the P-SOP^d. The experts took an online survey that randomized the descriptor items for each feature and asked them to rank the items from the most teacher-directed to the most student-directed. By having subject matter experts blindly rank these items in this way, I was able to ascertain whether the descriptors for each feature were ranked appropriately to match the NRC's original meaning of the inquiry continuum. After the blind Qualtrics survey ranking, I sent the entire, unblinded rubric to the experts for general comments and suggestions. These suggestions were incorporated in the final version of the P-SOP^d.

To address research question two, *In what ways do inservice elementary teachers adapt existing elementary science curriculum materials across the inquiry continuum,* I analyzed several aspects of the P-SOP^d scores. Because of the zero scores present in the original P-SOP data set, this analysis occurred feature by feature (i.e. comparing planned questioning to enacted questioning) through two separate analyses. These two phases of data analysis gave a more detailed picture of, not only the overall trends, but of the teachers' enactment of each feature of inquiry and how teacher- or student-directed the features were. First, the presence or absence of the feature in the plan and the video was analyzed to see if, for example, lesson plans included a teacher-directed form of questioning but teachers did not include questioning in their enacted lesson. This analysis was conducted using chi-square tests. Second, in the cases in which a non-zero score existed in both the planned and the enacted lesson, the scores (between planned and enacted) were analyzed using paired t-tests.

To address research question three, *What is the relationship between the overall quality of inquiry and variations of inquiry in elementary teachers' enacted science instruction*, I compared scores from the P-SOP and P-SOP^d for lesson plans, and from the P-SOP, RTOP, and P-SOP^d for enacted video lessons for each feature. As part of the data representation, I calculated cross-tabulations for each feature of inquiry with P-SOP scores on one axis and P-SOP^d scores on the other axis to see if a pattern existed between the amount of teacher direction and the level of inquiry-orientation (according to the five features) for both lesson plans and enacted science lessons.

Qualitative Coding

Each data source was explicitly coded using two *a priori* codes (Coffey & Atkinson, 1996) of teacher-directed and student-directed in ATLAS.ti qualitative coding software. These two codes served as a start list (Merriam, 2009) based on the conceptual framework of the inquiry continuum. I then ran coding reports for these two codes, dividing the data into teacher-directed and student-directed categories. Then in a second coding iteration, these coding reports were each coded using a much more open coding approach (Strauss & Corbin, 1990) within the features of interest, e.g. teacher-directed. The open codes (listed by teacher frequency in Table 10) emerged as I read over the coding reports from the first coding iteration as well as the original interview transcripts. This second iteration of coding contributed to the cross-case analysis and individual case report aspect of the qualitative strand of the study, and allowed for themes to develop within the generic categories of teacher-directed and student-directed inquiry.

Qualitative Analyses

In order to answer the fourth research question, *How do inservice elementary teachers' ideas about the inquiry continuum influence their adaptation of elementary science curriculum materials*, I took the following steps for qualitative analysis as outlined in Figure 9.

After all of the documents and interviews were coded through both iterations (first the *a priori* codes of teacher-directed and student-directed, then the open coding), I categorized the codes to look for emergent patterns and themes (Merriam, 2009) based on the suggestions given by Strauss and Corbin (1990) such as line-by-line analysis and entire document analysis. Within the focus of the inquiry continuum, I created subcategories of codes (Dey, 1999) based on these emergent themes (Ryan & Bernard, 2000). Table 11 divides the open codes into the categories. These categories eventually became the structure for the discussion of the qualitative phase findings. Case summaries were developed for each case-study teacher. Next, I compared across cases to build explanations (a special type of pattern-matching analysis) from the developing themes (Yin, 2009). This cross-case synthesis (Yin, 2009) helped determine not only *if* the teachers modified their lessons across the inquiry continuum, but also *how* and *to what extent* they made the modifications based on their ideas about the continuum and their specific lesson modifications.

Table 10

Code frequencies by case-study teacher

	Grace	Emily	Janet	Totals:
***a priori* Codes**				
Student-directed	83	29	22	134
Teacher-directed	43	21	36	100
Open Codes				
Change over time	33	4	1	38
Curriculum material modifications	14	12	8	34
Defining inquiry	9	2	10	21
Efficiently meeting students' needs	0	0	26	26
FOSS not inquiry	17	5	10	32
Giving up control	9	5	2	16
Going against norms	5	4	5	14
Gradual release of responsibility	1	12	0	13
Lets see what happens	22	1	0	23
More student direction = More inquiry	19	8	3	30
Science notebooks	11	2	3	16
Scientific Method	8	1	0	9
Student ability level / Differentiation	10	5	22	37
Teacher-directed questions	31	10	2	43
Totals:	315	121	150	586

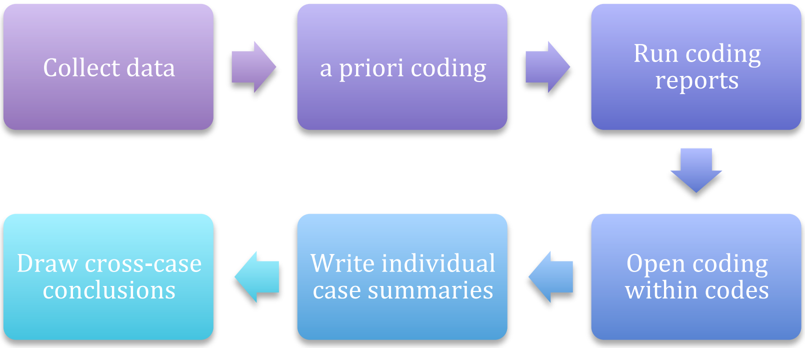

Figure 11. Qualitative analysis plan

Table 11

Open code categories

Teachers' Ideas About Continuum	How Teachers Modified Curriculum Materials Across Continuum
Defining inquiry	Curriculum material modification
FOSS not inquiry	Change over time
Perceived challenges to teaching student-directed inquiry	Teacher-directed questions
-- giving up control	Efficiently meeting students' needs
-- going against norms	Gradual release of responsibility
-- student ability/differentiation	Let's see what happens
More student-directed = more inquiry	

In addition to analyzing the case-study interview data, analysis of specific parts of the LPE document helped to answer this research question. Within this document, the teachers defined each feature of inquiry and gave specific instances where the features were located within the provided magnets lesson. This document was a major source of understanding the teachers' current ideas of the NRC (2000) five essential features, both how they are defined and how they are enacted in a lesson. The teachers' evaluation of the magnets lesson triangulated their ideas (Anfara, Brown, & Mangione, 2002) about the inquiry continuum with observation and interview data. This data extended and expanded the findings (Greene, et al, 1989) beyond the simple fact of seeing *if* the teachers adapted their curriculum materials across the continuum, but also *how* and *to what extent* they adapted the curriculum materials in such ways.

Trustworthiness. I implemented three main techniques for establishing trustworthiness: (a) member checking, (b) triangulation, and (c) thick description. First, I conducted member checks (Anfara, et al, 2002; Merriam, 2009; Yin, 2009) with the case-study teachers. After my initial case report analysis was written for each case-study teacher, I sent the data to the member for validation. As Maxwell states, “This is the single most important way of ruling out the possibility of misinterpreting the meaning of what participants say and do and the perspective they have on what is going on, as well as being an important way of identifying your own biases and misunderstanding of what you observed (2005, p. 111).

Second, I implemented two sources of triangulation (Merriam, 2009). These include (a) multiple sources, and (b) multiple investigators (Miles & Huberman, 1994). I triangulated my sources by combining data from two observation protocols (P-SOP and P-SOP^d), interviews, and documents (Lesson plans, LPE and LPR). I triangulated investigators for this study by using both multiple raters for the quantitative phase and multiple coders for qualitative phase. Laura Zangori, a PIESC[3] project researcher, helped code the data for the five essential features of inquiry. Since she was involved in the original project and familiar with the case-study teachers, I had regular peer debriefing sessions with her for my new coding of the teachers' ideas about the inquiry continuum. These two triangulation methods increased the trustworthiness of this study by not relying on one source, or one investigator to draw conclusions.

Third, I increased the trustworthiness of the study by including as much thick description (Lincoln & Guba, 1985; Merriam, 2009) of the context, participants, activities, and environments for each of the case-study teachers as I could. This thick description gave the reader as close to an "insider's view" of the classroom observations as I could provide to help them determine whether and/or how to generalize the findings to their own circumstances. I drew these descriptions from my observation data and field notes and by including the teachers' own words in quotations whenever possible. For example, I included screen shots of one case-study teacher's Smart Board presentation as one representation of how she incorporated the kit-based science curriculum materials in her classroom.

My purpose in this study was not to generalize to larger populations of elementary teachers. My purpose was to use this study to initially describe *if, how,* and *to what extent* these elementary teachers modified their curriculum materials across the inquiry continuum. This made the threat of external validity a lower priority than internal validity. In order to meet the purpose for this study, an instrument had to be developed to measure the amount of teacher-direction in a science lesson; therefore the P-SOP^d was developed as part of this study. Since this was a mixed methods study, I considered how the strands interacted and how to increase internal validity across the qualitative and quantitative phases. I sought to reduce threats to internal validity (as described by Creswell & Plano Clark, 2011) in the following ways (see Table 12).

Table 12

Strategies to minimize threats to validity in this mixed methods study

Potential validity threat	Strategies for minimizing threat
Selecting inappropriate individuals for the both phases of collection	Draw quantitative and qualitative samples from the same population to make data comparable
Collecting two types of data that do not address the same topics	Address the same question (parallel) in both phases of data collection
Using inadequate approaches to converge the data (e.g. un-interpretable display)	Develop a joint display with quantitative categorical display and qualitative themes
Not resolving divergent findings	Use strategies such as gathering more data, reanalyzing the current data, and evaluating the procedures
Choosing weak findings to follow up on qualitatively	Weigh the options for follow-up, and choose the results to follow-up that need further explanation

Summary

The data analysis for this study was conducted both quantitatively and qualitatively to answer each of the four research questions. The quantitative analysis included three main parts. First, the P-SOP^d underwent validity and reliability testing as a new instrument in the field of science education. Second, I compared the planned and enacted scores for the teachers' lessons when scored on the P-SOP^d rubric. This helped determine whether the teachers modified their curriculum materials to be more or less teacher-directed. Third, I compared the P-SOP^d scores to the scores from the original P-SOP rubric for each essential feature of inquiry to see if a relationship existed between the amount of inquiry orientation and the amount of teacher-directedness. Finally, the qualitative analysis consisted of a multiple case study across the three case-study teachers using two iterations of coding. The first iteration involved the use of *a priori* codes to narrow the data and focus on the phenomenon of the teachers' ideas about the inquiry continuum; while the second iteration allowed more open coding within the previous coding reports to look for themes across the teachers' ideas.

CHAPTER IV

QUANTITATIVE ANALYSIS FINDINGS

In Chapter IV, I present findings from the quantitative analysis of the 40 inservice elementary teachers' enacted videorecorded lessons and matching lesson plans. These findings are presented to address the first three research questions in which I asked, (1) *How valid and reliable is the P-SOP^d,* (2) *In what ways do inservice elementary teachers adapt existing elementary science curriculum materials across the inquiry continuum*, and (3) *What is the relationship between the overall quality of inquiry and variations of inquiry in elementary teachers' enacted science instruction*. In the following sections, I first provide descriptive statistics of the reliability and validity of the P-SOP^d instrument. Next, I provide results that show that the elementary teachers did not significantly modify their existing science curriculum materials to be more or less teacher-directed. Finally, I present findings that show a small amount correlation between the level of inquiry (measured by the P-SOP) with the amount of teacher-direction (measured by the P-SOP^d).

Research Question 1: How Valid and Reliable is the P-SOP^d?

In this section I present results from the field-testing of the P-SOP^d instrument for both validity and reliability. I first present the findings for content validity. The construct validity was presented in the methods section. I then present reliability findings for inter-rater reliability and test-retest reliability.

Validity

The eight subject matter experts' results from the Qualtrics survey showed a clear pattern of matching to the P-SOP^d rubric's descriptors, ranked from most teacher-directed to most student-directed. There was only one instance when two adjacent descriptors were flipped by one individual rater (see figure 12). Because of this, the two involved descriptors were considered carefully and modified to be explicitly clear which was the more teacher-directed. Figure 12 represents the eight rater's rankings of the descriptors and shows that rater 4 flipped item numbers 1.3 and 1.4 from the questioning feature.

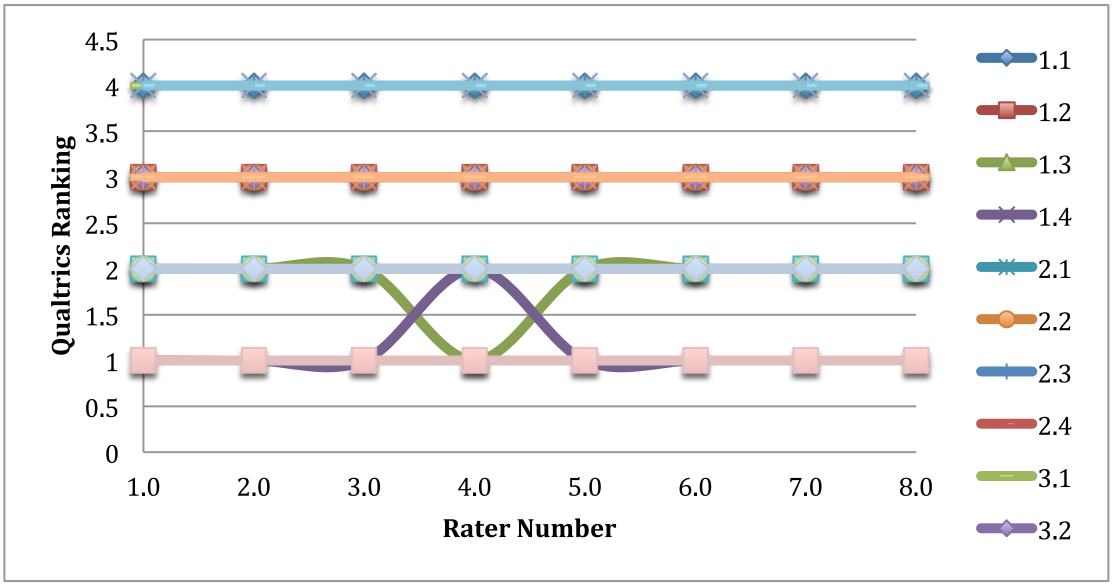

Figure 12. Subject matter experts' ranking of P-SOP^d items in Qualtrics

Reliability

The inter-rater reliability of the P-SOP^d analysis resulted in an average percentage match between the two raters' scores of 78.16% across all five features for both lesson plans and enacted lessons. The results are broken down by feature below (see Table 13 and figure 13) into the two raters' score correlations and Cohen's kappa values. The raters' average overall Cohen's kappa value was 0.729, which Landis and Koch (1977) define as "substantial". Rater 1 scored all 40 lessons the same value on feature 1 (questioning) resulting in a constant value. Rater 2 scored 39 out of the 40 lessons the same as rater one, which results in extremely high (almost perfect) reliability for this feature even though the statistical results are not reported.

Table 13

Inter-rater Reliability Between Two Raters' Scores of P-SOP[d]

	Questioning		Data/Evidence		Explanation		Alt. Explain		Communicate	
	Video	LP	Video	LP	Video	LP	Video	LP	Video	LP
N Valid Cases	40	25	40	40	35	24	12	6	37	31
Correlation Coefficient	N/A[a]		0.701	0.800	0.639	0.845	1.00	1.00	0.666	0.602
Cohen's Kappa	N/A[a]		0.571	0.763	0.546	0.833	1.00	1.00	0.532	0.589

[a] Can not be calculated because at least one of the values is a constant

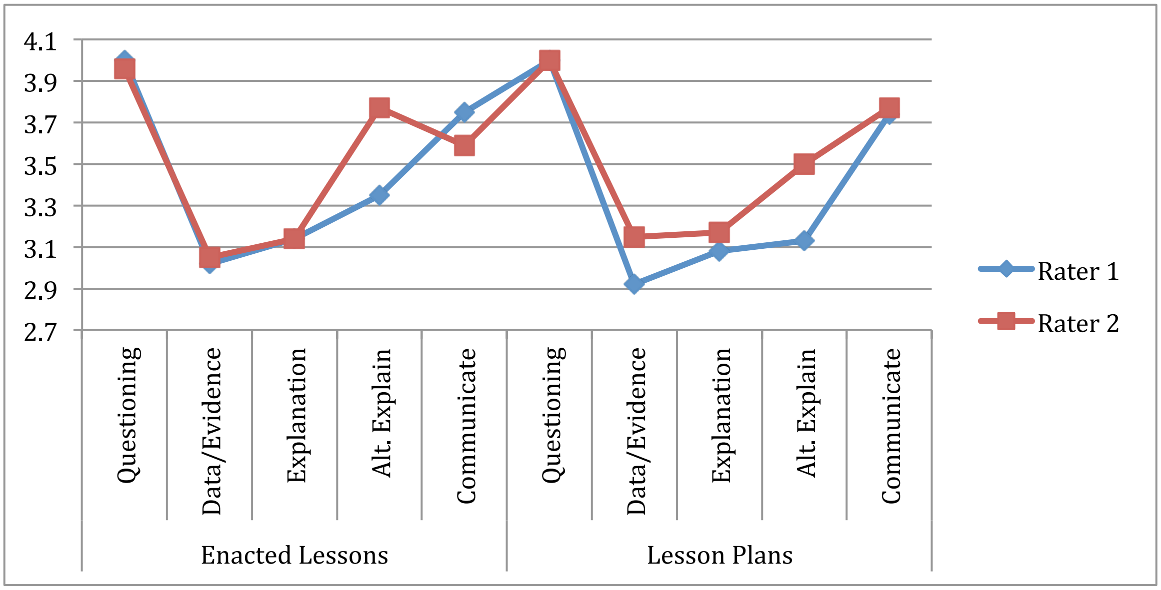

Figure 13. Rater 1 vs. rater 2 mean scores by feature for both enacted lessons and lesson plans

These results show substantial internal reliability for individual features on the P-SOP^d for the lesson plans and moderate reliability for the videorecorded enacted lessons, (Landis & Koch, 1977). The P-SOP^d was also found overall to be highly internally reliable through the analysis of Cronbach's alpha (4 items, $\boldsymbol{\alpha} = 0.865$). These results answer question 1 with evidence that overall the P-SOP^d exhibits strong validity and reliability, with the exception of the lesson plan scores that exhibited moderate reliability.

The fact that each teacher submitted three videos presents a particular form of nested data. I ran intra-class correlation statistics (see Table 12) to determine whether there was, in fact, a teacher effect across the three lessons submitted by each of the 40 teachers. The analysis was complicated by the fact that the directedness of the lesson could only be measured if the feature was present in the lesson. Thus, the sample size for each ICC was often much smaller than 40.

The intra-class correlations ranged from low (.104) to moderate (.472), however none of the correlations were statistically significant. Due to the low sample sizes, I was left not knowing whether or not there was a trend for teachers to be consistent in the directedness of their lessons. Because of the lack of significance and the low sample size, it was decided to go with the simpler analysis and use lesson as the unit of analysis rather than employing a nested model of lessons within teachers.

Table 14

Intra-class Correlation Across Each Teachers' Three Lessons

	Questioning	Data/Evidence	Explanation	Alt. Explain	Communicate
Video (*N*)	N/A$_a$	0.104 (*39*)	0.203 (*21*)	N/A$_b$	0.457 (*16*)
Lesson Plan (*N*)	N/A$_a$	0.472 (*38*)	0.333 (*12*)	N/A$_b$	0.463 (*13*)

$_a$: can not be calculated because scale has zero variance items

$_b$: can not be calculated because there are too few valid cases

None of the intra-class correlations were significant. These results show that the teacher effect was minimal at most for the nested lessons (three per teacher). In general, this means that there was not a trend for certain teachers to teach their lessons in either teacher- or student-directed manner. The amount of teacher-direction varied across lessons rather than across teachers. Within a single teacher, there was not a clear pattern of direction among the three lessons. A single teacher might teach one lessons very teacher-directed and another in a more student-directed manner. This leaves the unit of analysis at the lesson level rather than the teacher level, allowing analysis to continue for individual lessons rather than in nested packets per teacher. This reduces the complexity of the analysis moving forward, as a mixed model ANOVA will not be needed during the next section.

Research Question 2: In What Ways do Inservice Elementary Teachers Adapt Existing Elementary Science Curriculum Materials Across the Inquiry Continuum?

First, to address research question two, I ran descriptive statistics on the P-SOP^d scores for each of the five features of inquiry for both lesson plans and enacted lessons. These results show that both the plans and enacted lessons were very teacher-directed overall. I then ran two separate analyses on the video and lesson plan scores. The first set of analyses was completed using a chi-square matrix investigating the presence or absence of each feature in both the lesson plans and enacted videos. The data for this analysis were reduced to a binary system using 1 and 0 (1 meaning the feature was present and 0 meaning it was not present). The chi-square analysis was a 2x2 matrix comparing the 1 vs. 0 for lesson plans and enacted videos. I found that for one of the five features of inquiry - questioning - there was a statistically significant difference between when it was present in the lesson plan vs. the video recorded enacted lesson (see chi square results in Table 17). There were more cases when questioning was present in the lesson plan but not in the enacted video. For the second feature – data/evidence – the chi-square could not be calculated because every single lesson plan and video included this feature, causing the values to be constant. The remaining three features – explanation, alternate explanation, and communicate/justify – did not result in a significant difference between when they were present or absent in the lesson plans vs. the enacted lessons.

Second, when the feature of inquiry was present in both the lesson plan and the video, I conducted paired-t-test analyses to identify differences in scores between the lesson plan and enacted videos. As a reminder from the methods chapter, the plans and videos were scored on the P-SOP^d for each feature on a scale of 0-4 with 0 meaning the feature was not present in the lesson, 1 being the most student-directed and 4 being the most teacher-directed version of inquiry. There was no statistical difference between teachers' lesson plan scores or their enacted video scores on any of the five features (see Figure 14 and Table 17). The degrees of freedom shown in the table represent how many of the 120 scored lessons included that feature of inquiry in both the lesson and the video (N = 50, 119, 64, 8, and 76 respectively by feature). As both sets of analyses show, the teachers taught their kit-based curriculum materials with relatively high levels of fidelity on both the level of inquiry and the amount of teacher direction with the exception of the presence of the questioning feature which was more prevalent in the lesson plans than in the enacted lessons. Table 15 presents the mean scores and standard deviations by feature for both lesson plans and enacted lessons for the P-SOP^d, and table 16 presents the same for the P-SOP scores. The RTOP was not broken down by feature and was not used to score lesson plans, however, the mean for the RTOP scores (n=120) was 58.37 out of a possible 100 with a rather large standard deviation of 16.61.

Table 15

Mean P-SOP^d scores for enacted lessons and lesson plans by feature of inquiry.

	Feature	N (out of 120)	Mean (out of 4)	SD
Enacted Lessons	Questioning	71	4	0.000
	Data/Evidence	120	3.02	0.547
	Explanation	95	3.14	0.452
	Alt. Explain	31	3.35	0.709
	Communicate	106	3.75	0.494
Lesson Plans	Questioning	66	4.00	0.000
	Data/Evidence	120	2.92	0.602
	Explanation	75	3.08	0.427
	Alt. Explain	23	3.13	0.458
	Communicate	84	3.74	0.442

The multiple zero scores in the P-SOP and P-SOP^d data set posed a particular challenge in representing the amount of teacher or student direction in a lesson. When the zero scores were averaged in for each feature, the mean score for that feature appears to score on the more student-directed side of the continuum because the zeroes pull the average towards the student-directed side. In order to represent the mean P-SOP^d scores without the zero scores biasing the overall averages, I replaced the zero scores with a median score of 2.5 (neither student-directed nor teacher-directed) in a new data set. These sores were averaged and are presented in figure 14 with the median of the graph at 2.5. This representation shows the teacher-directed nature of the lesson scores for both enacted lessons and lesson plans, as all of the scores fall to the right side of the 2.5 median.

Table 16

Mean P-SOP scores for enacted lessons and lesson plans by feature of inquiry.

	Feature	N (out of 120)	Mean (out of 12)	SD
Enacted Lessons	Questioning	71	4.35	3.03
	Data/Evidence	120	5.81	2.15
	Explanation	95	2.67	2.37
	Alt. Explain	31	0.71	1.97
	Communicate	106	1.69	1.39
Lesson Plans	Questioning	66	4.01	3.41
	Data/Evidence	120	5.87	2.25
	Explanation	75	2.32	2.22
	Alt. Explain	23	0.44	1.23
	Communicate	84	1.16	0.91

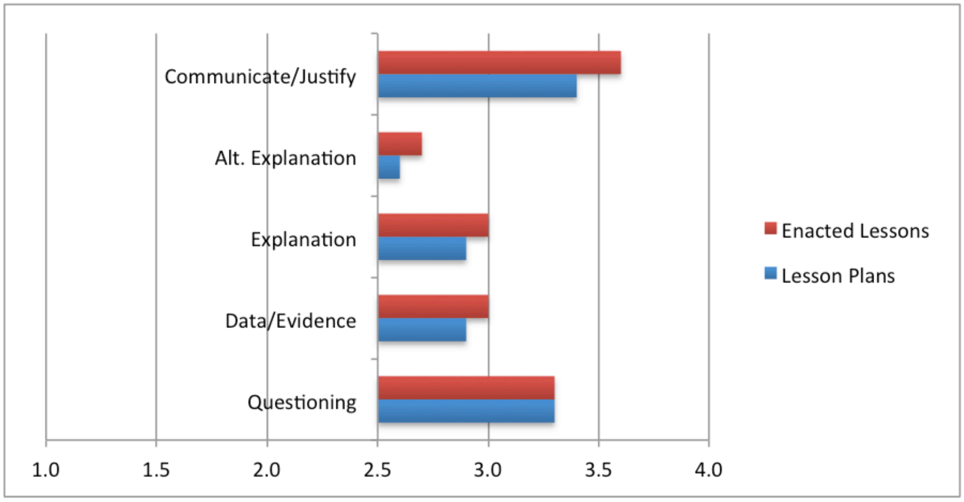

Figure 14. Overall P-SOP^{d} Scores for Both Planned and Enacted Lessons

Figure 15 shows the score frequencies broken down by feature of inquiry for the enacted lessons in the study. This graph was created by converting all zero scores to 2.5 which is neither student nor teacher directed on the P-SOP^d rubric. Only for the feature of data/evidence did an enacted lesson score a ‘1’ (the most student-directed variation) and that was only for a single lesson. Figure 16 shows the score frequencies of the lesson plans broken down by feature of inquiry. Just as with the enacted lessons, notice that 100% of the lesson plans scored a ‘4’ on the questioning feature, and that the overall trend of the lesson plans was very teacher-directed variations of inquiry. No lesson plans scored a ‘1’ on any of the inquiry features. Figures 17 and 18 break down the score frequencies of the aggregate scores of the enacted lessons and lesson plans respectively.

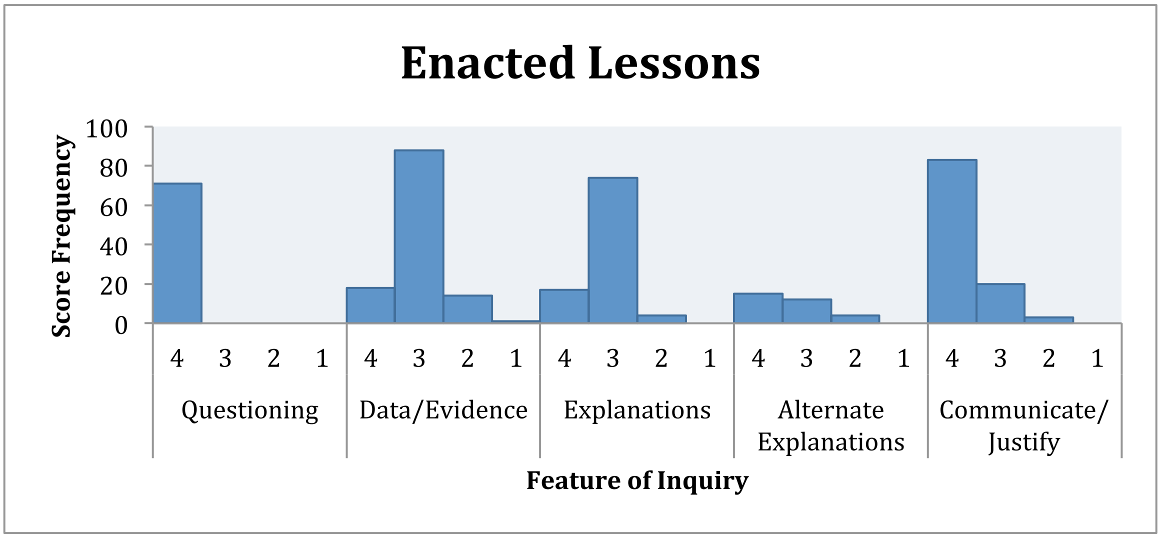

Figure 15. P-SOP^d score frequencies for enacted lessons by feature of inquiry

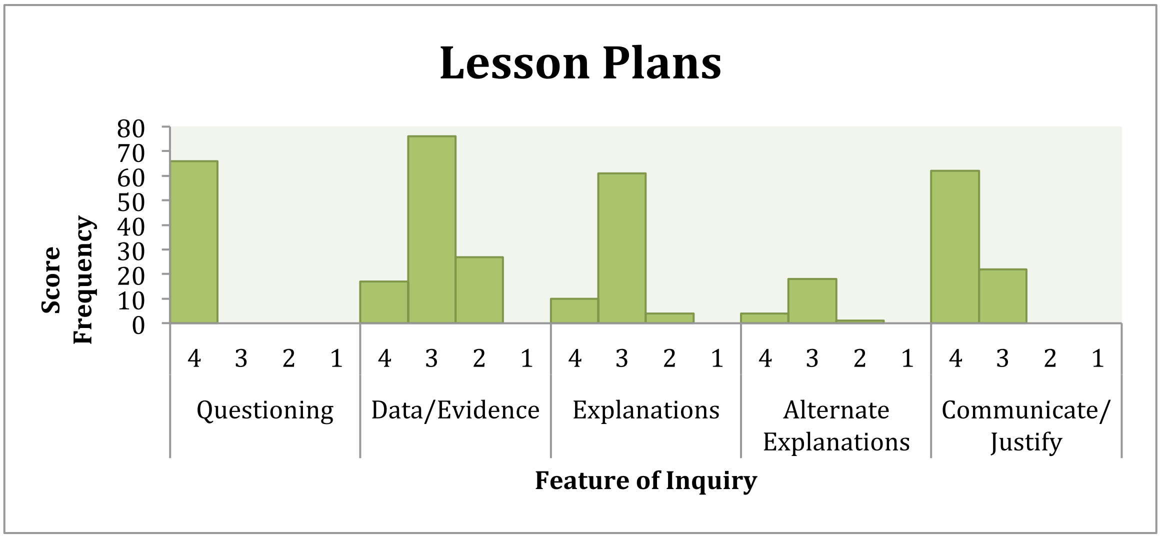

Figure 16. P-SOP^d score frequencies for lesson plans by feature of inquiry.

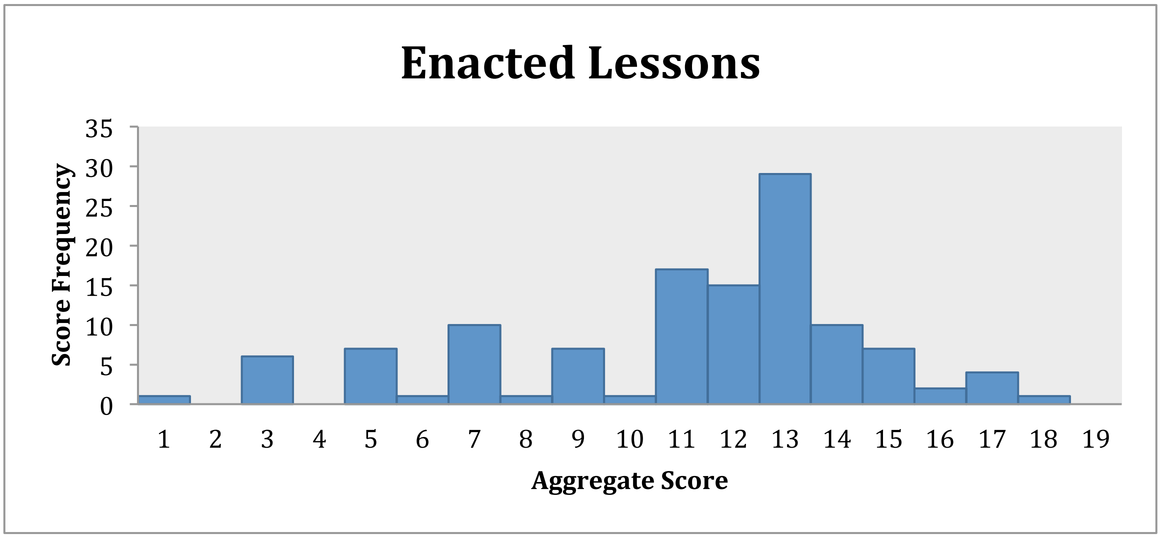

Figure 17. P-SOP^d aggregate enacted lesson score frequencies.

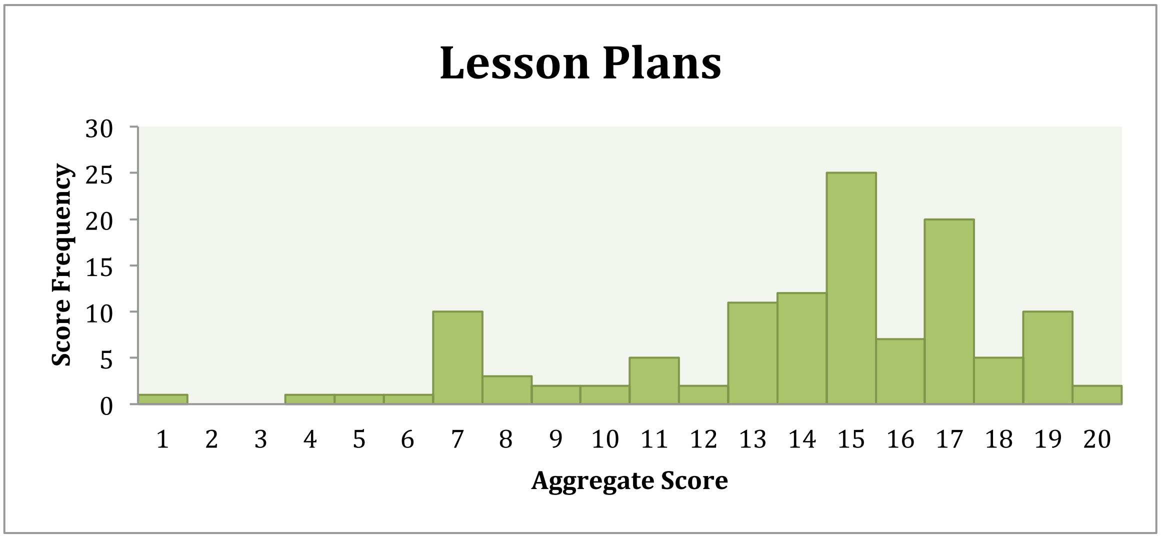

Figure 18. P-SOP^d aggregate lesson plan score frequencies.

Table 17

Comparison of Lesson Plans and Videos on the P-SOP^d by Feature of Inquiry

	Questioning	Data/Evidence	Explanation	Alt. Explain	Communicate
Chi Square (N=40)	20.706*	N/A[a]	7.776*	2.720	4.444
Paired t-test *(df)*	N/A[b] *(50)*	1.937 *(119)*	1.350*(64)*	1.00*(8)*	0.623*(76)*

* $p < 0.001$; [a] can not be calculated because both values are constants; [b] can not be calculated because the standard error of the difference is zero

These results show that with the exception of the questioning and explanation features, which were not enacted as frequently in the videos as was called for in the lesson plans, the teachers taught their curriculum materials with high levels of fidelity. The high incidence of zero scores posed a challenge by lowering the total number of scores for each feature, but the paired t-tests revealed that when a certain feature was present in both the lesson plan and the enacted lesson, it was enacted with virtually the same amount of teacher-direction as the lesson plan prescribed. These results extend the original P-SOP rubric findings, in which the teachers enacted their curriculum materials with high fidelity for the features of inquiry. This study shows that not only for the features of inquiry, but also for the amount of teacher-direction within the features, the elementary teachers enacted their curriculum materials with high levels of fidelity.

Research Question 3: What Is the Relationship Between the Overall Quality of Inquiry and Variations of Inquiry in Elementary Teachers' Enacted Science Instruction?

There was a small significant correlation between the amount of inquiry (measured on the P-SOP) and the amount of teacher-directedness (measured on the P-SOP^d) for both lesson plans and enacted lessons. The overall correlation between the P-SOP and the P-SOP^d was 0.646 for lesson plans, and 0.648 for enacted lessons (see table 18 and figures 20 and 21), each of which are significant at the 0.01 level. The positive correlations indicate that the higher level of inquiry (measured on the P-SOP) correlated with more teacher-directed inquiry (measured on the P-SOP^d). When broken down to individual feature level (i.e. questioning) there were two instances when the correlations between the rubrics were significant. One was for the data/evidence feature for the enacted lessons (-0.230, n=120, significance of 0.12), and the other was for the explanations feature for the lesson plans (-0.311, n=95, significance of 0.002). The negative correlations indicate that the higher level of inquiry correlated with more student-directed variations of inquiry.

The enacted lessons were also scored on the RTOP rubric. The RTOP emphasizes 'student-centered' variations of inquiry, and the P-SOP^d measures the amount of teacher direction in inquiry lessons. The overall correlation between the P-SOP^d and the RTOP (enacted lessons only) was 0.188 (see figure 19). The RTOP has not been validated for use with lesson plans, so it was only used to score the enacted lessons. The RTOP correlation cannot be broken down by feature because it is not aligned with the five essential features of inquiry, however, the P-SOP and P-SOP^d are both built around those five features, so the correlations between these two can be broken down by feature.

These results suggest that the different rubrics (P-SOP, P-SOP^d, RTOP) do not measure the same constructs, especially the RTOP and the P-SOP^d. The RTOP's emphasis on student-centered inquiry practices caused it to measure a different inquiry construct than the P-SOP^d, which measures the amount of teacher direction in an inquiry lesson. This would expectedly have a lower correlation between the scores. The P-SOP and P-SOP^d would be expected to have a higher correlation since they are both based on the same theoretical construct (the five essential features of inquiry [NRC, 2000]), although they measure different aspects of the construct. The P-SOP measures the level of inquiry and the P-SOP^d measures the amount of teacher direction for each feature of inquiry.

Table 18

Correlations between P-SOP and P-SOP^d broken down by feature

	Questioning	Data/Evidence	Explanation	Alt. Exp.	Communicate	Overall
Videos (N)	N/A[a]	-0.041 (120)	-0.307** (95)	-0.248 (31)	0.005 (106)	0.648** (120)
Plans (N)	N/A[a]	-0.226* (120)	-0.034 (75)	-0.276 (23)	-0.148 (84)	0.646** (120)

[a] can not be calculated because at least one of the variables is a constant; * significant at the 0.05 level (2-tailed); ** significant at the 0.01 level (2-tailed)

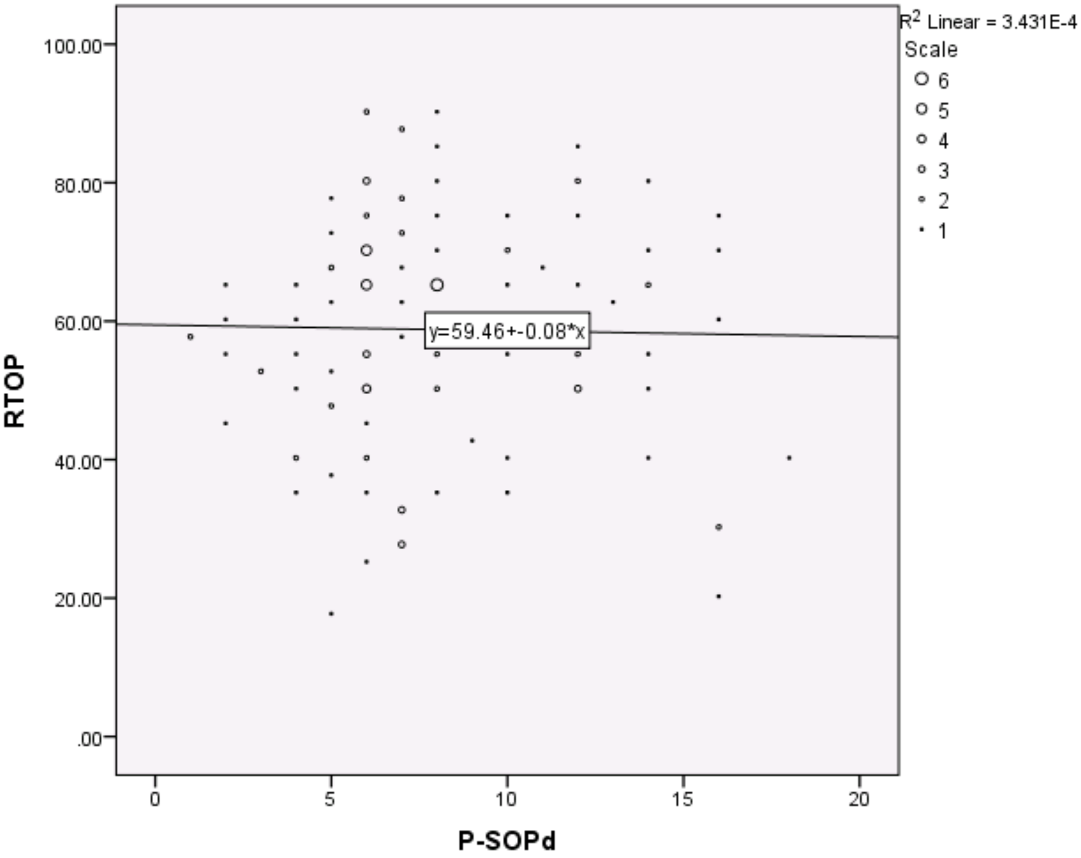

Figure 19. Correlation between averaged video scores of RTOP and P-SOP^d

As a reminder from the methods chapter, the RTOP scores do not break down along the same feature of inquiry equivalents as the P-SOP and P-SOP^d rubrics. The scores reported here are for an overall aggregate score of the RTOP for only the enacted lessons. The RTOP has not been validated for use with lesson plans, so it was not used to score the lesson plans from the data set for this study. The graph shows that there was no correlation between the RTOP and P-SOP^d scores, suggesting they measure different constructs.

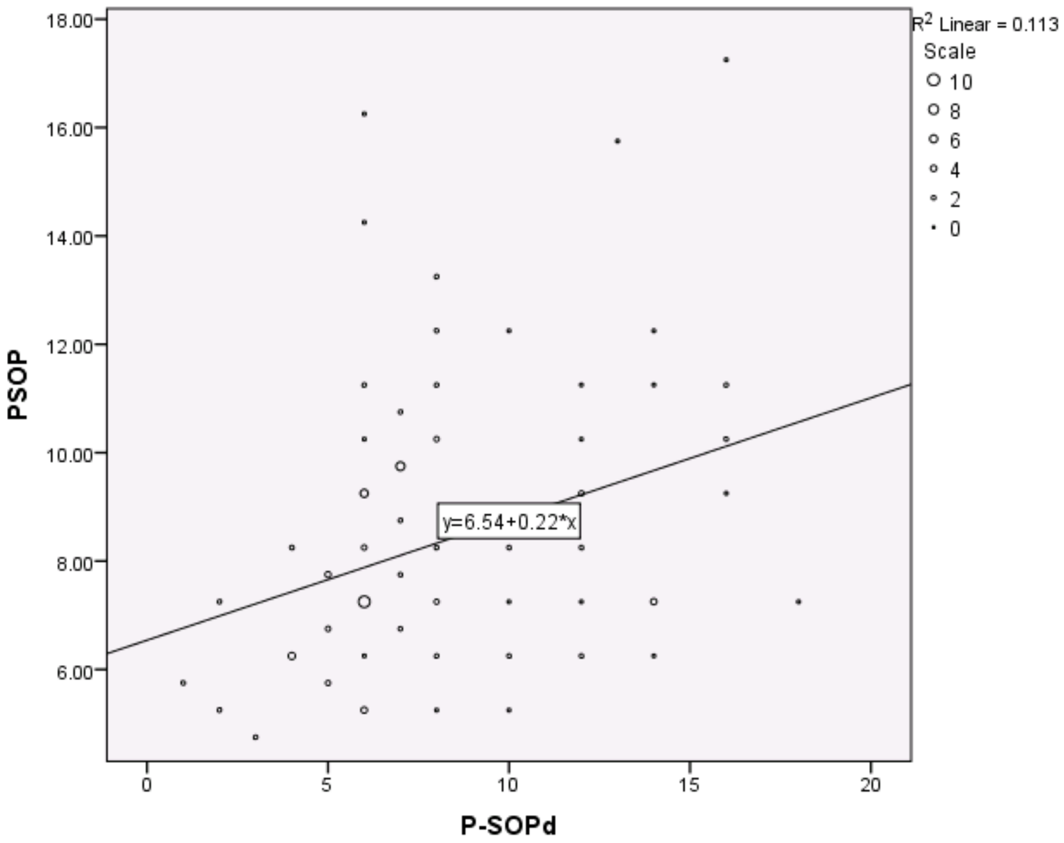

Figure 20. Correlation between enacted lesson P-SOP^d and P-SOP scores

As table 18 shows, there were two instances at the feature level where there existed a significant correlation between the P-SOP and the P-SOP^d scores. The first was for the data/evidence feature on the lesson plan scores. The second was for the explanation feature for the videos. The negative correlations reveal that higher level of inquiry (measured on the P-SOP) correlated with higher instances of student-directed inquiry (measured on the P-SOP^d). The overall correlations were also significant for both lesson plans and enacted lessons. The discussion section will return to this point of why there was an overall positive significant correlation and only two instances at the feature level that showed negative significant correlations.

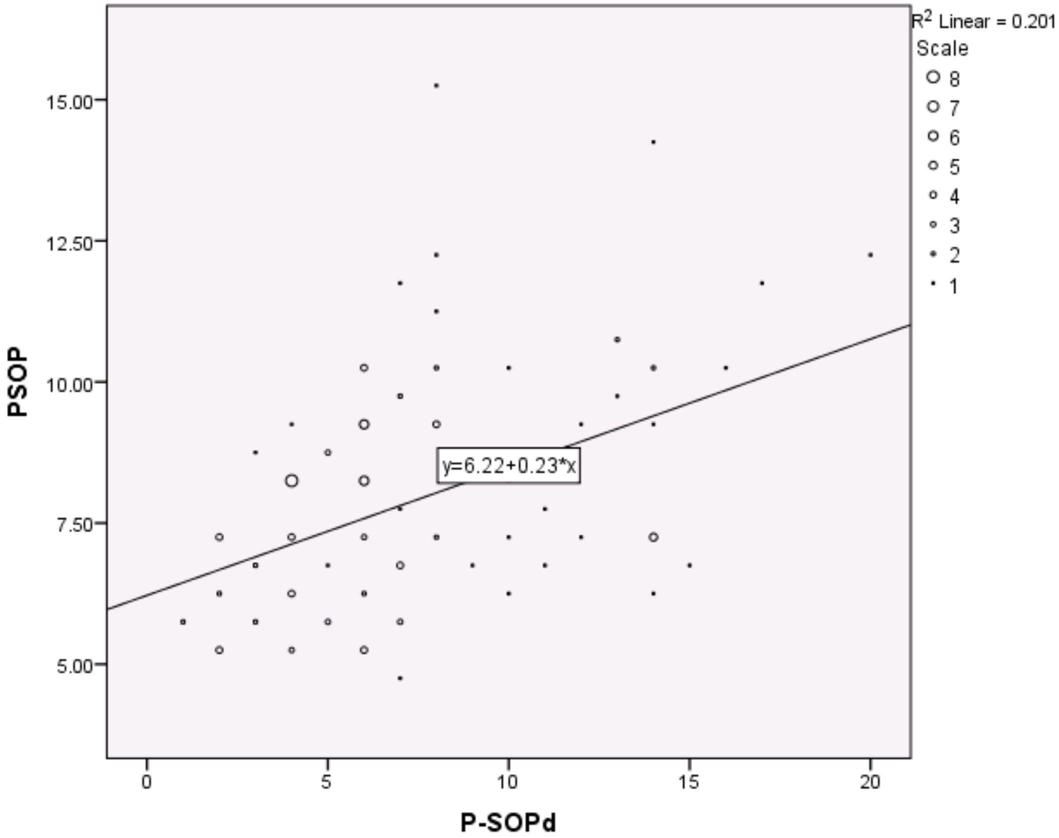

Figure 21. Correlation between lesson plan scores (N=120) of P-SOP^d and P-SOP

In order to represent the correlations between the P-SOP and P-SOP^d in a different way, I calculated cross-tabulations for each feature. Remember from the methods section about each of these instruments that the P-SOP possible score per feature is a 12, and the P-SOP^d possible score per feature is 4 because it does not break down the sub-feature levels like the P-SOP does. In order to have even matrix cross-tabulations, I collapsed the P-SOP feature scores into 4 categories to match the P-SOP^d scores. For the category names, I used the descriptors from the LPE document in which the teachers rated the lesson as "very, somewhat, not very, not at all" inquiry-oriented. Cross-tabs were only run on the set of scores for which there was a score present for that particular lesson's feature of inquiry on both the P-SOP and P-SOP^d. The scores were collapsed and re-titled as follows:

- P-SOP Original Score
    - 0-3: Not at all inquiry-oriented
    - 4-6: Not very inquiry-oriented
    - 7-9: Somewhat inquiry-oriented
    - 10-12: Very inquiry-oriented
- P-SOP^d Score Names
    - 1: Very student-directed
    - 2: Somewhat student-directed
    - 3: Somewhat teacher-directed
    - 4: Very teacher-directed

This collapsing of scores for the P-SOP allows for a 4x4 matrix for each feature for both video enacted lessons and also for lesson plans. I present these tables and analysis to help represent the correlations between the P-SOP and P-SOP^d per feature. Overall general trends indicate that very few features were taught in 'very student-directed' ways, and that very few lesson features were enacted as 'very-inquiry oriented'.

Questioning

For the feature of questioning, every single enacted lesson and lesson plan of the 120 analyzed lessons scored as 'very teacher-directed' (see table 19). This is quite a substantial finding. On the P-SOP^d, this translated as the teacher providing the investigation question to the students as opposed to students choosing from possible questions to investigate or deriving their own question. The scores on the P-SOP fell mainly in the ‘somewhat inquiry-oriented’ category, followed by nearly equal numbers in the categories directly above and below in the ‘very inquiry-oriented’ and ‘not very inquiry-oriented’ categories. The scores for the lesson plans fell in extremely similar categories (see table 20), with the majority of lesson plans scored as ‘somewhat inquiry-oriented’ followed by nearly equal numbers in the categories directly above and below.

Table 19

Cross-tabs between P-SOP and P-SOP^d Videos for Feature 1: Questioning

Very teacher-directed	3	16	33	19	71
Somewhat teacher-directed	0	0	0	0	0
Somewhat student-directed	0	0	0	0	0
Very student-directed	0	0	0	0	0
Totals	3	16	33	19	71
	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals

Data/Evidence

For the second feature, data and evidence, the majority of enacted lessons fell in the ‘somewhat teacher-guided’ category (see table 21). In this category on the P-SOP^d, the learners are directed to collect certain data. Similarly to the questioning feature, the majority of lessons’ P-SOP scores fell in the ‘somewhat inquiry-oriented’ category, with the highest cross-tab cell at the intersection of ‘somewhat inquiry-oriented’ and ‘somewhat teacher-directed’. However, the highest cross-tab cell for lesson plans for this feature fell at the intersection of ‘somewhat teacher-oriented’ and ‘not very inquiry-oriented’ (see table 22). This may indicate that the teachers’ enacted lessons were slightly more inquiry-oriented for this feature than their lesson plans.

Table 20

Cross-tabs between P-SOP and P-SOP^{d} Lesson Plans for Feature 1: Questioning

	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals
Very teacher-directed	7	18	22	19	66
Somewhat teacher-directed	0	0	0	0	0
Somewhat student-directed	0	0	0	0	0
Very student-directed	0	0	0	0	0
Totals	7	18	22	19	66

Table 21

Cross-tabs between P-SOP and P-SOP^{d} Videos for Feature 2: Data/Evidence

	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals
Very teacher-directed	5	6	6	1	18
Somewhat teacher-directed	11	32	38	6	87
Somewhat student-directed	2	6	4	2	14
Very student-directed	0	1	0	0	1
Totals	18	45	48	9	120

Table 22

Cross-tabs between P-SOP and P-SOP^d Lesson Plans for Feature 2: Data/Evidence

Very teacher-directed	7	5	4	1	17
Somewhat teacher-directed	6	38	29	3	76
Somewhat student-directed	1	12	12	2	27
Very student-directed	0	0	0	0	0
Totals	14	55	45	6	120
	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals

Explanations

Feature three, constructing explanations, parallels the pattern from the previous two features of the majority of lessons (both planned and enacted) falling in the ‘somewhat teacher-oriented’ category for the P-SOP^d scores (see tables 23 and 24 respectively). On the P-SOP^d this translated into the learner being guided in the process of formulating explanations from evidence rather than being provided with evidence or formulating explanations on their own. However, the majority of both enacted lessons and lesson plans by far fell in the ‘not at all inquiry-oriented’ category for the P-SOP scores. The highest cross-tabs cell was the intersection of these two categories (40 out of 95 lessons). Very few enacted lessons were either very inquiry-oriented or somewhat or very student-directed for this feature, indicating low inquiry-orientation and high teacher involvement.

Table 23

Cross-tabs between P-SOP and P-SOP^d Videos for Feature 3: Explanation Construction

Very teacher-directed	13	4	0	0	17
Somewhat teacher-directed	40	24	8	2	74
Somewhat student-directed	1	1	0	0	4
Very student-directed	0	0	0	0	0
Totals	54	29	8	4	95
	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals

Table 24

Cross-tabs between P-SOP and P-SOP^d Lesson Plans for Feature 3: Explanation Construction

Very teacher-directed	5	4	1	0	10
Somewhat teacher-directed	33	20	6	2	61
Somewhat student-directed	3	1	0	0	4
Very student-directed	0	0	0	0	0
Totals	41	25	7	2	75
	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals

Alternate explanations

Feature four, comparing and evaluating alternate explanations, had the fewest number of lessons with scores on both the P-SOP and P-SOP^{d}. The majority of enacted lessons fell in the 'very teacher-directed' and 'somewhat teacher-directed' categories for the P-SOP^{d} (see table 25). On the P-SOP^{d}, the 'very' teacher-directed version states that the learner is explicitly told whether his explanation is right or wrong and why; and the 'somewhat' teacher-directed variation states that the learner is explicitly told whether his explanation is right or wrong and provided specific resources to form connections to explanations. All of P-SOP scores fell in the 'not at all' or 'not very' inqiry-oriented categories with the majority in the 'not at all' category. The lesson plan scores for this feature follow similar patterns (see table 26), with the highest cell on the cross-tab matrix being the 'somewhat teacher-directed' and 'not at all inquiry-oriented' intersection.

Table 25

Cross-tabs between P-SOP and P-SOP^{d} Videos for Feature 4: Alternate Explanations

Very teacher-directed	14	1	0	0	15
Somewhat teacher-directed	11	1	0	0	12
Somewhat student-directed	4	0	0	0	4
Very student-directed	0	0	0	0	0
Totals	29	2	0	0	31
	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals

Table 26

Cross-tabs between P-SOP and P-SOP^d Lesson Plans for Feature 4: Alternate Explanations

	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals
Very teacher-directed	4	0	0	0	4
Somewhat teacher-directed	15	3	0	0	18
Somewhat student-directed	0	1	0	0	1
Very student-directed	0	0	0	0	0
Totals	19	4	0	0	23

Communicate/Justify

The final feature, communicate and justify, fell more closely with the questioning feature than any of the others (see table 27). The great majority of enacted lesson scores fell in the 'very teacher-directed' category for the P-SOP^d, and the majority of P-SOP scores fell in the 'not at all inquiry-oriented' category. On the P-SOP^d the 'very' teacher-directed category includes that the learner is told both what and how to communicate/justify, as opposed to having freedom in either of these areas as the less teacher-directed variations reflect. No lessons scored as 'very' inquiry-oriented for this feature for the enacted lessons or for the lesson plans. The lesson plan scores mirror those of the enacted lessons, with the majority falling in the 'very' teacher-directed category (see table 28).

Table 27

Cross-tabs between P-SOP and P-SOP^d Videos for Feature 5: Communicate/Justify

	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals
Very teacher-directed	77	4	2	0	83
Somewhat teacher-directed	18	1	1	0	20
Somewhat student-directed	2	1	0	0	3
Very student-directed	0	0	0	0	0
Totals	97	6	3	0	106

Table 28

Cross-tabs between P-SOP and P-SOP^d Lesson Plans for Feature 5: Communicate/Justify

	Not at all inquiry-oriented	Not very inquiry-oriented	Somewhat inquiry-oriented	Very inquiry-oriented	Totals
Very teacher-directed	59	3	0	0	62
Somewhat teacher-directed	19	3	0	0	22
Somewhat student-directed	0	0	0	0	0
Very student-directed	0	0	0	0	0
Totals	78	6	0	0	84

Summary

The quantitative analysis in chapter IV answered the first three research questions which were, (1) *How valid and reliable is the P-SOP^d,* (2) *In what ways do inservice* *elementary teachers adapt existing elementary science curriculum materials across the inquiry continuum*, and (3) *What is the relationship between the overall quality of inquiry and variations of inquiry in elementary teachers' enacted science instruction*. For research question one, I found evidence for both the content validity and the construct validity of the P-SOP^d . Also, I found adequate levels of inter-rater reliability and test-retest reliability. For research question two, I found that the teachers did not significantly modify their existing kit-based science curriculum materials across the inquiry continuum except for the presence of the questioning and explanation features which were present more often in the lesson plans than in the enacted lessons. For research question three, I found a small significant correlation between the P-SOP and the P-SOP^d rubrics, including two isolated feature-level instances (one for videos and one for lesson plans). There was not a clear pattern as to why these two features correlated significantly when the others did not.

CHAPTER V

QUALITATIVE ANALYSIS FINDINGS

This chapter presents the findings from the qualitative analysis of the mixed method study. This section answers the research question, '*How do inservice elementary teachers' ideas about the inquiry continuum influence their adaptation of elementary science curriculum materials?*' The results are divided into two main sections, (a) cross-case findings, and (b) individual case reports. I first discuss the cross-case findings to show similarities among the three teachers and how they represent in-depth explanations of the quantitative findings. I then present the individual case reports to show how the teachers differed in their pedagogical reasoning and curriculum adaptation even within the same series of lessons. The cross-case findings include themes of the teachers ideas about the inquiry continuum which were present across all three case- study teachers, and the individual case studies present a unique look at each of the case- study teachers' reasoning about whether and how they modified their curriculum materials across the inquiry continuum of teacher-directed to student-directed from the original lesson plan to their actual enacted lessons.

Cross-Case Findings

Across the three case-study teachers there were three themes that emerged consistently from the interview and observation data. The teachers ideas about the inquiry continuum included (a) the belief that student-directed variations of inquiry were more inquiry-oriented than teacher-directed variations of inquiry, (b) the belief that their FOSS curriculum materials were not inquiry-oriented, and (c) perceived challenges to teaching more student-directed variations of inquiry. These three cross-case themes will be discussed in the following section.

Student-Directed Inquiry Equals More Inquiry-Oriented

The case-study teachers collectively defined inquiry in terms of being student-directed or student-centered. This theme was persistent throughout the interviews over the course of the school year for all three teachers. The first evidence of the teachers' idea that inquiry should be student-directed is in their very definitions of inquiry. Grace, for example, asked a rhetorical question to the interviewer, "That's where we're going with this whole science inquiry, isn't it? Getting the kids to take the lead themselves" (01 LP Eval. Interview, 156:179). Emily's definition also focused on the student-direction of the inquiry process, "Um, I define inquiry as letting the students um, come up with their own investigable question and then doing an investigation" (04 exit interview, 15:20). Janet's definition of inquiry, also, was very student-directed. She defined inquiry as:

> My interpretation of science inquiry always has been it's more student-centered. Students get to come up with a couple more of the questions and do more of the um analyzing of the data, the hands-on experience, things like that… Um, discovery, kid-centered generated type things… The kids enjoy it because they have more freedom… they get to do more teamwork. They get to, you know, ask questions. They get to do more research on their own… They're constantly able to make connections and, you know, figure things out… They feel successful because they're discovering things on their own… It's not so teacher fed. (08 Formal interview, 87:92).

Grace defined inquiry in the following way:

> Inquiry is where the kids are doing more investigations, its not just reading out of a book, its not giving them an activity to do, they have either a guided question from the teacher, hopefully we'll be moving on to where the kids will be getting something, an activity where they will formulate their own questions but we're not there yet but a teacher guided question that the kids investigate in groups, that there is no one right or wrong answer that they have to work together to figure out why it happened and how it happened" (01 formal, 9:12).

Grace discussed in her first interview how her teaching philosophy about inquiry has changed over the past year since she learned about teaching science-as-inquiry:

> Um, I mean, I thought, when we had taught kids before, for years, but I did all the talking, I set everything up and never was it with a guiding question. I think they were just doing little activities and

> this is… and then I was always telling them the answer, this is why it happened. And I think if at all, that's what you're getting from most teachers; they don't understand inquiry at all. (01 Formal, 97:98)

This idea that her definition of inquiry has changed over time was recurrent throughout her interviews.

Emily defined inquiry, just as Grace did, in student-directed terms. Also similarly to Grace, she identified lessons as more inquiry-oriented if they were more student-directed.

> Um, I think of inquiry as starting out giving the students maybe a question to investigate, letting them investigate, go through all the steps and then come up with a conclusion and eventually, I'd like to get them to come up with questions to investigate and let them come up with conclusions. (04 Formal, 2:2).

Janet defined inquiry (as seen above), just as Grace and Emily did, in very student-directed terms. She was first introduced to the idea of inquiry during her science training in undergraduate methods classes. She admitted her training for inquiry was definitely student-directed. She used the term "discovery" several times in conversation, as well as "kid centered". She claimed that inquiry may cause teachers to "lose control of [their] classrooms" which indicated that she thought of inquiry as a free-for-all. Her specific definition was:

> Inquiry has to do with challenging students to have a more in depth thinking, um, being accountable for their learning, which means they get to create some of the ideas that go into what they're going to learn about. They get to create some of the questions that they will find answers to through their, um, their experiments and their research. (08 exit interview, 6:6)

Janet believed students needed scientific practices modeled for them, and that slowly introducing those skills over time was necessary in order to engage students in more student-directed forms of inquiry. She mentioned several times that students enjoyed student-directed inquiry more because they were "more active" (08 Exit interview, 45:45), which matched her definition of inquiry. She believed third graders needed more structure and modeling in order to help them to be successful in science.

She felt that she needed to scaffold scientific practices for them, which she calls “laying the groundwork”:

> T[7]: Um and it’s structured for the most part. Now, a lot of the inquiry that we do in third grade is more structured and that’s part of laying the groundwork for, you know, helping them think along those – those terms of asking more questions.
>
> I: OK. Tell me what some of that ground work is you have to lay.
>
> T: Well, just, you know, a lot of modeling needs to take place… You teach them how to think that way. You teach them how understand and ask those probing questions that will take them farther and deeper. (08 Exit interview, 45:48)

Second, the case-study teachers’ definitions of inquiry were also evident in their evaluation of the magnets lesson provided to them for evaluation as part of the LPE. Grace, for example, scored the magnet lesson as “not very inquiry oriented” and gave the following reasoning in the interview which followed up on her LPE responses,

> To me it’s not at all very inquiry oriented… you’ve guided them through it all. You know, do this, do this, do this. Not letting them you know take the lead themselves… You know, repeat the experiment, record the number of paper clips and new sheets you need for three pieces of tape, you know, maybe letting them figure that out themselves… you know, how many pieces of tape… I would be having them figure that out themselves, you know, their own data chart… giving students more responsibility for their learning… putting the ownership on the kids. (01 LP Eval. Interview, 156:179)

Grace’s interpretation of the magnets lesson was that it is too teacher-directed to ‘count’ as inquiry. She mentioned what she would do to make the lesson more inquiry oriented (making their own data chart, repeating the experiment, etc.). These actions would make the lesson more student-directed and therefore, in her mind, more inquiry-oriented.

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[7] T stands for teacher; I stands for interviewer

Similarly, Emily's reasoning for why she scored the lesson as 'not very inquiry-oriented' was:

> I look at this lesson as not much freedom… because it was very structured. You're telling the kids exactly what to do. You're asking all the questions and wanting the answers… So I didn't see it as…very inquiry." (04 LP Eval. Interview, 73:100)

Grace, Emily, and Janet each scored the lesson as lower than "very" inquiry-oriented, and indicated that in order for the lesson to be considered "very" inquiry-oriented it would need to be more student-directed in ways such as allowing the students to create their own data collection tables. These examples from the teachers' descriptions of the magnets lesson align with their definitions of inquiry as student-directed above.

In summary, the case-study teachers collectively defined inquiry as being student-directed and each scored the provided magnets lesson (on their LPE) as 'somewhat' or 'not very' inquiry oriented because they claimed it was too teacher-directed to count as 'very' inquiry oriented. The teachers also believed that in order to modify their curriculum materials to be more inquiry-oriented, the modifications needed to move the lesson toward the student-directed end of the inquiry continuum. These modifications are explored within the individual teacher case reports below.

FOSS Curriculum Materials

A second common theme throughout the three case-study teachers' interviews was that they did not consider their FOSS curriculum materials to be very (if at all) inquiry-oriented in two specific ways. First, the teachers claimed that the FOSS curriculum materials were too teacher-directed, and therefore not inquiry-oriented. Second, the teachers mentioned specific features of inquiry that were missing from their FOSS curriculum materials.

First, the teachers perceived the FOSS curriculum materials to be too teacher-directed to count as inquiry-oriented. This judgment of the perceived shortfall of the FOSS curriculum materials mainly rested in the teachers' definitions of inquiry, which were very student-directed definitions. Their descriptions of why FOSS did not meet their idea of what an inquiry-oriented curriculum materials might be all centered around the fact that the teacher was more involved than they would prefer. For example, Grace said about the first investigation:

> In the FOSS Kit they tell them exactly when you give them the bean pod. You give them the knife and you tell them that they open it. They got to find out what's inside and then after you do that, the teacher just tells them you open the fruit and it's the seeds. So basically, the teacher's telling them (Grace pre-enactment 1, 64:64)

In Grace's example here from the first part of investigation one, she believed the teacher gave too much direct instruction to the students.

Similarly, Emily used many terms to describe her FOSS curriculum materials which all had the connotation that the teacher was too involved in the lesson, and the lesson was not student-directed enough to 'count' as inquiry. Emily mentioned that there was no 'freedom' in the FOSS curriculum materials, which indicated that the amount of teacher-direction, in her mind, took away from the inquiry orientation of the lesson. Again, and similar to Grace's example, this aligned with Emily's definition of inquiry as being student-directed. Other words that Emily used to describe her FOSS curriculum materials when she was speaking about them not being inquiry-oriented were: guided (04 Formal interview, 56:56), structured (04 LP Eval. interview, 18:18), cookbook (04 pre-enactment 2, 199:199), scripted (04 post-enactment 3, 129:129), and recipe (04 exit interview, 48:48). Each of these terms highlighted the idea that Emily believed the FOSS curriculum materials had too much teacher-direction, which did not match her own definition of inquiry. In a parallel fashion, Janet stated,

> Knowing what I now know and what I thought about with inquiry, there's so many little things that they could have added to make it more student led and inquiry based. (08 Exit interview, 136:148)

This quote came from her exit interview after being involved in the project for one year. She clearly was looking more critically at her curriculum materials and how it matched (or in this case, did not match) her definition of inquiry as student-directed. She admitted that her ideas about the curriculum materials had changed over time. She communicated her previous beliefs about the curriculum materials in this way, “When you look at FOSS, you know, you’re thinking, oh, it’s hands on. The kids are, you know, answering questions by doing, not by sitting and lecturing so that was inquiry” (08 LP Eval. Interview, 124:124).

Second, the teachers claimed specific features of inquiry were missing from the FOSS curriculum materials when making the claim that FOSS was not inquiry oriented. In addition to a generic claim that the FOSS lessons did not follow the scientific method, each of the three case-study teachers mentioned at least one (and usually multiple) features of inquiry they considered to be missing from their FOSS curriculum materials, including the guiding question, a hypothesis, explanation construction, and explanation justification. Grace, for example, claims “They just… the scientific method is not in the FOSS kit, I mean really. It’s there but it’s not specifically. There’s no time ever that they ask them, ‘Ok, what’s your hypothesis’” (01 pre-enactment, 242:251). Emily and Janet argued that there is not an ‘essential’ question for the FOSS lessons, “As I look through this lesson plan, there’s no essential question at the beginning that’s like the overall… but um, sometimes I make up my own question to try to get them started” (08 pre-enactment interview 3, 15:30), and “so essentially, it doesn’t start out with questioning” (04 LP Evaluation interview, 42:3). As Janet’s quote eluded to, this lack of a focus, guiding, or ‘essential’ question caused the teachers to have to modify their curriculum materials in order to include this feature of inquiry. The individual case reports below describe specific ways the case-study teachers modified their FOSS curriculum materials.

Janet and Grace claimed that the FOSS curriculum materials did not encourage or support students to develop explanations, or to justify their findings in any way. Janet stated, “They are coming up with some of their own answers and getting to do hands-on, but there’s not a whole lot of explanation or anything” (08 pre-enactment 2, 113:2).

Similarly, Grace claimed that, “it doesn’t say anywhere that the teacher should be asking them to back up what they’re doing and justify” (01 pre-enactment 2, 260:264). The teachers emphasized that FOSS is a hands-on curriculum engaging students in the data collection and the ‘doing’ of science, but claimed FOSS fell short of asking students to formulate an explanation (or as Grace calls it, a ‘conclusion’) from their evidence.

Grace was correct that this series of lessons from FOSS never uses the term ‘hypothesis;’ however, there were many instances where FOSS asked the students to make predictions. For example, in investigation one part one it stated, “If you opened one more pod, how many seeds do you predict you would find in side (Predict and try it!)” (Investigation 1, p. 14). In part two of investigation one the students were asked “What do you think would happen if we just watered the seeds instead of planting them in the soil?” (Investigation 1, p. 22). Finally, in part three of investigation one the students were asked, “What changes do you think you might see in the sprouters after 5 more days?” (Investigation 1, p. 27). These examples show that Grace may not be able to identify a hypothesis in her curriculum materials if they do not use the exact term ‘hypothesis’. Grace’s reliance on the ‘scientific method’ may be too strict to not allow her to identify the features of inquiry in the FOSS curriculum materials.

In summary, the case-study teachers did not believe their FOSS curriculum materials were very inquiry-oriented in two main ways. First, they believed the FOSS curriculum materials were too teacher-directed, which lowered the overall inquiry-orientation of the curriculum materials in their minds. This finding aligned with their definitions of inquiry, which were extremely student-directed. The FOSS curriculum materials , in the teachers’ view, was too teacher-directed to ‘count’ as inquiry. Second, the teachers claimed that the FOSS curriculum materials were missing some of the essential features of inquiry such as explanation construction or investigation questions. These two elements formed the basis for the teachers’ modifications of the FOSS curriculum materials.

Perceived Challenges to Teaching Student-Directed Inquiry

A final theme persistent throughout the case-study teachers' ideas about the inquiry continuum was that they perceived certain challenges to teaching student-directed variations of inquiry. There were four challenges to teaching student-directed inquiry that the case-study teachers discussed in their interviews, (a) whether their students were prepared to be successful in student-directed inquiry, (b) giving up control of their classrooms for more student-directed versions of inquiry, (c) the amount of time it takes to teach student-directed inquiry, and (d) going against what they consider the 'norms' of science teaching practice when attempting student-directed inquiry.

First, the teachers were concerned that their third-grade students were not always capable of engaging in student-directed variations of the five essential features of inquiry. Janet, for example, claims:

> With the third grade, I mean even this was, for some of them, you know, they don't have any background knowledge and so it's so far above their heads that even something that we consider to be a simple task that on paper says oh, yeah they should be able to do this, when you put it into action with 22 students that don't have tons of background knowledge, it's not just going to go so smoothly… (08 post-enactment interview, 97:99)

Janet's mention of her students not having enough background knowledge indicated that she believed her students needed to have the content before they experienced the hands-on activities, which is contrary to the practices of scientific inquiry. It is through inquiry that the students should be formulating explanations on their own rather than being taught 'background knowledge' and then experimenting with a hands-on activity to confirm what they have been taught.

Emily also claimed that her third-grade students were not always capable of the scientific inquiry skills required for student-directed inquiry, especially for the practice of formulating explanations on their own. When asked, 'do you see that skill developing as they go through the inquiry process over and over that they get better at analyzing data or is it still a hard skill for third graders?' she answered,

> Um for third grade I think it's kind of a mixed bag… A lot of the students are getting better at it. They're looking at their data and I don't have to say oh, go back and look. They're doing a pretty good job of doing it. Then, you know, I've got that handful that I feel like I'm kind of still dragging along. (04 Exit interview, 105:109)

Here Emily indicated that her students were gaining proficiency at using their data/evidence to formulate an explanation, but that it was definitely not a skill that came naturally. She claimed to be 'dragging along' a handful of her third-grade students who were not as capable of student-directed inquiry practices, although she did not elaborate on how they differed from the students who were 'getting better at it.'

Grace also mentioned that her students differed in their abilities to successfully engage in student-directed forms of inquiry. She claimed, "It's hard for them, some kids they want to know what the one right answer is… learning that there is not just one right or wrong answer" (01 Formal interview, 75:76). This quote revealed that Grace believed that when teaching student-directed forms of inquiry, there was not one 'right' answer the students were aiming for, and that her students struggled with having to come up with an answer on their own. She implied here that her students were conditioned to always want to know what that 'right' answer was, and that student-directed inquiry, which may or may not provide them with the 'right' answer, was a difficult transition for her third graders to make.

A second perceived challenge the case-study teachers discussed was that they feared giving up control of their classrooms if they taught more student-directed versions of inquiry. Grace stated:

> Well you have to get used to giving up control. Which is fine and I mean really, you have to give up some control. And also, this isn't a weakness, but kind of, that you're not used to, as opposed to the other way. You know, it's having the teacher be quiet and let the kids work. I really don't look at it as a lot of weaknesses the more we get into it (01 Formal interview, 77:78).

Janet, also, described how she felt that she lost control of her classroom if she attempted to teach more student-directed variations of inquiry. She stated, "Even if I have a curriculum in front of me that is more inquiry based, you lose more control of your classroom and, you know, some teachers… don't like to let go as much" (08 Formal interview, 125:130). Emily's discussion of giving up control centered around removing herself from the discussion, which matched with her student-directed definition of inquiry. She conveyed the idea that it was difficult for her to engage in this type of student-directed teaching because it was unnatural for her to let the students do the investigating. She had to remind herself to "shut up" and not "give them all the answers". She discussed having to alter her own teaching style from being the giver of information to allowing the students to investigate for themselves when implementing more student-directed variations of inquiry.

> Um, I guess for me I have to just shut up and let the kids investigate *(laughs)*… that was one thing was learning to just listen to the kids and not give them my input… I just gotta remember to be quiet. Personally it has been hard for me to shut up. (04 exit interview, 35:42).

These examples support the idea that the case-study teachers considered it a challenge to release the control of their classrooms over to their students in more student-directed forms of inquiry.

A third perceived challenge the teachers mentioned for teaching student-directed inquiry was the amount of time student-directed inquiry takes in the classroom. All three teachers mentioned that student-directed inquiry takes more time to complete in their classrooms, and that they were up against time constraints by their district and their other teaching requirements. Janet mentioned several times that student-directed inquiry takes time (especially if it is done "correctly"[08 LP Eval. Interview, 124:124]). She acknowledged that she was fighting for science teaching time against requirements for teaching math and reading. She did a lot of prep work ahead of time in order for her students to get to the "doing" part of the science lesson rather than spending time on trivial activities, such as gluing seeds to paper. She stated, “I wish we had more time for it… but there’s just no time (08 post-enactment 2, 133:147).

The final perceived challenge that the three case-study teachers presented was the fact that student-directed inquiry goes against what they consider the ‘norms’ of science teaching practice. The main idea heard from the teachers was the fact that students were not used to investigating on their own and coming up with their own answers. The students struggled with wanting to be told the ‘right’ answer, or if they had found the ‘right’ solution. As Grace stated, “You know, they’re used to you telling them the answers” (01 LP Eval. Interview, 179:179). When asked to follow up why this was a problem for teaching student-directed variations of inquiry, she claimed:

> I think science has been taught out of reading, reading nonfiction books, reading to them all the time. Um, I mean, I thought, when we had taught kids before, for years, but I did all the talking, I set everything up and never was it with a guiding question. I think they were just doing little activities and this is… and then I was always telling them the answer, this is why it happened. And I think if at all, that’s what you’re getting from most teachers; they don’t understand inquiry at all. (01 LP Eval. Interview, 197:198)

Grace’s quote mentioned that she (as well as other teachers) was used to giving students the ‘right’ answer, and insinuated that teachers who teach this way ‘don’t understand inquiry at all’. Emily’s ideas aligned with Grace’s on this point. She said, “I think we’re so used to giving them every single thing… That’s one thing at the beginning of the year is they were really looking at me to just give them all the information, give them all the answers” (04 Exit interview, 35:42).

Janet’s views also aligned with Grace’s and Emily’s, but her explanation added a new dimension to the idea that student-directed inquiry goes against the norms of teaching practice. Janet stated this specific challenge:

> One thing that I have noticed in the last several years is kids are not responsible for their learning. They- they sit there and they think ok, I’m being quiet. I’m being good. I’m doing my work, but they’re not actually trying to retain it or, you know, and some of it’s sad because they’re not excited about learning anymore because the structure of the classroom has really changed,

> especially in our district with pacing guides and rigor, you know the rigor and the rigid curriculum. So trying to get them to take personal meaning from whatever we're doing. (08 LP Eval. Interview, 54:56).

While her idea here went beyond the science classroom, it was apropos to this perceived challenge of teaching student-directed inquiry. If students as a whole are no longer 'excited about learning' anymore, student-directed inquiry takes on a new challenge for teachers when attempting to engage students in more independent forms of inquiry. In order for student-directed forms of inquiry to work, students need motivation and creativity for solving problems. Janet's claim was that these things were missing in her students because of the way her district's pacing guide dictates how much content she must cover in a certain amount of time.

In summary, the case-study teachers described four perceived challenges to teaching more student-directed forms of inquiry in their classrooms. Those challenges were (a) whether their students were prepared to be successful in student-directed inquiry, (b) giving up control of their classrooms, (c) the amount of time it takes to teach student-directed inquiry, and (d) going against what they consider the 'norms' of science teaching practice.

Individual Case Reports

Because the teachers did not identify FOSS as inquiry-oriented, they each believed that in order to engage students in inquiry-oriented science, they must make modifications to their curriculum materials. The teachers' modifications varied across the features of inquiry as well as the amount of teacher direction (see table 29). Their individual curriculum material modification is described below in each of their case reports, but there was a general consensus that the FOSS curriculum materials needed modification in order to be inquiry-oriented, which the teachers defined as student-directed.

Table 29

Case-study teacher P-SOP[d] *scores for lesson plans (LP) and enacted lessons (video) categorized by FOSS investigation (best viewed in color)*

		LP	Video	LP	Video	LP	Video	LP	Video	LP	Video
Inquiry Feature		1		2		3		4		5	
Seed Search (Bean pods)	Grace	0	4	3	2	0	3	0	0	4	3
	Janet	0	0	3	3	0	2	0	4	4	4
Seed Search (Fruit)	Grace	0	4	2	3	0	4	0	0	0	3
	Janet	0	4	3	3	0	3	0	0	0	4
Mini Sprouters	Grace	4	4	3	3	0	0	0	0	3	3
	Janet	4	4	3	3	0	3	0	0	3	4
	Emily	4	0	3	3	0	2	0	0	3	2
Seed Soak part 1	Emily	4	4	3	3	0	3	0	3	0	4
Seed Soak part 2	Emily	4	4	2	3	3	3	3	4	3	3

Color coding key:

Amount of teacher direction

LP > Video; LP < Video; LP = Video; Not present in either; Enacted but not planned; Planned but not enacted

Chapter three detailed how the three case-study teachers were chosen for this study, aiming for variation amongst the teachers' ideas about the inquiry continuum within three teachers who enacted their three lessons from the same FOSS investigation, and how they modified their curriculum materials accordingly. Grace was selected because she showed an overall modification score that revealed her enacted lessons were more teacher-directed than her lesson plans. This conflicts with Grace's ideas about the inquiry continuum, which showed she has a very student-directed definition of inquiry.

Emily, on the other hand, was selected because her enacted lessons were (overall) more student-directed than her lesson plans. Janet's score differential between her enacted lessons and lesson plans was very nearly zero, meaning she had very few modifications across the inquiry continuum for any feature of inquiry.

Grace

Grace attempted to fit the FOSS curriculum materials into how she organized her science lessons in her students' science notebooks, "Um they nowhere in Foss set up a science notebook. You know, there's no- so that is a change that I made" (01 pre-enactment interview 2, 242:251). There were three main themes in Grace's reasoning about if and how she modified her curriculum materials across the inquiry continuum, (a) let's see what happens philosophy, (b) change over time, and (c) the scientific method. When asked what changes to her lesson had made it more inquiry-based answered,

> It's putting more ownership on the kids. You know, like I said, I know last year it was step by step… and I'm giving up that ownership tomorrow and just going to see what they do…we'll see what happens… when you deviate from the step by step you are getting inquiry. I mean, you get it a lot more. (01 pre-enactment interview, 195:202).

First, Grace possessed a "let's see what happens" philosophy about modifying her curriculum materials across the continuum toward student-directed inquiry. She believed that the less direction she gave her students the more student-directed the lesson became, and therefore it was more inquiry-oriented. Second, she discussed how much her teaching has changed since the last year. Grace mentioned multiple times how much more student-directed she has modified her teaching to be this year compared to last year. She believed that these changes of teaching in a more student-directed style increased the quality of inquiry in her lessons. Third, Grace was tied to the idea of 'the scientific method' for her idea of how her classes should be engaged in the process of 'doing science'. Her class's science notebooks were set up using a very specific version of the scientific method each and every time. This idea of the scientific method drove Grace's curriculum material modifications across the inquiry continuum. In the following paragraphs, I look at each of these three themes in further detail. Table 30 shows a visual representation of Grace's lesson modifications by features of inquiry. There were two instances when Grace modified the feature from the lesson plan to be more student-directed, and one case she modified the enacted lesson to be more teacher-directed.

Table 30

Overview of Grace's lesson modifications by feature of inquiry

Grace	Questioning	Data/Evidence	Explanation	Alt. Explain	Communicate
Lesson 1	*	←	*	=	←
Lesson 2	*	→	*	=	*
Lesson 3	=	=	=	=	=

Key:

*: enacted but not in lesson plan;

=: lesson plan score same as enacted score;

←: enacted more student-directed than lesson plan;

→: enacted more teacher-directed than lesson plan

Let's see what happens. First, Grace's reasoning behind her curriculum material modification toward more student-directed inquiry (or "open inquiry" (01 exit interview, 2:10)) was grounded in a "let's see what happens" philosophy. Her ideas of how to increase the level of inquiry in a lesson were to remove (or withhold) directions and "see what happens" (01 pre-enactment 1, 80:80) when students attempted a more student-directed variation of the lesson. For example in lesson one, she did not give directions to her students on the bean pod lesson because she wanted to see what they did rather than directing them herself. Grace gave as little direction to her students as possible, including not revealing the investigation question or purpose to her students. Grace extended this idea of “lets see what happens” when she referred to student-directed inquiry as a blind endeavor, “I’m not sure how it is going to go to be honest with you, but I mean… you know, it’s unknown but I guess that’s inquiry… sometimes you don’t know which way its even going to spin off” (01 pre-enactment 1, 174:176).

As she answered interview questions in a pre-enactment interview about how the lesson would address a particular feature of inquiry, Grace changed her mind on-the-fly in order to address where the particular feature of inquiry would fall on the inquiry continuum. These on-the-fly ideas did not (for the most part) get enacted in the observed lesson. For example, when she described how she planned to modify the amount of teacher direction for the feature of data/evidence during her second lesson, she stated:

> OK. I could let them choose… Which is more towards inquiry a little bit, right?... Or one at a time to get it. Yeah, I’m going to let them choose how they want to record the data and present it. I think I’m going to give them a choice (01 post-enactment 2, 59:66).

This full removal of teacher directions was not successful with her students. Grace’s students’ explanations were not scientifically based, and were mostly conjectures including some misconceptions, which she never corrected in her attempt to remove teacher instruction from the FOSS lesson. For example, one student sliced his bean pod completely down the middle, which included slicing each seed in half. The student went on to count each seed half as an entire bean when he counted his seeds. He reported this incorrect number on the class histogram, which transmitted his misconception to the rest of the class. Grace never corrected him, although she did attempt to get him to realize his mistake before allowing him to report his incorrect finding on the class histogram. She clearly still had a goal in mind for them (in this case, counting the number of seeds in a bean pod), but rather than asking them a specific question or giving specific instructions, she wanted to see what the students could come up with on their own.

Even with her emphasis on student-directed inquiry, there were only two instances in Grace's lessons when her enacted lesson scored more student-directed on a particular feature of inquiry than the FOSS curriculum materials. This occurred (as is shown in table 30 above) for the data/evidence and communicate/justify features for lesson one. For the second feature of her first lesson, Grace modified her enactment to be more student-directed than the FOSS lesson plan. In this specific instance, the lesson plan scores a 'C' on the P-SOP[d] whereas Grace's enactment scored a 'B' for this feature. Grace did not give her students direction as to what they should do with the bean pod. She said to her students, "I want you to make observations about the properties of bean pods in your group… I did not give you a title… We are not setting up our notebook today like we usually do" (01.1a 10:15). She claimed in her interview that her enactment of this lesson would be more student-directed than the FOSS curriculum materials:

> In the FOSS kit they tell them exactly when you give them the bean pod. You give them the knife and you tell them that they open it. They got to find out what's inside and then after you do that, the teacher just tells them you open the fruit and it's the seeds. So basically, the teacher's telling them so I've kind of changed that with it and I'm just going to… who knows what will happen. I'm just going to give them the stuff after we talk about properties of the apple and I'm going to give them the knives and I'm just going to um you know… what, what can you tell me about the bean pods? Ok. I'm not really going to necessarily going to tell them to cut them open… we'll see what happens, right?... Well, but truly isn't that more inquiry? (01 Pre-enactment 1 64:64).

In this case, her ideas matched her classroom enactment. She intended to make the enacted lesson more student-directed because of her ideals of student-directed inquiry, and in this instance for this particular feature, her enacted lesson scored more student-directed than the FOSS lesson plan.

Grace's first enacted lesson was also more student-directed for the communicate/justify feature than the FOSS lesson plan. In the FOSS lesson, students are directed in both *what* and *how* to communicate. They created a class histogram of the number of seeds in each bean pod and were asked specific questions to discuss (What is the most common number of seeds?). Grace, on the other hand, called her class to a whole-class discussion on the carpet where they discussed their results (not their explanations). She asked them "Did you have anything you wanted to share? (e.g. 01.1d, 1:20), which allowed students to decide *what* to communicate, but not necessarily *how*.

For the second feature of her second lesson, data and evidence, Grace's enactment was more teacher-directed than the FOSS lesson plan. The lesson plan stated, "they will open the fruits, find the seeds, and record their observations on the sheet. Students should put the seeds on the plates after they remove them from the fruits" (Investigation 1 p. 15). Grace, however, did not provide them the pre-made data sheet from the FOSS curriculum materials. She did give the pre-made data sheet to her behaviorally disturbed students (n=2) and a native Spanish-speaking student as an accommodation. She believed that in making this modification (removing pre-made data sheets), "They get much more freedom… I think they have a much better understanding of what a scientist is without the worksheet" (01 pre-enactment 2, 108:114).

This modification of removing pre-made data sheets, however, did not in this particular instance cause the enacted lesson to score more student-directed on the P-SOP^d rubric. The FOSS curriculum materials simply asked students to record their observations on the data sheet, but Grace's enacted lesson ended up giving her students more teacher-direction because they did not have a data sheet to fill in. They needed help and extra teacher guidance understanding what their task was since they did not have a data sheet to guide them. Without this direction, the students seemed a little bit lost as to what their purpose was. On the video you could hear students asking Grace what they were supposed to do with the fruit, and many of the students were simply playing with the fruit and the seeds, i.e. squeezing the oranges to get as much juice out as possible, rather than comparing the number and kind of seeds in each type of fruit Grace provided.

In this instance, the modification Grace made in hopes of making the lesson more student-directed actually ended up causing her to need to provide more teacher direction to her students because they were unsure of what to do with the fruit.

Change over time. Second, Grace emphasized how much her curriculum material modification had changed over the past two years. It was in the previous year that Grace was exposed to teaching science-as-inquiry through a note-booking class she took with the district science coordinator. This class challenged the way she taught science in her third-grade classroom, and Grace took the ideas to heart as she implemented notebooks in her science class beginning one year prior to this study. Grace claimed that being exposed to inquiry (which she equates with student-directed or ‘open inquiry’) caused her to make modifications to the FOSS curriculum materials. She felt she was on the path this year to being more inquiry-oriented, “Yeah, I’m trying to get it open-ended, more than I did in the past” (01 pre-enactment 1, 108:108). She constantly referred to how much she had grown since last year and gave examples of how she taught the lesson in the past, how she modified it to be more student-directed, and in a few cases even gave examples of how she would modify the lesson when she teaches it again in the future.

Grace even laughs at herself at one point as she looks back on the previous year’s student notebooks to see what she thought at the time was a good investigation question. “[Another teacher] and I were laughing… look what we wrote for our teacher guided question last year!” (01 pre-enactment 1, 160:160). This investigation question was one she felt could be answered with a simple yes or no, and she had attempted this year to engage her students in more thought-provoking questions that are less teacher-directed.

Grace referred constantly to how much she has grown over the past year with regard to her student-directed inquiry teaching abilities. She pointed to examples where she gave fewer directions to her students this year as opposed to last year, and claimed that this type of modification of her curriculum materials made this year’s lessons more inquiry-oriented. When asked how the changes she is making to her FOSS curriculum materials made it more inquiry-oriented, she answered the following:

> It's putting more ownership on the kids. You know, like I said, I know last year I… it was a step by step. You take that bean, you cut that bean, you open it up, look what you see and I'm giving up that ownership tomorrow and just going to see what they do. (01 pre-enactment 1, 195:202)

When asked why she made the modifications this year to be more student-directed, she referenced the note-booking class taught by the district science coordinator as well as other professional development opportunities through the Area Education Agency (AEA) for teaching her that student-directed inquiry should be her ultimate goal. "That has been a big feature of the work with [the district science coordinator] and the note-booking stuff… giving the students more responsibility" (01 LP Eval. interview, 156:179). These resources influenced her ideas about inquiry and why she felt she must modify the FOSS curriculum materials to be more student-directed. For example, she discussed the bean pod lesson differences between this year and last year:

> See, originally like this… that was not inquiry. That wasn't really inquiry. You know, everybody got it. Everybody write your three, everybody count those seeds, everybody, you know. Although, I guided them to do it they had this sheet and it was just what you're going to do. I think there was much more inquiry this way. (01 post-enactment 2, 294:294).

She still felt she has room to grow, however, and that she was still working on asking the right questions, leading whole class discussions, and giving the students more ownership of their learning. Two specific examples she gave about moving toward the future and how she planed to modify the curriculum materials further the following year includes putting the ownership of the investigation question on the students and removing more pre-made data sheets:

> I would like to make it even more inquiry based and I don't know at this point exactly what I'm going to do. I want to, you know, over the weekend sit down and reflect over the three days and take some notes. Write down some ideas so when I look at it again next year, I'll have my thoughts written down… Because I would like to try and make it a little bit more inquiry. Um I think what I'll- I

> think next year, and I don't know if we talked about this or not, but I'd like to have them help come up with the question… So I will try that again next year…Probably take that worksheet component out and see how they record the data. See if anybody thinks to trace and so on. (01 post-enactment 3, 238:243).

Scientific method. Third, Grace was still very much tied to a "scientific method" which she defined as the following series of steps: (1) teacher guided question, (2) student prediction, (3) materials, (4) procedure, (5) observations/data, and (6) conclusions. Grace referred often to this scientific method when discussing how she used science notebooks in her classroom, as well as how she modified her FOSS curriculum materials to match this scientific method and her definition of student-directed inquiry. Her process for science notebooks was very prescriptive, following a cannonical scientific method format. This method was how she set up her science notebooks (in this precise order) each and every time. The students were only responsible for writing items 2, 5 and sometimes 6 (predictions, data, and conclusions). She almost always provided the question, purpose, procedure, and materials for them to copy off of the overhead. Her thoughts on teacher/student-directed inquiry overlapped with her reasoning. She felt that in order to reach the highest category of inquiry on the Lesson Plan Evaluation scale ("very"), the students had to come up with everything. Therefore, she rated lessons as more inquiry oriented if the teacher was less involved in each of the steps; and she attempted to modify her enacted lessons to be more student-directed.

Grace hoped that over the course of the year her students would begin to ask their own questions, and take ownership of their learning: "eventually I'd like to get them to come up with questions to investigate" (01 Formal, 2:2). One piece of the students' scientific notebooks did not change, and that is the fact that she gave them a teacher-guided question. Grace viewed the question as the central focus of the lesson:

> To keep them engaged. It keeps them focused. It gets them right back into the investigation. You know, why? What evidence do you have? How do you know that? That questioning just keeps them moving on and it keeps them thinking. (01 post-enactment 1, 156:161)

Teacher-directed questions were one way she felt she could easily modify her FOSS lessons to become more inquiry oriented, by allowing the students to develop questions on their own. This was one way she attempted to modify her lessons to be more inquiry-oriented over the course of the school year. She realized that her investigation questions were teacher-directed currently, but compared this to even a year ago when she claimed she did not use inquiry at all, which tied in with her idea of how she made modifications to her curriculum materials over time to make her lesson enactments more student-directed. She stated, "So right now it's teacher-guided. I'm starting to be able to move a little farther than I was last year… Last year I didn't see, I don't think I would have even figured that out" (01 LP Eval. interview, 54:58).

Grace also specifically claimed that inquiry questions needed to be of the "how" or "why" variety. She looked for these types of questions specifically in her curriculum materials, and found few. She attempted to stay away from questions that could be answered with a simple 'yes' or 'no'. This was one specific adaptation she provided from her FOSS curriculum materials. In two of her three lessons, she added a teacher-directed question to the enacted lesson when there was not one included in the FOSS curriculum materials. She stated, "that is a change that I made and I'm using a teacher-guided question" (01 pre-enactment 2, 242:251). She asked her students questions that were not answered by a simple 'yes' or 'no' as she facilitated both small group and large group discussions, "I really tried hard to not ask them 'yes' or 'no' questions, if you noticed" (01 post-enactment 1, 180:191).

Summary. Grace subscribed to a very student-directed definition of inquiry as her ideal, and attempted to modify her FOSS curriculum materials accordingly. However, only in two instances did the feature of inquiry in the enacted lesson actually end up being more student-directed than the curriculum materials (according to the P-SOP^{d} scores). Grace's curriculum material modifications to make the lessons more student-directed included removing teacher directions and "let's see what happens". This strategy, however, was unsuccessful with her third-grade class, as they were unprepared to engage at this level of inquiry at this point in time. They ended up struggling with what the purpose of their activity should have been, and Grace ended up scaffolding the lesson even more than she would have according to the original FOSS curriculum materials. Her curriculum material modifications had changed over the past few years to what she considered to be moving toward more student-directed inquiry. She was still driven, however, in how she engaged her students in the practices of science by the iconic 'scientific method' for how they set up their science notebooks and how her classes were structured.

Emily

Emily's modifications were mostly to 'tweak' (04 pre-enactment interview 3, 103:120) the FOSS curriculum materials to be more student-directed. She made small changes over time in order to scaffold her students through the practices of science. One way she drove her curriculum material modifications was through focusing on what kind of questions she was asking her students, both as investigation questions and also in whole-class and small-group discussions. For example, she stated:

> I think that made it a little bit more inquiry based. I still don't think the whole shebang is very inquiry based, but um that's where I'm trying to come up with questions for them that are not 'yes' or 'no' questions and um not always a 'why' question. Where during some of the discussion I noticed I do use more 'why' questions, but I think that's because I'm trying to get information from them. I want them to give me the information. (04 post-enactment interview 2, 39:46)

Emily's curriculum material modifications varied by feature, as she modified two features to be more teacher-directed during her enactment than the lesson plan, and one feature to be more student-directed than the lesson plan (see table 31).

Table 31

Overview of Emily's lesson modifications by feature of inquiry

Emily	Questioning	Data/Evidence	Explanation	Alt. Explain	Communicate
Lesson 1	=	=	🡐	=	*
Lesson 2	=	🡒	=	🡒	=
Lesson 3	=	=	*	*	*

Key:

*: enacted but not in lesson plan;

=: lesson plan score same as enacted score;

🡐: enacted more student-directed than lesson plan;

🡒: enacted more teacher-directed than lesson plan

Emily's ideas about the inquiry continuum and how she modified her curriculum materials across it fell into two interconnected ideas. First, she believed that the best way to get students to a more student-directed version of inquiry (which was her goal) was through what she called a 'gradual release of responsibility' (04 LP Eval. interview, 86:88). By gradually releasing the responsibility of each feature of inquiry to her students, she modified her instruction (and her curriculum materials) from teacher-directed to more student-directed across the school year. Second, in order to engage students in this gradual release of responsibility, Emily believed modification of the FOSS curriculum materials was essential in order to make it more inquiry-oriented, which she identified as student-directed.

Gradual release of responsibility. First, Emily discussed the gradual release of responsibility she aimed for when engaging students in science-through-inquiry. One specific example she gave was that she had a conversation with her students about what to write down as observations before their first science inquiry lesson of the school year. In this case, the students' abilities did not match her expectations:

> I asked my class before our first inquiry lesson this year how they could record observations and they all stared at me. I didn't have one hand go up…. I was like, ok. This tells me a lot. (*laughs*) I'm like, 'Could we write our observations?' (*imitating students*) 'Oh yeah, we could write our observations in our notebook'. And I'm like, ' Ok. What else could we do… could we draw pictures and label them?' And so I really had to give it to them… so we're working on that and talking about writing good observations and being scientists. (04 Formal interview, 70:74).

This was a curriculum material modification for the inquiry feature of data/evidence, which she modified during her enactment of the lesson because her students were not writing down very many, if any, observations. She scaffolded this beginning-of-year conversation because the students were not sure what to write down. After Emily gave the students a few suggestions they started coming up with their own ideas, but this was not a skill she felt her third graders would have been able to do without some direction in the beginning. This highlighted that at the beginning of the year she taught with more teacher-directed variations of inquiry, and how Emily gradually released the responsibility of engaging in the practices of science over to her students.

She also mentioned another aspect of this particular feature of inquiry in which her students needed scaffolding in order to successfully engage in this particular scientific practice; she claimed that they need to be taught how to look at the data and analyze it. This brought about further curriculum material modifications in Emily's classroom. Not only did her third graders need help collecting and organizing their data (as the last example showed) but they also needed help making sense of the data:

> And um so I think teaching them to look at the data and analyze it and think about it, think about what the question is so that they can draw a conclusion is really important and that's something that we talk about in like whole group discussion in class… for third grade it is a mixed bag… a lot of students are getting better at it. They're

> looking at their data and I don't have to say, oh, go back and look. They're doing a pretty good job of doing it. Then you know, I've got that handful that I feel like I'm kind of still dragging along. (04 Exit interview, 105:109)

Emily specifically stated that she aimed for her students to get to a student-directed variation of inquiry by the end of the year, but she recognized that she needed to modify her curriculum materials over the course of the year, starting out with more structured variations in order to help them to be successful along the way. The skill of analyzing data in order to answer an investigation question was a skill that her students were unable to do on their own, but after almost a year of practice at different levels of independence, she claimed that most of them 'are getting better at it'. These two pieces of the data/evidence feature were specific examples Emily scaffolded throughout this particular school year as she made modifications to her existing FOSS curriculum materials.

Another feature that Emily modified in her gradual release model is the fifth feature of inquiry. Feature five, communicate and justify, was enacted in Emily's first and third lessons although it was not specifically included in the FOSS lesson plans. Her enactment of this feature was moderately student-directed in her first lesson (scoring a 'B' on the P-SOP[d]). The students decided in their small groups what to report, "I'm going to give you three minutes to talk with your group and decide with your reporter what you would like to share with the whole class" (04.1b, 6:05). She recorded their oral reports on the overhead as they shared their findings and explanations. This modification aligned with Emily's idea that more student-directed versions of inquiry increased the overall level of inquiry in an enacted lesson, and showed an example of how she modified the curriculum materials over the course of the school year to meet her end-of-year goal of more student-directed variations of inquiry for each feature.

In addition to these examples of how she modified her curriculum materials during this current school year, Emily also discussed a few specific ways she might move toward a more student-directed version of scientific inquiry in the future. First, she mentioned three possible modifications of the variations of inquiry centering on the feature of questioning that would meet her students' needs at different levels depending on where they were in the school year:

> Hopefully, the um experiment here would lead them to wonder something like um, 'What would happen if we did this?' Well, there you go. There's a question… And then we could lead into- and then it would be a little- it'd be maybe more guided where they would come up with a question and I could help them with the procedures…Or if we were- you've kind of gone through that continuum- I could say, 'Ok. Write your question. Write up your procedures and find out.' (LP Eval. interview, 112:116)

These three variations that Emily mentioned (students coming up with a new question after doing an investigation, students coming up with a question when she helps them with the procedure, and students writing their own question and procedure) showed her flexibility in meeting the needs of students at different success levels of the differing variations of inquiry, and how Emily's flexibility in modifying her curriculum materials aimed to meet her students' needs.

Second, Emily mentioned that she would modify her lessons further in the future to remove the FOSS data sheets when she teaches these lessons again, and that this modification would increase the amount of inquiry in the lesson[8]:

> I: Are there going to be any changes you think you're going to make to this lesson next year?
>
> T: Um yes, actually the um page out of the FOSS kit with the picture of the balance on it… I think next year I will not use that… I would like them to record all that on their own. And I want to see if any of them put their own picture. I did notice today [student name removed for confidentiality], and I think there was one other, they did draw the balance in their notebook… And had some notes. But um, I'd like to see next year if any of them think to trace it if they draw because we've talked about drawing and labeling as part of recording your data so I'd like to see if they kind of come up with that on their own.

---

[8] I stands for Interviewer, T stands for teacher

> I: Do you think it will make it more inquiry driven?
>
> T: Um I think it will make it a little more inquiry driven… I'm not telling them how to collect their data. They'll be coming up with how they record that on their own. (04 post-enactment 2, 103:120)

Emily discussed several times in her interviews that she saw this as part of her job as a science teacher to gradually release responsibility to her students by giving them "more freedom" (04 LP Eval. interview, 79:79) as they progressed.

In order to gradually release responsibility to her students, Emily modified her FOSS curriculum materials in different ways throughout the school year. During Emily's first lesson, she purposefully removed questions that the FOSS curriculum materials included because she felt they guided the students too much in their explanation construction. This emphasized both of her ideas that student-directed inquiry was what she aims for, and that she must modify the curriculum materials in order to do so. She wrote on her Lesson Plan Rationale (LPR):

> I took both of these questions from FOSS plan out of my lesson: 'What could be causing the seeds to appear swollen?' And 'If the seeds are soaking up water, how can we find out how much water the seeds are holding?' I decided to have students prepare their science notebooks to record their investigation and data on the first day. By not asking these questions I'm allowing the students to come to their own hypothesis and conclusions and not leading them… I considered that I did not want to directly lead the students to the seeds soaking up water. I wanted them to come to that conclusion on their own. (04 LPR)

The two questions she cited were not investigation questions for the lesson, but were included in the FOSS curriculum materials to scaffold discussion about what the students were observing. By making this modification of removing the questions, Emily believed the amount of inquiry increased slightly in her enacted lesson (which she scored as "not very inquiry oriented" on her LPR) from the original FOSS lesson plan (which she scored as "not at all inquiry oriented" on her LPR), again highlighting her idea that student-directed inquiry is the gold-standard which she aimed for through her curriculum material modification.

She discussed a specific example of when she attempted a more student-directed lesson by drawing the procedure out of the students rather than giving it to them upfront. She felt they did a relatively good job. Interestingly, however, after enacting this rather student-directed lesson (her third lesson), in her post-interview she mentioned that she would modify it the next time she taught it to be more teacher-directed so the students had more specific directions (procedures).

> I: So, for your next inquiry lesson, what things will you change based on what you've done so far with them?
>
> T: Um I would probably be very specific and talk about the procedure more… And what I expect, not just give them the procedure and have them follow it… To start with, I'd probably be- and I might even change um my procedure a little bit for next time… Make the directions more specific… I'd probably make those steps smaller and more detailed… Be more specific and detailed in my procedure directions for them. (04 Formal, 236:249)

She felt this would help her students to be more successful than the way she enacted it for the videorecorded observation, where she drew the procedure out of the students rather than giving it to them directly. She noted this in her interview, as well as the fact that this was the first time she has asked them to help her come up with the procedure.

> I've mostly given them the procedures. For this particular investigation, I drew the procedures out of them… So they came up with their hypothesis, we made a list of materials, wrote down the things we would need and then we talked about in class what we would do. And they were popping out with it, so I just let them come up with it and I listed them and they copied them… so we came up with the list of procedures together and the materials together for this investigation… this is the first time I've had them help me with the procedures. (04 post-enactment 3, 146:155)

In this instance and others she cites, her students' abilities did not match her expectations of what she thought they were able to do.

> I mean that's where you were in the class when we talked about – that's where you want to be eventually, but you have to start out very structured… then you do – then you go to more guided because you're doing that gradual release. You got to get them to learn the steps and then you give them a little more freedom and then you give them a lot of freedom. (04 LP Eval, 73:100).

This caused her to “back down” to a more teacher-directed form of inquiry and scaffold her students to meet their needs. These examples highlight Emily’s ability to read the needs and abilities of her students, and adjust her instruction accordingly.

Curriculum material modification is essential. Second, as mentioned in the above cross-case section about how she did not believe FOSS was inquiry-oriented, Emily defined the FOSS curriculum materials using many different words including: guided (04 Formal interview, 56:56), structured (04 LP Eval. interview, 18:18), cookbook (04 pre-enactment 2, 199:199), scripted (04 post-enactment 3, 129:129), and recipe (04 exit interview, 48:48). She believed FOSS must be modified in order to be inquiry-oriented curriculum materials. However, when describing what FOSS was missing she listed several pieces of the classic scientific method, “None of this is in FOSS… listing the question, hypothesis, materials, procedure, conclusion” (04 post-enactment 3, 113:115).

While all of the above examples of how Emily modified her curriculum materials to engage in what she calls a “gradual release of responsibility,” two specific instances represented how she felt it was essential to modify the FOSS curriculum materials in order to make it more inquiry-oriented, which she defined as student-directed versions of inquiry. First was a lesson centered around the topic of measurement. Students in her 2nd lesson used the FOSS balances to weigh 5 lima beans against gram cubes. As part of the FOSS lesson plan, students attempted measuring the beans themselves and each group came up with different measurements. A discussion about why people got different answers ensued in which Emily states to her students, “If we were all supposed to get the same mass, we would all have to use the same procedure for using the balance” (04 2b, 00:18). The students decided they had not all followed the exact same procedure and wanted another chance to weigh the beans. This time, the class came up with a procedure that each student would follow and the students at each table came up with the same measurements for their beans.

Second, Emily's enactment of feature three, explanation construction, during her first enacted lesson was more student-directed than the FOSS lesson plan. She went from group to group minimally guiding the students in their explanation construction. They were allowed some freedom in how they formulated their explanations. Some of them wrote their explanations in their science notebooks, some shared orally in their small groups, and some students were called on (voluntarily) to explain to the whole class. The FOSS curriculum materials, however, scaffolded the explanation construction in a very teacher-directed manner. The teacher guide gave scripted questions for the teacher to ask the students in order to help them formulate an explanation such as, 'What could be causing the seeds to appear swollen?' and 'If the sees are soaking up the water, how can we find out how much water the seeds are holding?' These are questions Emily purposefully removed from her lesson, fearing they led students in too much of a teacher-directed manner to their conclusion/explanation. She believed this made the lesson more student-directed, and therefore more inquiry-oriented. She stated:

> I wanted to see if they could come up with that, um because I thought it would make it more inquiry if they- instead of me giving them that question then I'm giving them the answer essentially. I felt like with that part so that's why I had taken those questions out. (04 post-enactment interview 1, 125:127)

Emily removed these questions from her enacted lesson with hopes that the students would make the connection between how much water the seeds absorbed after they saw the difference between how much the wet and dry seeds weighed.

Summary. Emily believed that the best way to engage students in more student-directed versions of inquiry was to gradually release the responsibility of the five features to the students over time. In order to gradually release this responsibility, Emily believed modification of her FOSS curriculum material was a necessary step in her enactment of the FOSS lessons. The two main ways she modified her FOSS lessons were purposely removing guiding questions from the FOSS curriculum materials from her instructions and discussions, having the class help her come up with the procedure for the investigation, and by removing pre-made data sheets from the FOSS curriculum material and expecting her students to create their own data tables. Emily aimed to have her students at student-directed versions of inquiry by the end of the school year.

Janet

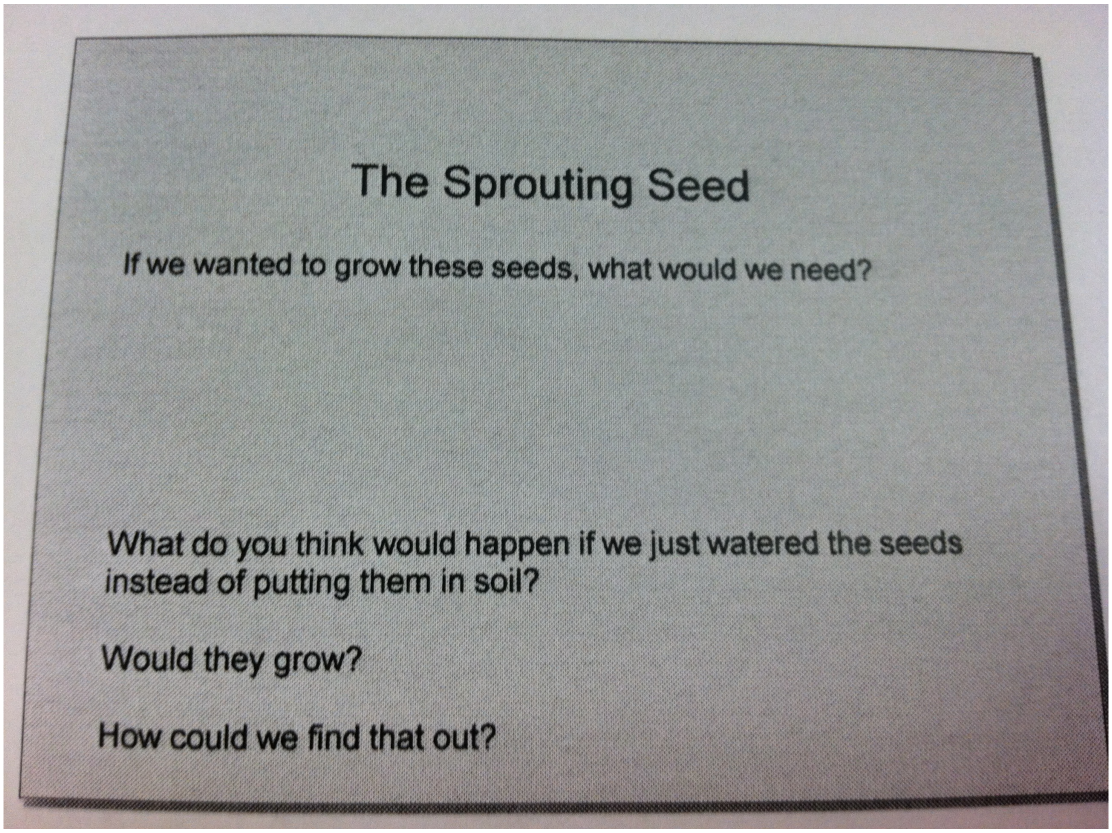
Janet's reasoning for modifying her curriculum materials revolves around one central idea that is recurrent in her interviews and also apparent in her videos; she made modifications to efficiently meet the needs of her third-grade students. In her interviews, Janet believed in a dichotomy between either giving students information or allowing them the opportunity to "do inquiry". She constantly referred to what is "best" for her students, and she modified the curriculum materials to eventually meet their needs.

Unique to Janet's case was the fact that she did not modify a single feature of inquiry over her three lessons to be more teacher- or student-directed on the P-SOP[d] (see table 32). There were features that she included in her enacted lessons that were not included in the lesson plan, but when a feature was present in the lesson plan she enacted it with the same amount of teacher direction as the lesson plan represented. For this reason, Janet's case description is unlike Grace and Emily's since there are no examples of features when Janet modified her enacted lesson to be more teacher- or student-directed. What I did describe, however, were examples of instances when Janet included a feature in her lesson that was not included in the existing FOSS curriculum materials. In all but one case, these enacted features were very teacher-directed.

Janet did use the FOSS response sheets, and copied them smaller than usual so they fit into the students' science notebooks. She claimed this helps her use time "wisely" (08 post-enactment 2, 114:123) but sacrificed some of the student autonomy. One way she used her time efficiently was by using the Smart Board in her classroom. Janet claimed that the FOSS curriculum material was very 'scripted' She felt that this did not match her teaching style.

> And so yeah, this is scripted. However, I'm not… the kids don't respond well to me standing here reading from a packet… I'd have to look carefully and say, oh, I didn't do this, but I did this… I'm not a script teacher. I don't – I can't stand there and read, you know, something straight out of a guide because kids don't respond to that. (08 post-enactment 1, 16:20)

She pre-prepared her slides to match the FOSS content (almost word for word), which helped her stay on track and not miss anything she planned to do. In some ways, this made her lesson as scripted as reading out of a FOSS lesson plan. Figure 22 shows a slide from Janet's Smart Board during her first enacted lesson in which the questions she presented to her class were directly word-for-word out of the FOSS 'script.'



The Sprouting Seed

If we wanted to grow these seeds, what would we need?

What do you think would happen if we just watered the seeds instead of putting them in soil?

Would they grow?

How could we find that out?

Figure 22. Screen shot of Janet's Smart Board presentation representing how the FOSS 'script' is still driving her lesson

Table 32

Overview of Janet's lesson modifications by feature of inquiry

Janet	Questioning	Data/Evidence	Explanation	Alt. Explain	Communicate
Lesson 1	=	=	*	*	=
Lesson 2	*	=	*	=	*
Lesson 3	=	=	*	=	=

Key:

*: enacted but not in lesson plan;

=: lesson plan score same as enacted score;

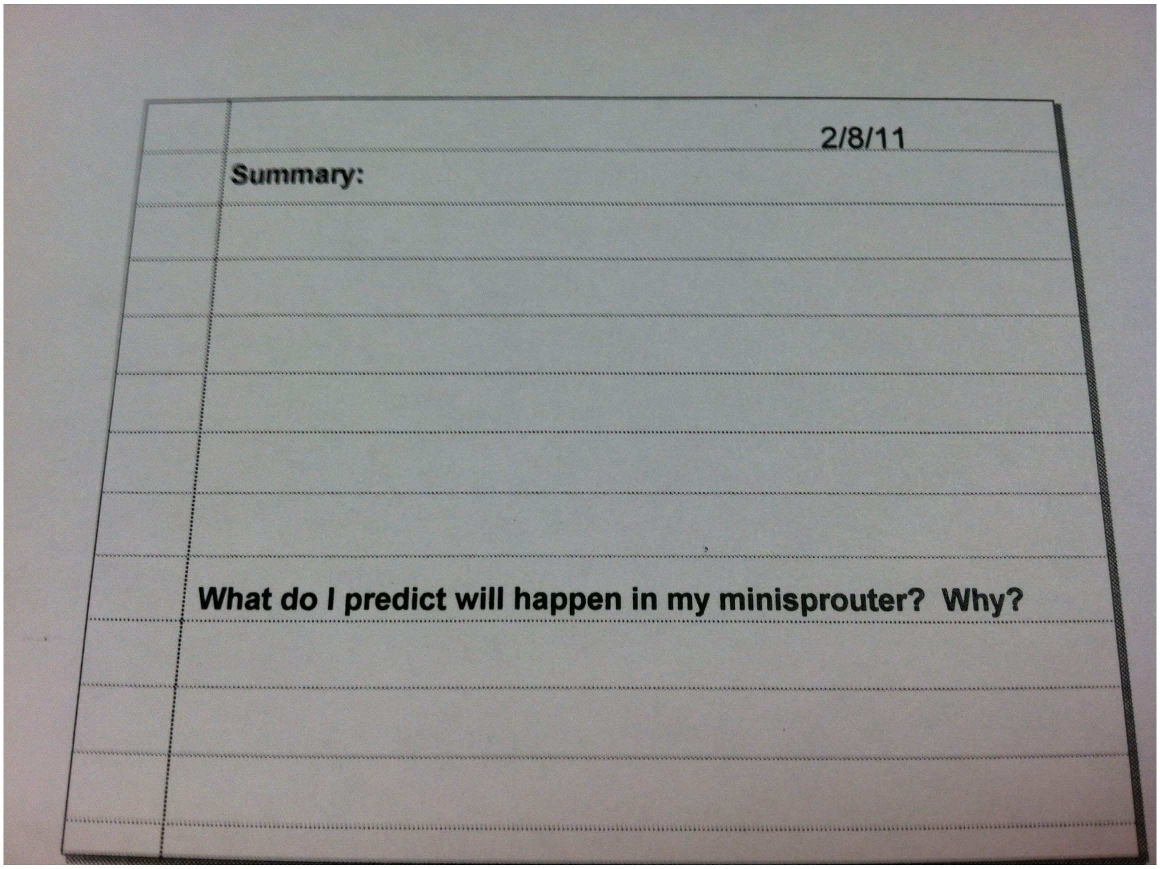
First, for the features of questioning and data/evidence, Janet included a teacher-directed question in her second lesson when there was not one specifically mentioned in the FOSS lesson plan. Janet's teacher-directed question, 'What are the properties of seeds?' was projected on the class' Smart Board and was written in the students' science notebooks. She stated, "I couldn't find a specific overlying question [in the FOSS curriculum materials] so what we did was on our KWL we just said, 'ok what do we know about seeds?'... that was the question I went with for them because I was looking for that" (08 Pre-enactment 1, 29:35). This lesson, lesson two, was the only one of Janet's three where she added a question to the lesson that there was not one included in the FOSS lesson plan. For any of her three lessons, there was not one instance when Janet modified the feature of data/evidence to be more teacher- or student-directed.

Second, Janet enacted the third feature, explanation construction, even though it was not explicitly included in the FOSS lesson plans. In her first lesson, Janet enacted this feature in a moderately student-directed manner (scoring a 'B' on the P-SOP^{d}). Specifically, she had her small groups engage in discussions during and after their opening of the bean pods. She traveled from group to group minimally guiding the groups in their explanation construction. She did ask a few times, "Why do you think that?", (08.1b, 16:10) however; the students were given freedom as to how they wanted to formulate their explanation. Some of them wrote their explanation in their journals, while some discussed it orally with their small groups.

In her second lesson, after the students removed the seeds from their fruit, Janet engaged the students in a whole-class discussion of their findings. This discussion focused on answering their investigation question (which Janet enacted but was not included in FOSS). They shared their findings one fruit at a time, which allowed for the groups to compare their findings (not their explanations) for each of the four fruits they investigated. Janet mentioned in her interview after this lesson that when she teaches this lesson again, she would modify it to be even more teacher-directed in the following way:

> When I do it again next year, I probably will try and cut down, like you said, maybe on the number of fruits. And you hate to make it so structured, however, you want to use your time wisely so that they're getting more of the scientific, you know, experiment out of it, other than just the getting to play with the seeds and pull them out and things like that… Um so I guess by trying to structure it a little bit more which takes away some of the inquiry, you hope that they learn a little bit more um- I just- sometimes they're just not ready to be let loose. (08 Post-enactment 2, 114:123)

In her third lesson, Janet used her smart board and revealed one line at a time with directions for what the students would do and explain. She asked for student explanations for why they must drain the extra liquid off of the mini-sprouters, and for why they used a weak bleach solution when watering their seeds. One specific teacher-directed example included, "Write a summary of what we did today in science. Then make a prediction about what you think might happen. Explain your thinking" (08.3b, 14:14). This was shown to the class on the Smart Board and they read it aloud one word at a time with Janet. She modeled for them on the board exactly what she wants this explanation to look like, by modeling on the Smart Board what an example of their science notebook page should look like (see figure 23).



2/8/11

Summary:

What do I predict will happen in my minisprouter? Why?

Figure 23. Screen shot of Janet's Smart Board presentation showing how she modeled in a very teacher-directed fashion how her students' science notebooks should look.

Third, for the fourth feature of alternate explanations, Janet included this feature in her first lesson when it was not included in the FOSS curriculum materials. It was a very teacher-directed variation of this feature, as students were told whether they were right or wrong and why. "No, [student name], that is incorrect. You counted those seeds each as two when they are really just one seed that is split in half. Go back and re-count. Get an eraser and fix your data" (08.1a; 32:11). This scores a 'D' on the P-SOP[d] for the feature of alternate explanations, which was the most teacher-directed variation of the feature possible.

Janet spoke of modifying her FOSS curriculum materials to be more 'structured' for her students, which she acknowledged would reduce the overall amount of inquiry. She stated:

> When I do it again next year, I will probably try and cut down… maybe on the number of fruits. And you hate to make it so structured… so I guess by trying to structure it a little bit more which takes away some of the inquiry, you hope they learn a little bit more, um, I just, sometimes they're just to ready to be let loose." (08 post-enactment interview, 114:123).

She admitted that she was reluctant to make this change in her lesson the next time she taught it, but at the same time she felt that the structure was necessary for her third-grade learners. She made a loose tie between student-directed inquiry meaning students are 'let loose' which aligns with a discovery-based inquiry perspective.

Janet also modified her lessons through questioning, although her point was slightly different. She admitted that FOSS may include an investigation question with the lesson, but that it was not conveniently located for the teacher. She claimed,

> There's no essential question at the beginning that's like the overall… and so if you go back in the overview at the very beginning of the entire binder you can find the information there… but as a teacher, I don't take that entire binder home. I take my lesson. That's a little inconvenient the way they set the curriculum up, but um I sometimes make up my own question to try to get them started. (08 pre-enactment interview 3, 15:30)

.

Finally, for the communicate/justify feature, Janet enacted this in her second lesson when it was not included in the FOSS curriculum materials. Her enactment was very teacher-directed in this instance, with the groups sharing their results one group at a time and one fruit at a time (out of four fruits each group investigated).

Summary. Janet defined inquiry as student-directed, and made modifications to her curriculum materials across the continuum in order to meet the needs of her third-grade students. She aimed to have efficient use of her science classroom time, and therefore follows the FOSS teacher guide closely by integrating the scripted questions into slides she projected on her Smart Board. She believed that her third-grade students needed scientific practices modeled for them in order to be successful. Janet did not modify a single feature of any of her three lessons to be more or less teacher-directed than the original FOSS curriculum materials. She did, however, include features in her enacted lessons that were not included in the original FOSS curriculum materials (such as questioning) and her enactment of these features was in most cases very teacher-directed.

Summary

The findings from the qualitative phase of this study fell into two main categories: cross-case findings and individual case findings. Each attempted to help answer the qualitative research question, '*How do inservice elementary teachers' ideas about the inquiry continuum influence their adaptation of elementary science curriculum materials?*' There were three main cross-case findings, (a) the belief that student-directed variations of inquiry were more inquiry-oriented than teacher-directed variations of inquiry, (b) the belief that their FOSS curriculum materials were not inquiry-oriented, and (c) perceived challenges to teaching more student-directed versions of inquiry. The individual case-study teachers each had their own unique themes as well. Grace attempted to modify her curriculum materials in order to make it more inquiry-oriented, which to her meant more student-directed. She removed instructions to her students from the FOSS curriculum materials to ‘see what happens’ if they attempted it on their own. Grace was driven by the iconic ‘scientific method’. Emily believed that she should gradually release the responsibility of the features of inquiry to her students over time. In order to gradually release this responsibility over time, Emily believed that she must modify the FOSS curriculum materials in more student-directed ways. Janet did not modify a single feature of inquiry to be more or less teacher-directed in any of her three lessons, but she did include features in her enactment that were not included in the FOSS curriculum materials. These enacted features were mostly teacher-directed. These cross-case findings and individual case summaries answer the question of how these case-study teachers modified their curriculum materials across the inquiry continuum.

CHAPTER 6

DISCUSSION AND IMPLICATIONS

In line with current science education reform, elementary students need to be engaged in the practices of science (AAAS, 1993; NRC, 2000, 2007, 2012). However, in order to be engaged in these practices their science teachers need to understand the practices themselves and how to modify their curriculum materials in order to include the practices in their science instruction. One of the major findings of this study and other related previous studies (Biggers & Forbes, 2012; Biggers et al., in press; Forbes, et al., 2013; Zangori, Forbes, & Biggers, submitted) was the infrequent engagement in the five essential features of inquiry in both elementary science curriculum materials and enacted classroom science lessons. The teachers in this study claimed through their interviews that teaching through inquiry methods is essential, but they struggled to engage students in inquiry practices during instruction.

In order to answer the mixed method questions from this study, it is at this point of the interpretation phase that I drew ‘meta-inferences’ (Creswell & Plano Clark, 2011; Teddlie & Tashakkori, 2009) across both the qualitative and quantitative strands of the study. I have identified four meta-inferences from this work that I will explore in this section (see Appendix J for joint data display). First, I discuss the newly developed P-SOP^d instrument and its’ contribution to the field of science education. Second, I explore the elementary teachers’ classroom science teaching practice across the inquiry continuum. Third, I discuss the teachers’ modifications of their science curriculum materials across the inquiry continuum. Finally, I examine the elementary teachers’ ideas about the inquiry continuum. After these four discussion sections I present possible implications to the field of science education.

Discussion

P-SOP^d Instrument Development

The field-testing of the P-SOP^d instrument demonstrated that overall it is a valid and reliable instrument for the field of science education. The P-SOP^d has the potential to be an extremely useful tool in measuring the amount of teacher-direction in a science-as-inquiry lesson, and/or in a science lesson plan from either existing curriculum materials or a teacher's lesson plan. There are two limitations to this general acceptance of validity and reliability, however. First, the P-SOP^d has only been validated with elementary science lessons. It would need to be further validated for secondary science classroom use. Second, the P-SOP^d exhibited greater reliability among the lesson plans than it did for the videos. Reasons for this mismatch are unclear, but it might have two possible explanations. One is the possibility that seeing the features of inquiry in written form is easier to interpret than recognizing them enacted in a videoed classroom observation. Another is that the written lesson plans followed a structured format, as most of them were FOSS curriculum materials. There was little variation between different FOSS units, even though the content varied from unit to unit; the practices of science were similar throughout all the units scored in this study. This could have caused the scorers to agree more often when scoring the amount of teacher direction on lesson plans rather than videos.

The P-SOP^d adds to a current battery of instruments in the field of science education for measuring the teaching of science-as-inquiry. These existing instruments include the P-SOP (Forbes et al., 2013), the RTOP (Sawada et al., 2002), the STIR (Bodzin & Beerer, 2003), and the EIOR (Luft, 1999). Of these existing instruments, only the STIR attempts to measure the amount of teacher direction in an inquiry investigation. However, it has only been reliably studied with a small group of teachers (N=5); and although its intent was to measure the five essential features of inquiry (NRC, 2000), the authors made changes to that structure as they designed the STIR instrument. For these two reasons (low numbers of field-testing and mismatch of the five essential features) the STIR was not used in this study. The P-SOP^d more closely aligned to the five essential features, and was field-tested with a total of 120 classroom observations. Additionally, only the P-SOP and the P-SOP^d instruments have been validated for enacted elementary science lessons and lesson plans.

A natural extension of the current study involves developing a continuum for the NGSS eight practices of science (NRC, 2012) and an observation protocol to measure the amount of teacher direction across that continuum. Much of the P-SOP^d would be useful in this endeavor, but descriptors for the newest features of modeling, math and computational thinking, and argumentation would need to be developed and incorporated with the existing P-SOP^d features. This new continuum for the eight practices of science would be a useful tool moving forward with the current wave of science education reform, and should be developed sooner rather than later. It took nearly 20 years for the P-SOP observation protocol to be developed to measure the NRC's five essential features of inquiry (Forbes et al., 2013). Our field should not wait this long to develop an observation protocol for the framework of the Next Generation Science Standards.

Teachers' Classroom Practice and the Inquiry Continuum

When examining how teachers' classroom practice was influenced by the inquiry continuum, there are two main discussion points. First, there was a slight positive significant correlation between the overall level of inquiry (measured on the P-SOP) and the amount of teacher direction (measured on the P-SOP^d). Second, teachers in this study relied heavily on their existing science curriculum materials. This section will further discuss these two findings.

Correlation. Overall, there was a slight positive significant correlation between the level of inquiry in a science lesson (measured by the P-SOP) and the amount of teacher-direction (measured by the P-SOP^d) for both enacted lessons and for lesson plans. The directionality of the correlation revealed that higher levels of inquiry correlated with more teacher-directed variations of inquiry. However, the overall correlations for enacted lessons and lesson plans should be carefully considered. As was mentioned in the methods section, not every lesson included every feature of inquiry, so this overall (aggregate) correlation should be interpreted with caution. The higher sample size for the overall correlations (n=120) could partially explain the significance, as some of the individual features of inquiry had low sample sizes (because of the number of zero scores for that particular feature), and significance was more difficult to attain (Royall, 1986). Further exploration in future studies should look at these correlations with larger sample sizes.

There were two individual features of inquiry that showed significant correlation between higher inquiry scores and student-directed inquiry. These were (1) the feature of data/evidence for the lesson plans, and (2) the feature of explanations for the video observations. These two isolated instances are not connected, but do reveal that in some cases student-directed inquiry can lead to higher overall inquiry measures. Opposite to the overall correlations, the directionality of these significant findings suggest that higher levels of inquiry correlate with more student-directed variations of inquiry. These two instances need to undergo further exploration in future studies to understand why they alone showed significant correlation between these two values, as there was no data in the case studies that further explained this empirical finding. These two features also had high sample size numbers (n=120 and n=95 respectively), which may have influenced the correlation significance.

Although it was not a significant finding, there was one feature level correlation that went in the opposite direction from all others. The feature of communicate/justify for the enacted lessons was a positive correlation, whereas the other feature level correlations were all negatively correlated (whether significant or not). This anomalous data point needs to be studied further in order to explain why it does not match the pattern of the rest of the data.

It may seem counterintuitive that the overall (aggregate) correlations were positive when the majority of the feature level correlations were negative. This is most likely explained by the extremely high (r = 1.00) of the questioning feature for both lesson plans and enacted lessons. Since the aggregate correlations include the sum of the five features (not counting zero scores), this extremely high correlation overshadows the negative correlations of the other features.

There is, however, still a debate in the current science education literature about how much involvement the teacher should have in the teaching of science-as-inquiry. Some scholars argue that open inquiry should be the goal and focus of all science instruction (Johnston, 2007). Others contend that open inquiry is a myth that should no longer be perpetuated to preservice teachers as they begin their teaching careers (Settlage, 2007). There has been an attempt by some authors (i.e. Clark et al., 2000) to instruct classroom teachers through practitioner journals in how to go about modifying their curriculum materials from 'cookbook' style labs (teacher-directed) to more open forms of inquiry (student-directed). This study was not designed to show that one type of inquiry (open or guided) is better than the other, but rather to explore elementary teachers ideas about the spectrum of teacher guidance in inquiry lessons and how those ideas influence the teachers' modification of their curriculum materials accordingly. I agree with the position taken here:

> We see that the optimal form of inquiry is determined by a number of factors, and a specific context may call for a different form of inquiry to be enacted. We would expect that the nature of support that is needed in inquiry activities will vary as the level of the inquiry is shifted (Crawford, 2000), but we must be clear in our explanation that open-ended, Level 3 inquiry is NOT ALWAYS the optimal approach to teaching science in all cases. The level of inquiry should vary as the different contextual and content factors vary. (Abrams, Southerland, & Evans, 2008, p. xxxiv, emphasis in original)

Scaffolding. In order to know how much support their students need, elementary teachers need to be skilled in the art of scaffolding science lessons the appropriate amount. Vygotsky's (1962) work on the zone of proximal development (ZPD) is the basis for the scaffolding literature, and applies to the current study. Teachers need to challenge students within their ZPD in order to avoid overwhelming them beyond their current abilities or boring them by scaffolding too much.

Slater, Slater, and Shaner (1999) present a model, although not aligned with the five essential features, which allows for a process called "faded scaffolding." In this sequence of introducing students to inquiry (see table 33), teachers begin at the more teacher-directed variations of inquiry and allow students more autonomy with each successive attempt.

Table 33

Faded scaffolding model of teaching science inquiry (Slater et al., 1999)

Sequence	**Research Question Source**	**Research Procedure Source**	**Data and Evidence Source**	**Conclusion Source**
1	Teacher	Teacher	Teacher	Teacher
2	Teacher	Teacher	Teacher	*Student*
3	Teacher	Teacher	*Student*	*Student*
4	Teacher	*Student*	*Student*	*Student*
5	*Student*	*Student*	*Student*	*Student*

This faded scaffolding model is opposed to the “forward scaffolding” model, in which students engage in a unit about the nature and processes of science and then start by creating their own hypotheses and investigation questions right away (Slater, et al, 1999).

van der Valk and de Jong (2009) also present a framework for differing the levels of support to students based on their needs. The most teacher-directed form of inquiry would involve *guiding by prescribing*. In these instances, teachers provide the investigation question, the data, how to formulate an explanation from the evidence, how to evaluate the explanation (or provide an alternative explanation to evaluate) including a judgment from the teacher of whether the student’s explanation is correct or not and why, and what and how to communicate and justify. This type of scaffolding would meet the characteristics on the P-SOP^d that score in the most teacher-directed category (scoring a ‘4’), and the faded scaffolding sequence 1.

One step removed from *guiding by prescribing* is *guiding by modeling*. In this case, the teacher models or demonstrates the practices of science to the students, which offers them a tiny bit more autonomy in the process. Guiding by modeling would correspond in most cases to scoring a ‘3’ on the P-SOP^d, and a sequence 2 or 3 on the faded scaffolding matrix. In these lessons, the learner could sharpen or clarify a teacher-provided investigation question, is directed to collect certain data, is guided in the process of formulating their explanation from the evidence collected, and is given direction on what and how to communicate.

Guiding by scaffolding is one step further toward ‘open’ inquiry. This level of support might correspond with scoring a ‘2’ on the P-SOP^d, and a sequence 3 or a 4 on the faded scaffolding matrix. In these lessons, for instance, students could select from a list of possible investigation questions, select from possibilities of what and how to collect data, select among possible ways to formulate an explanation from that evidence, could be directed toward alternate explanations to evaluate against their own explanation, and decides either what or how to communicate.

In the most student-directed variations of inquiry, the teacher provides *guiding by laisser-faire*. This level of scaffolding allows the most student autonomy with very little (if any) teacher direction. These lessons are rare, as this study showed, and might correspond with scoring a '1' on the P-SOP^d, and a sequence 5 on the faded scaffolding matrix. Examples of what this might look like in the classroom include learners posing their own questions, deciding what to collect as data, formulating their own explanations from their evidence, independently locating alternate explanations to evaluate, and deciding both what and how to communicate.

The results from this study emphasize that elementary teachers can use the inquiry continuum as a tool to modify their existing science curriculum materials in order to enact inquiry lessons that meet the *current needs of their students* as far as how much teacher-direction is provided. Some students (especially early learners) need more scaffolding than others (Leher & Schauble, 2004; Metz, 2004; 2008). This is a critical skill that elementary science teachers need to possess. Students' ability levels will differ between and across students, classes, and years of teaching. As this study found, elementary science curriculum materials are written with an overall emphasis on teacher-directed variations of inquiry, and also that elementary teachers taught their curriculum materials with high levels of fidelity. Teachers need flexibility in order to meet their class's changing needs, and the inquiry continuum is one tool that helps offer suggestions of how to scaffold (or remove scaffolding from) existing science lesson plans to meet those needs.

Teacher Modifications of Science Curriculum Materials

This study extends previous research to show that elementary teachers rely heavily on their science curriculum materials. (Abell & McDonald, 2004; Century et al., 2010; Forbes & Davis, 2007; Grossman & Thompson, 2004; Kauffman et al., 2002; O'Donnell, 2008; Schulte et al., 2009). The majority of research on teachers' adaptations of science curriculum materials has been done at the secondary level (Enyedy & Goldberg, 2004; Fogleman et al., 2010; Penuel et al., 2009; Roehrig & Kruse, 2005; Schneider et al., 2005), and at the elementary level for mathematics (Collopy, 2003; Lloyd, 1999; Remillard, 1999; Remillard & Bryans, 2004), but is lacking for elementary science.

There is a participatory relationship between teachers and their curriculum materials (see figure 24, Remillard, 2005). This relationship shapes classroom instruction by influencing how teachers enact their curriculum materials. Ball and Cohen (1996) mention five domains that affect how teachers enact their curriculum materials:

- What teachers think about their students
- Teachers' own understanding of the material
- How teachers fashion the material (adaptation)
- Intellectual and social environment
- Community and policy contexts

Of these five domains, this study looked specifically at the third domain: how teachers adapt the curriculum materials. The specific adaptations studied were whether the teachers adapted their lesson plans in their enacted lessons across the inquiry continuum of teacher-directed to student-directed inquiry. When enacting their curriculum materials, teachers can either enact it as written, adapt it in some way, or use it as a source of inspiration for something new (Davis & Smithey, 2009). This translates into whether the teachers view their curriculum as a *curriculum of reproduction* meant to be replicated or a *curriculum of inquiry* (Abell & McDonald, 2004).

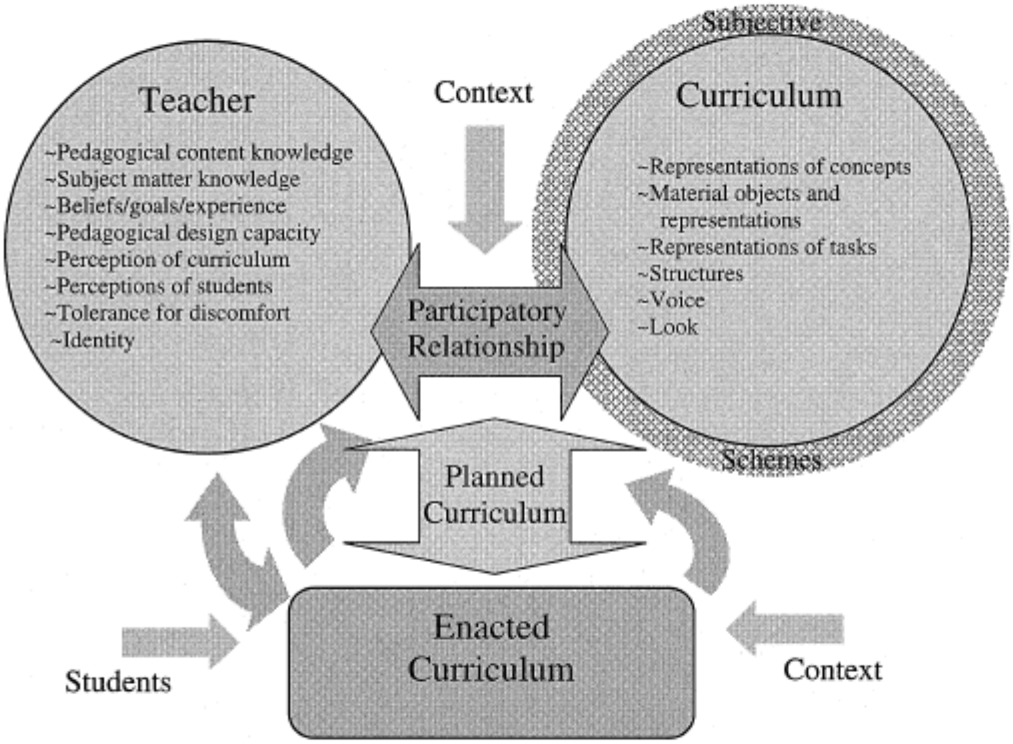


Figure 24. Elements of the teacher-curriculum relationship (Remillard, 2005, p. 235)

The teachers' modifications in this study occurred in two related yet distinct ways. First, the teachers did not modify their curriculum materials for the five essential features of inquiry. In general, if a feature (i.e. scientifically-oriented questioning) was not included in the lesson plan, the teachers did not generally modify the curriculum materials to include it in their enacted lesson. This is supported by the scores from the P-SOP instrument that showed no significant difference between the lesson plan and enactment scores by feature (Forbes et al., in press). Second, the teachers did not modify their science curriculum materials across the inquiry continuum. If a lesson plan called for a teacher-directed version of a feature of inquiry that is how the teachers enacted it during their instruction. This finding is supported by the scores from the P-SOP^{d} instrument that showed no significant difference between the lesson plan and enactment scores for each feature of inquiry. These two findings together support the fact that these teachers taught their science curriculum materials with high levels of fidelity during their implementation (Century, et al., 2010; O'Donnell, 2008; Schulte, et al., 2009).

We know from existing literature that elementary teachers as a whole have weak science content knowledge from the lack of science courses required for their degrees. (Abell, 2007; Abell & McDonald, 2004; Beyer & Davis, 2008; Davis et al., 2006; Eshach 2003). We also know that science as a subject has been de-emphasized at elementary schools because of the lack of accountability from legislation such as No Child Left Behind, which focuses on math and reading (Center on Educational Policy, 2006). Schools cut science time in favor of more time for math and reading. (Abell, 2007; Beyer & Davis, 2008; Forbes & Davis, 2008; Marx & Harris, 2006; Spillane et al., 2001).

The combination of these factors is a possible explanation for why elementary teachers do not modify their existing science curriculum materials. In order to engage students in the practices of science, elementary teachers need curriculum materials that explicitly provide opportunities to engage with the five features of inquiry (or soon, the eight practices of science, NRC, 2013). Teachers need tools, such as the inquiry continuum, to scaffold lessons with the correct amount of teacher-direction to meet their learners' needs. Teachers also need to know that they have 'permission' to modify their curriculum materials rather than viewing them as a prescribed set of instructions or a script to follow verbatim (Bullough, 1992; Davis & Smithey, 2009; Eisenhart et al., 1988). These tools should also be made available to and emphasized in the training of preservice teachers, as they have been shown to successfully adapt science curriculum materials (Beyer & Davis, 2009-a, 2009-b; Davis, 2006; Forbes, 2011; 2013; Forbes & Davis, 2010; Schwarz et al., 2008).

Teachers' Ideas About the Inquiry Continuum

There was a mismatch between the teachers' ideas about student-directed inquiry and their practice during classroom lessons in this study. These ideas influenced their science instruction in several ways. First, the teachers in this study defined inquiry in student-directed terms, regarding lessons with too much teacher-direction as 'not inquiry oriented'. Second, the teachers did not feel that their existing science curriculum materials were very inquiry oriented. Finally, third, the teachers perceived multiple challenges to teaching more student-directed versions of inquiry in their classrooms. These three rationales show reasoning why the teachers enacted their curriculum materials with such high levels of fidelity, as was discussed in the previous section. In the following paragraphs, I explore each of the teachers' ideas.

Defining inquiry. The teachers in this study, as others have done in previous studies (i.e. Biggers & Forbes, 2012), narrowly defined inquiry in student-directed terms. If a lesson plan included too much direction from the teacher, the elementary teachers defined it as 'not very inquiry oriented' or 'not at all inquiry oriented'. The case-study teachers also qualified each of their enacted lessons as the same category designation if they felt they had been too involved in the lesson. This actually did not give themselves enough credit for the inquiry they were enacting in their classrooms. They might have enacted a particular feature of inquiry (i.e. data/evidence) but felt it was not inquiry oriented 'enough' because they had directed the students along the way, when in reality the fact that the students engaged in the process of collecting and analyzing data and evidence should have been the measure of inquiry in the classroom.

This phenomenon ties back to the teachers' very definitions of inquiry, which were all student-directed. Defining inquiry in student-directed terms is not isolated among inservice teachers. Preservice teachers have also been shown to possess student-directed definitions of inquiry (Biggers & Forbes, 2012). This type of definition of inquiry is too narrow, and needs to be broadened to include more teacher-directed variations. Further research needs to be conducted to find out where this idea of student-directed inquiry being the 'gold standard' for inquiry lessons came from and why it has been perpetuated for so long.

Curriculum materials. The teachers in this study did not consider their existing science curriculum materials to be inquiry-oriented because they did not match their student-directed definitions of inquiry. As was mentioned above, if there was too much teacher-direction present in a lesson plan the teacher did not consider the lesson plan to be inquiry oriented. In this case, the teachers defined inquiry in terms of the amount of teacher direction rather than whether the practices of science are present or missing. Even though they did not consider their curriculum materials to be extremely inquiry-oriented, the teachers still taught them with high levels of fidelity. The fact that the curriculum materials did not parallel their own definitions of inquiry was not reason enough to modify the curriculum materials to be 'more' inquiry oriented by modifying it to be more student-directed.

Perceived challenges. The teachers in this study rationalized teaching their curriculum materials as written (rather than modifying it to match their student-directed definitions of inquiry) because they perceived various challenges associated with teaching student-directed variations of inquiry. These challenges fell into four main categories, (1) questioning student success, (2), relinquishing control, (3) time, and (4) going against the norms of teaching. The teachers' ideas about each of these challenges surpassed their need to teach in student-directed variations of inquiry in order to match their own definitions as I discussed earlier.

These findings extend previous research that recognized elementary teachers' perceived challenges to teaching science-as-inquiry (i.e. Abell & McDonald, 2004; Davis et al., 2006; Davis & Smithey, 2009) to specific challenges associated with teaching student-directed variations of inquiry. Some challenges to teaching science-as-inquiry previously recognized in the literature include such things as (a) understanding the content and disciplines of science, (b) understanding learners, (c) understanding instruction, (d) understanding learning environments, and (e) understanding professionalism (Davis et al., 2006). Any attempt at teaching science-as-inquiry is an improvement over the two main teaching methodologies common in elementary classrooms. These are (a) didactic, direct instruction techniques; and (b) 'activitymania' which Abell and Roth (2004) identified as the technique of teaching a string of unrelated activities. While this looks good on the surface because students are engaged in the 'doing' of science, it often leaves out the explanation construction aspect which is critical to student understanding of scientific phenomena.

Limitations

This chapter has described how the findings from this study are important for elementary science teaching and elementary science curriculum development. However, the study was limited in three main ways: (a) curriculum limitations, (b) teacher training, and (c) low power in some of the statistical models. First, the majority of teachers in this study (64.8%) used the same kit-based curriculum materials (FOSS). This high percentage of one curriculum is nice when comparing scores on the various rubrics used to score the enacted lessons and lesson plans, however; it does limit the generalizability of the study findings. If this study were replicated with a different set of curriculum materials, one cannot say the results would be exactly the same. Take for example the teacher-directed nature of the FOSS curriculum found through this study. If the majority of the curriculum materials teachers used in the study were more student directed, would the results be similar?

Second, the training provided (and even required) by the various districts in the study could have influenced how the teachers enacted their curriculum. One of the districts has a very structured set of professional developments around the FOSS kits, which encourage teachers to teach the curriculum as written. This factor is a limitation of the study because it could have been a confounding factor on why the teachers taught their curriculum with such high fidelity. Although this particular district represented a minority of the teachers in the study, this 'training effect' might have had an influence on the results of the study.

Finally, third, the varying number of zero scores from the original P-SOP data set (and thus the P-SOP^d data set) caused low power to be attained in some of the statistic models. The fourth feature of inquiry (alternate explanations) for example, out of the possible 120 videos, was only present in 33 of the enacted lessons and 30 of the lesson plans. These extremely low numbers cause the power to be so low that the results for this particular feature are almost negligible. This feature was the most extreme example, but the other features exhibited zero scores as well. The low power associated with these features is a definite limitation of the study. Limitations aside, this study still holds valuable implications for the field of science education and elementary science curriculum materials.

Implications

Professional development. An important implication from this study is that teachers need training in order to successfully use the inquiry continuum to modify their curriculum materials. Teachers in the current study taught their curriculum materials with high levels of fidelity for both the features of inquiry as well as the level of teacher-direction for each feature. Training, in the form of professional development, should first expose teachers to the inquiry continuum. Many of the teachers in this study had never even seen the continuum even though it has been in publication for nearly 15 years and is common among science education researchers. Training must go beyond exposure, however, giving teachers tools and tips of how to modify their existing curriculum materials in order to meet their students needs. Sometimes the changes are small but they can make a big difference. Teachers need to realize that they do not have to completely overhaul their existing curriculum materials in order to meet their learners' needs.

In addition to professional development for inservice elementary science teachers, training of preservice elementary teachers also needs to take place. These future teachers also need exposure to the continuum and how to modify curriculum materials across it to meet their learners' needs. In previous research (Biggers & Forbes, 2012), preservice teachers defined inquiry in extremely student-directed terms, parallel to the findings of this study with inservice elementary teachers. Science methods courses should be a place we aim to broaden their definitions of inquiry to include more teacher-directed variations of inquiry. In the case of preservice teachers, teacher-directed inquiry is one way they can implement inquiry lessons in their classrooms while lessening the obstacles they perceive to teaching through student-directed inquiry (Biggers & Forbes, 2012). This benefits the preservice teachers as well as the elementary students in being successful in engaging in the practices of science. Inservice and preservice teachers' ideas about the inquiry continuum should continue to be explored further. The majority of existing science curriculum materials in this study were FOSS materials, but other curriculum materials need to be studied (especially curriculum materials that are not as scripted as FOSS lessons tend to be) to see if elementary teachers have different ideas about how inquiry-oriented the curriculum materials are. Secondary teachers also need to be studied to explore their ideas about the inquiry continuum and their existing science curriculum materials.

Curriculum development. The lack of modification of their existing science curriculum materials has three main implications. First, curriculum developers should take this information into account when developing science curriculum materials for elementary students. Care should be taken when curriculum materials are developed to present them to teachers in a way that engages students in the practices of science. As this study has shown, teachers tend to enact what their science curriculum materials require. Therefore, the curriculum materials should ideally be written to include all five of the features of inquiry (or all eight of the Next Generation Science Standards' 'practices of science' (NRC, 2012)). Teachers should not be required to modify their curriculum materials in order to make it meet the goals of science education reform, but they should have the flexibility to do so if their curriculum material does not include the essential practices. If they produce a product that encourages teachers to engage their students in the practices of science, there is theoretically a higher probability that students will actually engage in these practices because their teachers will most likely enact the curriculum materials as written.

Second, it is important to note, however, that in order to meet the needs of their changing student population, teachers need to understand that modifications of their science curriculum materials are sometimes necessary. This is especially true for the amount of teacher direction provided in different science lessons. If curriculum developers write curriculum materials as all extremely student-directed variations of inquiry, not all students will be successful. On the other hand, if the curriculum material is written as entirely teacher-directed, then students will not have the opportunity to independently engage in the practices of science. Teachers need flexibility in their curriculum materials to adapt the level of scaffolding they provide to their students across the continuum of the features of inquiry, as suggested by the NRC (2000). As Barab & Leuhmann (2009) indicate, the model should not be:

"Designed Curriculum = Implemented Experience"

Rather, curriculum designers should opt for the following model:

"Teacher Perceptions + Designed Curriculum + Classroom Culture

= Implemented Experience" (p. 462).

Several possibilities exist for encouraging teachers to modify their curriculum materials across the continuum of teacher-directed to student-directed inquiry. First, the curriculum materials could be written with varying degrees of teacher-direction over the course of the school year beginning with more teacher-direction and scaffolding students toward more student-directed variations as the year progresses. This would be the easiest option to write, but does not address the fact that students' needs still differ. One class, for example, may have more experience with inquiry and be ready to move to more student-directed forms of certain features of inquiry while other classes may need more scaffolding even further into the school year.

Second, the curriculum developers could include with each lesson (or investigation) differing levels of scaffolding so the teacher enacting the lesson could choose which level meets his/her students' needs at that particular moment. These type of curriculum materials are referred to in the literature as "educative curriculum materials" (Ball & Cohen, 1996; Beyer & Davis, 2009a, 2009b; Davis & Krajcik, 2005; Schneider & Krajcik, 2002). Educative curriculum materials are meant to teach *to* teachers rather than teaching *for* teachers. This is helpful in cases such as the inquiry continuum when individual classrooms might enact very different variations of the same lesson. Educative curriculum materials promote both teacher and student learning through the materials. This would obviously take more effort in writing the curriculum materials up front, but would possibly do a better job of meeting students' skill levels.

Finally, a third implication involves the fact that no matter what kind of curriculum materials an elementary science teacher has, a key to modifying the curriculum materials to meet the needs of a class of students involves learning how to determine what students know when they begin studying a particular concept and having a clear goal of what the students need to learn over the course of the unit. Previous research has shown that teachers were not successfully scaffolding their students to be successful in the practices of science (Hmelo-Silver et al., 2006). Before the curriculum materials can be modified, teachers need to know what their students know. This can be done through formative assessment throughout the school year (Black & Wiliam, 2009; Bybe et al., 1989; Cronin-Jones, 1991; Lee & Houseal, 2003). A natural extension of the current study would be to explore how elementary science teachers elicit students' ideas and how they use that information to inform their instruction. Knowing how teachers take the information elicited from student ideas and use it to modify their existing science curriculum materials is an unexplored phenomenon in science education research.

Policy level changes. Just as the literature has described challenges that exist to elementary teachers teaching science-as-inquiry, (i.e. Davis et al., 2006), this study established that perceived challenges exist to teaching student-directed variations of inquiry, but further research needs to be conducted to explore how we can help teachers overcome the perceived challenges to teaching differing variations of inquiry. An important question that underlies these perceived challenges is that even if we can help teachers overcome these challenges, would they then feel successful teaching all the variations of inquiry?

The four perceived challenges found in this study need to be taken into consideration by curriculum developers, science educators, and policy makers: (a) questioning student abilities, (b) relinquishing control, (c) time, and (d) going against teaching norms. The teachers perceived these as real threats to teaching more student-directed variations of inquiry, and therefore enacted their curriculum materials as written, which were more teacher-directed according to the P-SOP^d lesson plan scores. Although they valued student-directed inquiry, they claimed that these four obstacles were not worth overcoming in order to attempt more student-directed forms. This type of change requires a major shift in the culture of the classroom. 50% of elementary teachers reported that one of their main roles in the classroom was to explain scientific phenomena to the whole class of students during each class period (Banilower et al., 2013). Getting away from this idea that the teacher holds all the knowledge and transmits it to the students will take a shift in the culture of the science classroom, and new roles for teachers (van der Valk & de Jong, 2009).

Another implication of the teachers' ideas about the inquiry continuum is that science needs more contact time during the school day (NRC, 2007). The heavy emphasis on time for math and reading should not cause science to suffer by elimination. Table 34 shows the disproportionality of time spent on math vs. science in elementary classrooms divided by primary and secondary grades. Clearly, math instruction occurs every day, while science instruction does not even occur half of the time during some weeks of the school year.

Table 34

Frequency of instruction time of math and science in elementary classrooms (Banilower, et al., 2013)

	Percent of Classes	
	Science	Math
Grades K-3		
All/Most days, every week	20	99
Three or fewer days, every week	39	1
Some weeks, but not every week	41	1
Grades 4-6		
All/Most days, every week	35	98
Three or fewer days, every week	33	2
Some weeks, but not every week	32	0

A final implication is that other subjects should model the practice of gradually releasing responsibility to students over the course of time so that this is not such a foreign idea in a science class. This would help alleviate the perceived challenge of 'going against the norms of teaching'. The teachers felt their students needed to be told the ‘right’ answer in the end and that this impeded their ability to attempt student-directed inquiry. Other subjects such as social studies have begun to study the amount of scaffolding teachers provide to students (Serriere, Mitra, & Reed, 2011). The area of civic engagement has even developed its own sort of continuum for the amount of adult (teacher) direction given to students (see figure 25).

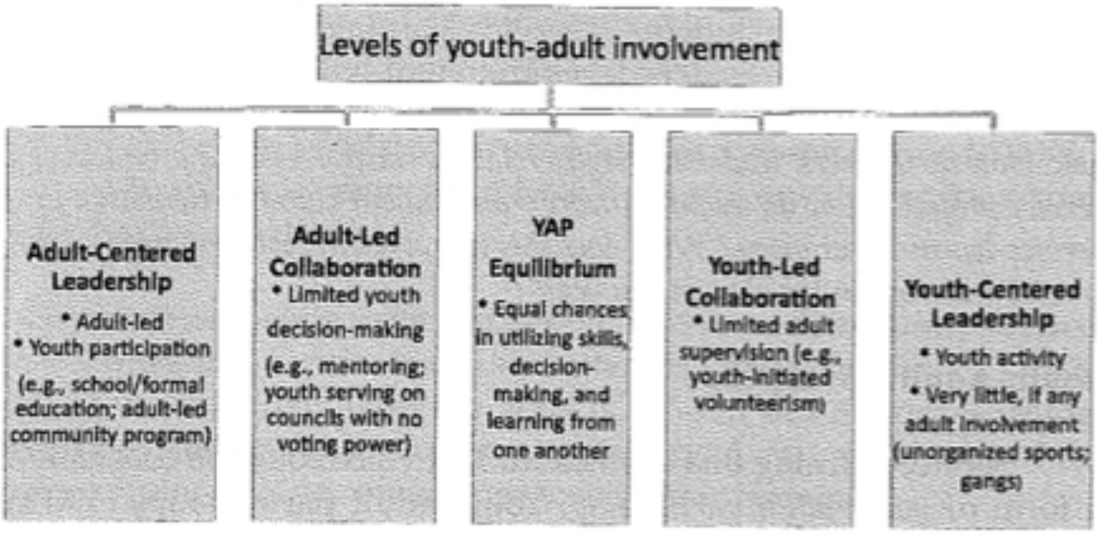


Figure 25. Continuum of youth-adult partnerships (based on Jones & Perkins, 2005)

Summary. This study has implications for three main sources, (a) professional developers, (b) curriculum developers, and (c) policy makers. First, science education researchers should take this information from these three findings into the planning of future professional development sessions. Inservice and preservice teachers need training in the varying amounts of teacher-direction in inquiry lessons and the importance of teaching the ‘just right’ level to their students. This professional development and training should be conducted to broaden their definitions of inquiry, expose them to the inquiry continuum, and give them tools to use in order to meet the needs of their learners. Preservice teachers would benefit from this exposure and training early in their careers before adopting a narrow, student-directed definition of inquiry as they begin teaching. Ultimately, these implications will increase the opportunity of preservice and inservice teachers to engage students in the practices of science and, in the end, increase student learning.

Second, curriculum developers should take notice of the findings of this study in order to design educative curriculum materials that give flexible choices in how much teacher-direction a science lesson includes. As this amount of scaffolding will vary from one class to the next, teachers need tools built directly into their curriculum materials that allow for variations of how to enact each feature of inquiry based on their students’ needs. These educative curriculum materials inform teachers as well as students.

Finally, policy makers should make changes to the paltry amount of science instruction currently happening in elementary schools. The emphasis on reading and math because of accountabilities to legislation such as No Child Left Behind has caused science to be de-emphasized in elementary schools. Teachers need time to properly teach science in their classrooms. At the national level, a shift in classroom culture needs to take place that allows for more flexibility in teaching methods and expectations. When students constantly expect to be told the ‘right’ answer, the culture of scientific inquiry will not be successful in elementary classrooms. Other subjects need to adopt the gradual release of responsibility model in their instruction so students become accustomed to investigating their own questions and having more autonomy. Overall, these changes will allow students to engage in all the variations of inquiry and ultimately in the practices of science.

APPENDIX A: PRACTICES OF SCIENCE OBSERVATION PROTOCOL [P-SOP]

Engaging students in scientifically oriented questions	
1a. Students engage with an investigation question that is contextualized, motivating, and meaningful for students	0 1 2 3
1b. Students engage with an investigation question that focuses on standards-based content/phenomena	0 1 2 3
1c. Students engage with an investigation question that is answerable through scientific inquiry	0 1 2 3
1d. Students engage with an investigation question that is feasible and answerable in the context of the classroom	0 1 2 3
Engaging students in giving priority to evidence in responding to questions	
2a. Students engage with phenomenon of interest	0 1 2 3
2b. Students work with data related to phenomena of interest	0 1 2 3
2c. Students generate evidence by organizing and analyzing data	0 1 2 3
2d. Students reflect upon and verify the data collection process, accuracy of data, and transformation of evidence from data	0 1 2 3
Engaging students in formulating explanations from evidence to address scientifically oriented questions.	
3a. Students formulate explanations about phenomenon of interest that are based on evidence	0 1 2 3
3b. Students formulate explanations about phenomenon of interest that answer	0 1 2 3

investigation question	
3c. Students formulate explanations about phenomenon of interest that propose new understanding	0 1 2 3
3d. Students formulate explanations about phenomenon of interest that build on their existing knowledge	0 1 2 3
Engaging students in evaluating their explanations in light of alternative explanations	
4a. Students evaluate their explanations by comparing to alternative explanations to consider whether evidence supports their proposed explanation	0 1 2 3
4b. Students evaluate their explanations by comparing to alternative explanations to consider whether their proposed explanation answers the investigation question	0 1 2 3
4c. Students evaluate their explanations by comparing to alternative explanations to consider any biases or flaws in reasoning connecting evidence with their proposed explanation	0 1 2 3
4d. Students evaluate their explanations by comparing to alternative explanations to consider whether alternative explanations can be reasonably derived from the same evidence.	0 1 2 3
Engaging students in communicating and justifying their explanations.	
5a. Students clearly share and justify their investigation question	0 1 2 3
5b. Students clearly share and justify their procedures, data, and evidence	0 1 2 3

5c. Students clearly share and justify their proposed explanation and supporting evidence	0 1 2 3
5d. Students clearly share and justify their review of alternative explanations.	0 1 2 3

APPENDIX B: REFORMED TEACHING OBSERVATION PROTOCOL [RTOP]

II. LESSON DESIGN AND IMPLEMENTATION

		Never Occurred				Very Descriptive
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2)	The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3)	In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4

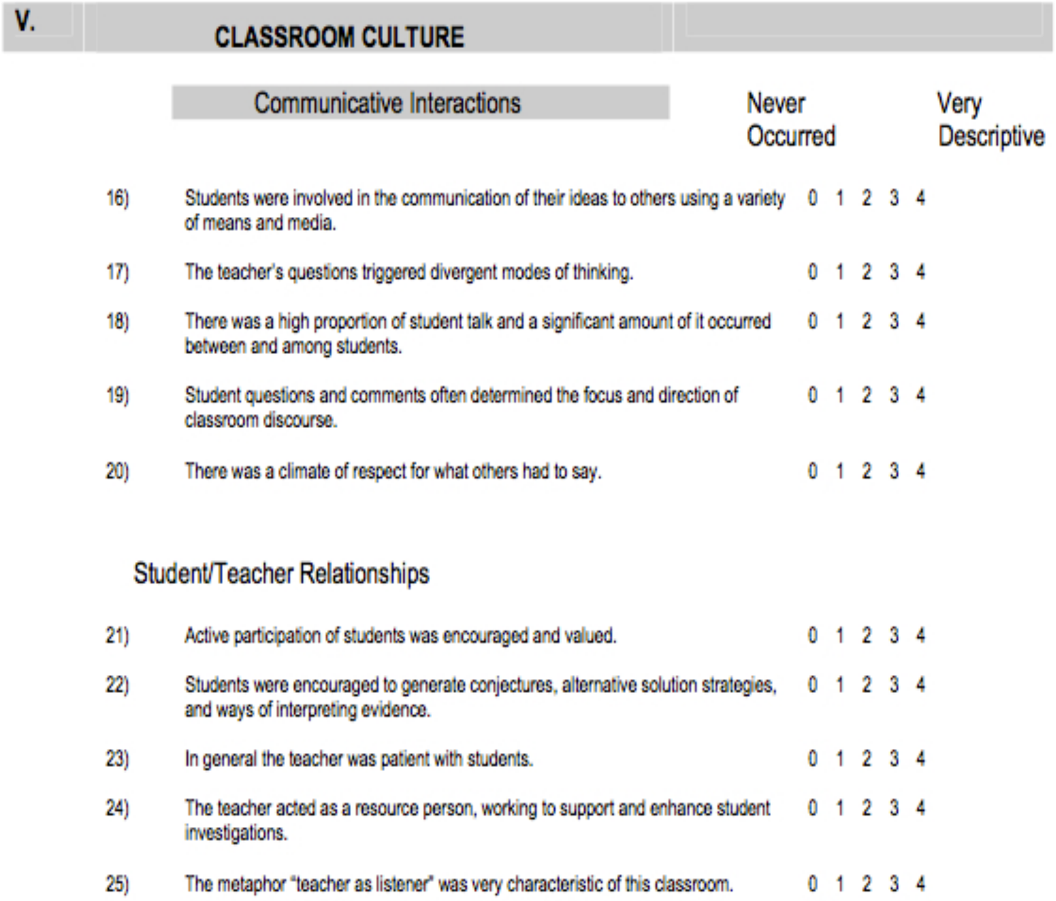
IV. CONTENT

Propositional knowledge

6)	The lesson involved fundamental concepts of the subject.	0	1	2	3	4
7)	The lesson promoted strongly coherent conceptual understanding.	0	1	2	3	4
8)	The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4
9)	Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	0	1	2	3	4
10)	Connections with other content disciplines and/or real world phenomena were explored and valued.	0	1	2	3	4

Procedural Knowledge

11)	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0	1	2	3	4
12)	Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	2	3	4
13)	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	3	4
14)	Students were reflective about their learning.	0	1	2	3	4
15)	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	3	4



V. CLASSROOM CULTURE

Communicative Interactions

		Never Occurred				Very Descriptive
16)	Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17)	The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18)	There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4
19)	Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4
20)	There was a climate of respect for what others had to say.	0	1	2	3	4

Student/Teacher Relationships

21)	Active participation of students was encouraged and valued.	0	1	2	3	4
22)	Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	0	1	2	3	4
23)	In general the teacher was patient with students.	0	1	2	3	4
24)	The teacher acted as a resource person, working to support and enhance student investigations.	0	1	2	3	4
25)	The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4

APPENDIX C: PRACTICES OF SCIENCE OBSERVATION PROTOCOL + DIRECTEDNESS [P-SOP^d]

Engaging students in scientifically oriented questions	**No evidence ← → Strong Evidence**			
1a. Students engage with an investigation question that is contextualized, motivating, and meaningful for students	0	1	2	3
1b. Students engage with an investigation question that focuses on standards-based content/phenomena	0	1	2	3
1c. Students engage with an investigation question that is answerable through scientific inquiry	0	1	2	3
1d. Students engage with an investigation question that is feasible and answerable in the context of the classroom	0	1	2	3

Learner directed			**Teacher directed**
A. Learner poses a question	B. Learner selects among questions, poses new questions	C. Learner sharpens or clarifies question provided by teacher, materials, etc.	D. Learner engages in question provided by teacher, materials, or other source

Engaging students in giving priority to evidence in responding to questions	**No evidence ←→ Strong Evidence**			
2a. Students engage with phenomenon of interest	0	1	2	3
2b. Students work with data related to phenomena of interest	0	1	2	3
2c. Students generate evidence by organizing and analyzing data	0	1	2	3
2d. Students reflect upon and verify the data collection process, accuracy of data, and transformation of evidence from data	0	1	2	3

Learner directed			**Teacher directed**
A. Learner determines what constitutes evidence and collects it (and analyzes it on his own/with help)	B. Learner directed to collect certain data (and analyzes it on his own/with help)	C. Learner given data and asked to analyze	D. Learner given data and told how to analyze

Engaging students in formulating explanations from evidence to address scientifically oriented questions.	**No evidence ← → Strong Evidence**			
3a. Students formulate explanations about phenomenon of interest that are based on evidence	0	1	2	3
3b. Students formulate explanations about phenomenon of interest that answer investigation question	0	1	2	3
3c. Students formulate explanations about phenomenon of interest that propose new	0	1	2	3

understanding				
3d. Students formulate explanations about phenomenon of interest that build on their existing knowledge	0	1	2	3

Learner directed			**Teacher directed**
A. Learner formulates explanation after summarizing evidence	B. Learner guided in process of formulating explanations from evidence	C. Learner given possible ways to use evidence to formulate explanation	D. Learner provided with evidence and how to use evidence to formulate explanation

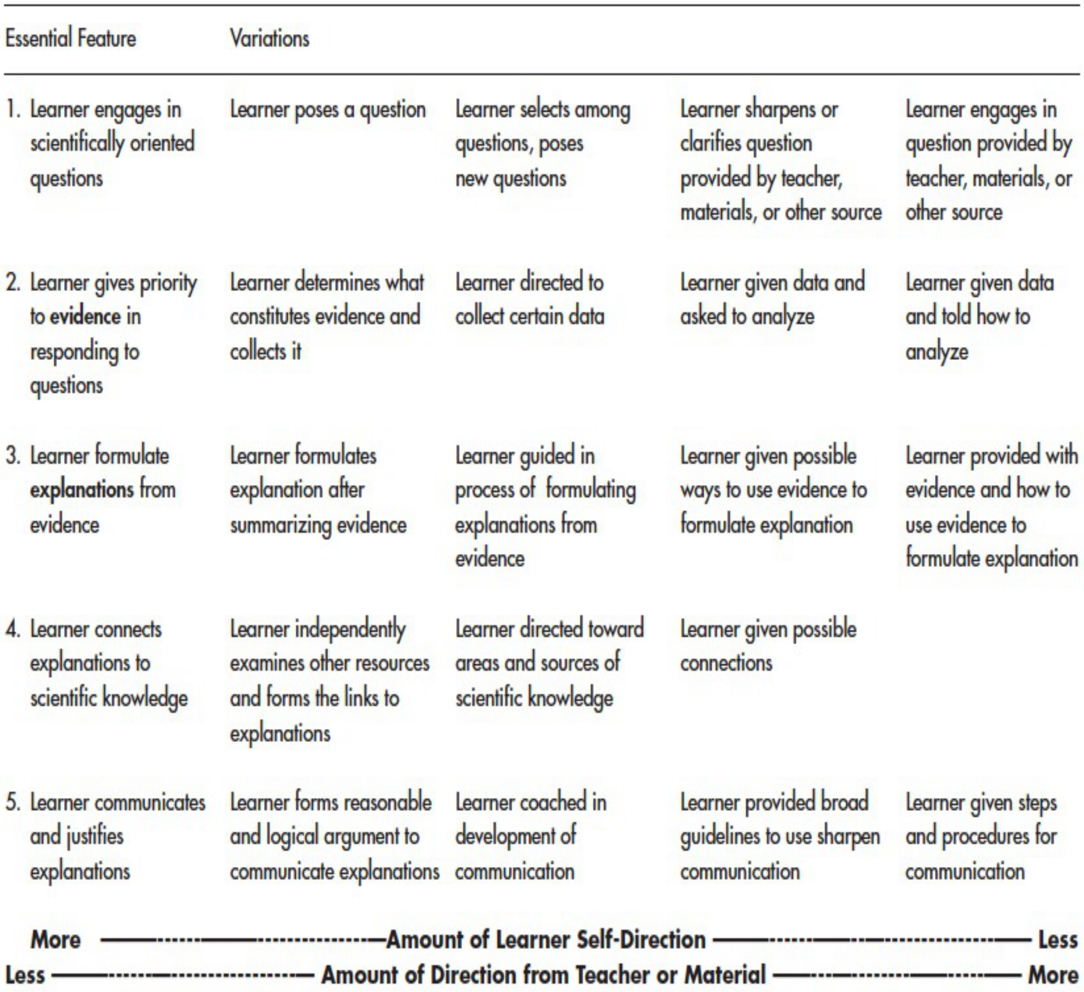
Engaging students in evaluating their explanations in light of alternative explanations	**No evidence ← → Strong Evidence**			
4a. Students evaluate their explanations by comparing to alternative explanations to consider whether evidence supports their proposed explanation	0	1	2	3
4b. Students evaluate their explanations by comparing to alternative explanations to consider whether their proposed explanation answers the investigation question	0	1	2	3
4c. Students evaluate their explanations by comparing to alternative explanations to consider any biases or flaws in reasoning connecting evidence with their proposed explanation	0	1	2	3
4d. Students evaluate their explanations by comparing to alternative explanations to consider whether alternative explanations can be reasonably derived from the same evidence.	0	1	2	3

Learner directed			**Teacher directed**
A. Learner independently examines other resources and forms connections to explanations	B. Learner directed toward possible sources of scientific knowledge and forms connections to explanations	C. Learner is explicitly told whether his explanation is right or wrong and specific resources provided to form connections to explanations	D. Learner is explicitly told whether his explanation is right or wrong and why

Engaging students in communicating and justifying their explanations.	**No evidence ← → Strong Evidence**			
5a. Students clearly share and justify their investigation question	0	1	2	3
5b. Students clearly share and justify their procedures, data, and evidence	0	1	2	3
5c. Students clearly share and justify their proposed explanation and supporting evidence	0	1	2	3
5d. Students clearly share and justify their review of alternative explanations.	0	1	2	3

Learner directed			**Teacher directed**
A. Learner forms reasonable and logical argument to communicate explanations	B. Learner coached in development of communication	C. Learner provided broad guidelines to use sharpen communication	D. Learner given steps and procedures for communication

APPENDIX D: VARIATIONS OF INQUIRY MATRIX (NRC, 2000)



Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

More ——————————Amount of Learner Self-Direction —————————— Less

Less —————————— Amount of Direction from Teacher or Material —————————— More

APPENDIX E: TEACHER FORMAL SEMI-STRUCTURED INTERVIEW

Formal Interview

1. Based on your experience, how would you define science as inquiry in the elementary classroom?
    a. What are the strengths of teaching science as inquiry?
    b. What are the weaknesses of teaching science as inquiry?
2. Based on your experience how effective is teaching science as inquiry?
3. Do you think most elementary teachers teach science as inquiry?
4. Scientific Inquiry Questions
    a. How important is it for students to ask scientifically-oriented questions?
    b. How would you provide opportunities for students to ask scientifically-oriented questions?
    c. How important is it for students to use data (e.g., measurements, graphs, or number counts) to answer scientifically-orientated questions?
    d. How would you provide opportunities for students to use data to answer a scientifically-oriented question?
    e. How important is it for students to have lessons that formulate an explanation from the data and evidence they have collected?
    f. How would you provide opportunities for students to formulate an explanation from the data and evidence they have collected?
    g. How important is it for students to compare their explanations to an alternative explanation to address a scientifically-oriented question?

    h. How would you provide opportunities for students to compare their explanation to an alternative explanation to address a scientifically-oriented question?
    i. How important is it for students to share their data with others and justify aspects of their investigation with others for their scientifically-oriented question?
    j. How would you provide opportunities for students to share their data with others and justify aspects of their investigation with others for their scientifically-oriented question?

5. That covers everything I wanted to ask. Anything you would like to add about science as inquiry?

APPENDIX F: TEACHER LESSON SEMI-STRUCTURED INTERVIEW

(Conducted before/after each observed lesson)

1. Pre-Enactment Questions

1. I'd like to hear about your lesson.
    a. How inquiry based do you think your original lesson plan is?
        i) How does it engage students in asking scientifically-oriented questions?
        ii) How does it engage students in using data (e.g., measurements, graphs, or number counts) to answer scientifically-orientated?
        iii) How does it engage students in formulating an explanation from the data and evidence they have collected?
        iv) How does it engage students in comparing their explanations to an alternative explanation to address a scientifically-oriented question?
        v) How does it engage students to share their data with others and justify aspects of their investigation with others for their scientifically-oriented question?
    b. What changes did you make to your original lesson plan?
        i) Describe each of the changes you made.
        ii) How did these changes make your lessons more inquiry based?
        iii) What other factors did you consider for making these changes?
    c. That covers everything I wanted to ask. Anything you would like to add about your science lesson?

2. Post-Enactment

1. I'd like to hear about your enacted lesson.
    a. Was the enacted lesson different from the lesson you planned?
        i) How was the enacted lesson different?
        ii) What created these differences?
    b. How inquiry based do you think your enacted lesson was?
        i) How did it engage students in asking scientifically-oriented questions?
        ii) How did it engage students in using data (e.g., measurements, graphs, or number counts) to answer scientifically-orientated?
        iii) How did it engage students in formulating an explanation from the data and evidence they have collected?
        iv) How did it engage students in comparing their explanations to an alternative explanation to address a scientifically-oriented question?
        v) How did it engage students to share their data with others and justify aspects of their investigation with others for their scientifically-oriented question?
    c. How will you change this lesson plan? Please describe the changes that you will make.
        i) What is your reason for making the changes?
        ii) How do you think the changes will make your enacted lesson more inquiry-oriented?
        iii) What other factors are you considering for making these changes?

d. That covers everything I wanted to ask. Anything you would like to add about your science lesson?

APPENDIX G: LESSON PLAN RATIONALE (LPR)

Lesson Plan Rationale

1) What **existing lesson plans, curriculum materials, and other resources** did you use to develop your lesson? Please list them here.

	Name/Title	**Type of Resource**	**Additional Information**
Ex.	Mealworms	FOSS kit	Investigations 1 & 2
1.			
2.			
3.			
.4.			

2) How inquiry-oriented do you think your **original lesson** was?

☐ Very inquiry-oriented

☐ Somewhat inquiry-oriented

☐ Not very inquiry-oriented

☐ Not at all inquiry-oriented

Please **explain** your answer to question #2. Why do you think your original lesson was or was not inquiry-oriented?

3) What **changes** did you make to your original lesson plan?
   - a) Describe **each** of the changes you made.
   - b) How did these changes make your lessons **more inquiry based**?
   - c) What **other factors** did you consider for making these changes?

4) How inquiry-oriented do you think your **<u>revised lesson</u>** is?

☐ Very inquiry-oriented
☐ Somewhat inquiry-oriented
☐ Not very inquiry-oriented
☐ Not at all inquiry-oriented

APPENDIX H: LESSON PLAN EVALUATION (LPE)

Please analyze the attached PDF lesson on magnets for each of these 5 essential features of inquiry. Use as much space as you need.

1. **In general, what does it mean to engage students in scientifically oriented questions?**

How does the magnets lesson engage students in scientifically oriented questions? Please provide specific examples from the lesson to explain your answer. How do your examples illustrate this feature of inquiry

2. **In general, what does it mean to engage students in giving priority to evidence?**

3. **How does the magnets lesson engage students in giving priority to evidence in responding to questions? Please provide specific examples from the lesson to explain your answer. How do your examples illustrate this feature of inquiry?**

4. **In general, what does it mean to engage students in formulating explanations from evidence?**

5. **How does the magnets lesson engage students in formulating explanations from evidence to address scientifically oriented questions? Please provide specific**

examples from the lesson to explain your answer. How do your examples illustrate this feature of inquiry?

6. **In general, what does it mean to engage students in evaluating their explanations?**

7. **How does the magnets lesson engage students in evaluating their explanations in light of alternative explanations? Please provide specific examples from the lesson to explain your answer. How do your examples illustrate this feature of inquiry?**

8. **In general, what does it mean to engage students in communicating and justifying their explanations?**

9. **How does the magnets lesson engage students in communicating and justifying their explanations? Please provide specific examples from the lesson to explain your answer. How do your examples illustrate this feature of inquiry?**

10. **Overall, I would classify this lesson as:**
    a. **Very Inquiry-Oriented**
    b. **Somewhat Inquiry-Oriented**
    c. **Not very Inquiry-Oriented**
    d. **Not at all Inquiry-Oriented**

PIESC^3

APPENDIX I: RECRUITING EMAIL

Dear DCSD elementary teachers;

The Douglas Community Schools, in partnership with the University of Iowa, has recently received a grant for a 2-year project that will provide opportunities for you to learn more about inquiry-based teaching and learning as articulated in the Iowa CORE and *National Science Education Standards*, develop in-depth knowledge about a science kit you currently use to teach science (of your choosing), and to analyze your teaching and evidence of student learning. We are now recruiting elementary teachers to participate in the project for 2 years starting in September of 2010. There are 4 levels of participation from which you may choose:

Level 1a • Participate in 48 hours of science professional development in each year. • These include 4, 2-hour evening seminars during each school year, as well as a 5-day professional development institute in each summer (2011 and 2012). • Complete a lesson plan evaluation and videorecord 3 science lessons of your choosing in each school year. • **Receive a $720 stipend with the option of earning 3 credit hours of UI graduate course credit (at a discount rate of $45/ credit hour) in EACH YEAR of the project.**	Level 1b • Participate in all Level 1a activities. • You will be interviewed by UI researchers before and after each of the 3 observed and videorecorded lessons, at the beginning and end of each year, and complete an additional written artifact for each of the 3 lessons. • **Receive a $1120 stipend with the option of earning 3 credit hours of UI graduate course credit (at a discount rate of $45/ credit hour) in EACH YEAR of the project.**
Level 2a	Level 2b

• Complete a lesson plan evaluation and videorecord 3 science lessons of your choosing in each school year. • However, you will NOT participate in any of the professional development experiences. • **Receive a $60 stipend for EACH YEAR of participation.**	• Participate in all Level 2a activities. • You will be interviewed before and after each of the 3 observed and videorecorded lessons, at the beginning and end of each year, and complete an additional written artifact for each of the 3 lessons. • You will NOT participate in any of the professional development experiences. • **Receive a $460 stipend for EACH YEAR of participation.**

Participation in this project is completely voluntary and poses no risk to you or your students. No data collected in this project will be shared with DCS administrators or used to evaluate your teaching in any way. If after receiving this letter, you have any questions about this study, please feel free to contact Cory Forbes at 319 335 5591 and/or cory-forbes@uiowa.edu.

We appreciate your interest in this research and thank you for your consideration of our project. Please reply to this e-mail and indicate your interest in participation at one or more of the levels of participation described. If you do not wish to participate in this study, please reply to this e-mail with a "Not interested in participation." statement.

Cory T. Forbes
Assistant Professor of Science Education
Department of Teaching and Learning
N252 Lindquist Center
University of Iowa College of Education
Iowa City, IA 52242-1529

APPENDIX J: JOINT DATA DISPLAY

		Lesson Modifications (QUAN)														
		Student-directed ←--→Teacher-directed														
	Ideas about Continuum (QUAL)	1	2	2.5	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	Ideas about curriculum modification (QUAL)
Grace	“Inquiry is letting the students come up with their own question”					LP (3.16)	→	Video (3.27)								“Let’s see what happens if I remove teacher directions”
Emily	“Inquiry should be student-directed”			Video (2.38)	←	LP (3.11)										“Gradual release of responsibility”
Janet	“You lose more control of your classroom”									LP (3.33) = Video (3.39)						“We follow the FOSS lesson plan”

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