Understanding and Structuring Inquiry: A Tale of Three Teachers

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Abstract

This study explored 3 secondary science teachers' conceptions of inquiry and the use of an inquiry framework to support students during inquiry-based activities. These secondary science teachers were in their first years of teaching and were part of a state-wide professional development (PD) program that emphasized a structured approach to inquiry instruction. These teachers were purposefully selected with each indicating that they implemented the equiry levels framework (ELF) emphasized in the PD. The researchers employed a constant comparative approach to analyze the data set, which included classroom observations, surveys, and interviews. Results indicated the participants' understanding of inquiry became more aligned with the VISTA framework. However, differences in participants' understanding ELF and beliefs about inquiry may have contributed to their varied emphasis on scientific practices and types of interactions in their classroom science instruction. The teacher with the strongest understanding of ELF and fewest perceived barriers to implementing inquiry incorporated more scientific practices and allowed for more student-student interactions. The present study has the potential to inform how methods of structuring inquiry instruction and teaching scientific practices are taught to in-service teachers.

Keywords: inquiry, scientific practices, in-service teachers

Introduction

As early at the 1970's there has been a call for science instruction to incorporate inquiry (Herron, 1971). Since 1996 and the development of the National Science Education Standards in 1996 research on inquiry has drastically increased (Yeh, Jen, & Hsu, 2012). Thus the use of scientific inquiry in the classroom is an area of interest to researchers and teachers alike. Literature reviews on the topic of inquiry indicate varied student outcomes in science classrooms (Lott, 1989; Minner, Levy & Century, 2010); thus, researchers debate whether inquiry is a beneficial approach to science instruction (Kirschner, Sweller & Clark, 2006; Hmelo-Silver, Duncan, & Chinn, 2007). From a teacher's perspective, both internal barriers (i.e. teacher beliefs and values) and external barriers (i.e. lack of resources, focus on assessments) limit the implementation of inquiry (Anderson, 2002; Keys, 2001). Inquiry can also seem confusing and overwhelming for teachers, especially new teachers, which can impede the use of inquiry in the classroom (Wee, Shepardson, Fast & Harbor, 2007; VanHook, Huziak-Clark, Nurnberger-Haag, & Ballone-Duran, 2009). The present study explores how one approach, inquiry levels, holds promise as an effective method for teachers to implement inquiry (Blanchard et. al, 2010).

Inquiry

An early classroom definition of scientific inquiry was developed by John Dewey in the early 1910s (Barrow, 2006). Dewey described inquiry as an active process facilitated by the teacher in which students construct their own knowledge. Some of the main characteristics of

Dewey's characterization of inquiry include: developing a hypothesis, collecting data, and forming a conclusion. Over the years inquiry has developed into a diverse and complex concept with varied definitions of what constitutes inquiry-based instruction.

Currently, there are many ways to categorize inquiry such as "inquiry as ends" or "inquiry as means" (Adb-El-Khalick et. al. 2004, p. 398), and "scientific inquiry", "inquiry learning", or "inquiry teaching" (Anderson, 2002, p.2). The goal of inquiry as ends and inquiry learning is for students to learn about the active process of gaining knowledge in science. This process of gaining knowledge is what scientists do, called scientific inquiry. Inquiry as means characterizes inquiry as a process where students learn science content rather than the process of inquiry. Finally, inquiry teaching is the method of implementing inquiry in the classroom, which can be extremely varied to the point that there is no operational definition of inquiry teaching (Anderson, 2002).

The National Research Council (NRC) (2000) also describes inquiry and identifies what inquiry should look like in the classroom. The NRC characterize inquiry according to five characteristics: learners are engaged in scientifically oriented questions, learners give priority to evidence, learners formulate explanations from evidence, learners evaluate their explanations, and learners communicate and justify their personal explanations (p. 26). However, it is unclear whether an inquiry-based activity must include all or some of these classroom characteristics, which may be one reason why there is a lack of consensus on inquiry-based instruction. In an attempt to simplify what constitutes inquiry, researchers have defined inquiry as "students asking questions, collecting and analyzing data, and using evidence to solve problems" (Maeng & Bell, 2012, p. 3). Another simplified definition identified inquiry as "an active learning process in which students answer research questions through data analysis" (Bell, Smetana, and Binns 2005, p 31). These streamlined definitions make it easier for teachers to identify whether they are doing inquiry in their own classrooms.

Scientific Practices

Most recently the NRC developed scientific practices as a common set of characteristics incorporating students' use of both knowledge and skills in scientific investigations (NRC, 2012). Scientific practices may be incorporated in to inquiry-based activities or non-inquiry-based activities and are described by students' engagement in:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating results (NRC, 2012, p. 42).

The purpose of the scientific practices is to emulate what scientists do in practice. For example, when students are involved in *asking questions* the questions should be empirically answerable questions. Like scientists, the *development of models* can be helpful to visualize a science concept/process in order to make predictions. The *planning and carrying out of investigations* should be systematic in nature and should involve the collection of data. In science, data itself does not lead to gaining new knowledge, thus students should be engaged in *analyzing and interpreting data*. This may take the form of a graphical representation to understand the relationship between the data. Many times in science these relationships can be expressed using quantitative measures, so it is important students are involved in *mathematical and computational thinking*. Students' build upon the analysis of data and make connections with their current scientific understandings in order to *construct explanations*. However, like scientists, students may provide multiple explanations for a single set of data. Students should therefore be involved in defending their own explanation by *engaging in argument from evidence*. Finally, throughout an investigation students should continually practice *obtaining, evaluating, and communicating information*. This may take the form of gathering data, evaluating the most pertinent data in order to effectively graph data, and presenting results in the form of a lab report or presentation.

Scientific practices are further categorized based upon the types of activities the teacher incorporates into the classroom (Figure 1). During an investigation students may be involved in *asking questions* and *planning and carrying out investigations*. As students critique the investigation they *analyze and interpret data*, *engage in argument from evidence*, and *obtain, evaluate, and communicate results*. Finally, as students develop solutions to the investigation they may *develop and use models*, *use mathematics and computational thinking*, and *construct explanations*. Depending on the grade level the teacher may provide more or less support for a specific scientific practice, or the teacher may incorporate different numbers of scientific practices into inquiry-based activities. By the end of high school the NRC recommends that students be able to engage in each scientific practice with little teacher guidance. For example, by 12th grade students should be able to develop their own research question, develop their own model, and plan and implement their own investigation. In order for students to make this type of progression for each scientific practice how the teacher structures inquiry-based activities becomes essential.

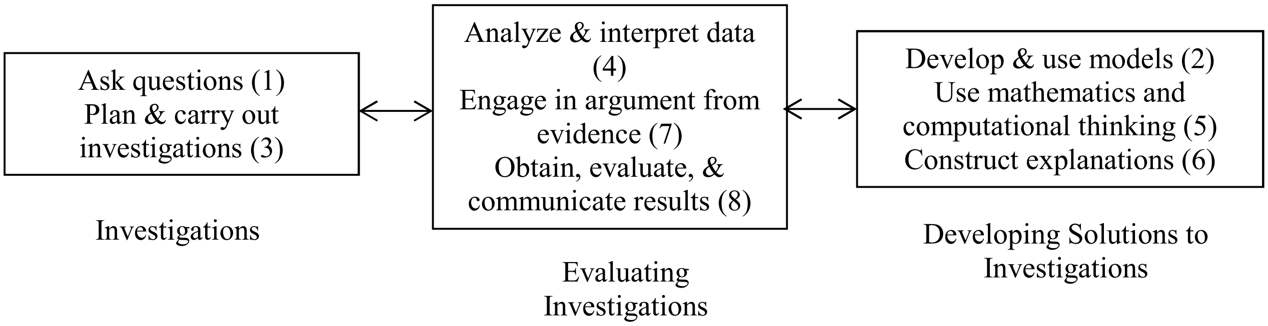

Figure 1. Scientific practices organized by types of activities. Adapted from *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*, by the National Research Council, 2012, p. 45. Copyright by the The National Academies Press.

Structuring Inquiry

In addition to defining and characterizing inquiry, there are also many ways teachers can structure these inquiry-based activities in the science classroom. As a result, researchers debate which method is the most effective for implementing inquiry in the classroom. Some researchers argue that providing students little to no structure, called open inquiry, best emulates what real scientists do (Etheredge & Rudnitsky, 2003). However, others argue this is not the only method which can be successful in the classroom (Settlage, 2007). Still other researchers state open inquiry creates cognitive overload for students (Kirshner, et al., 2006). In response to Kirshner et al., Hmelo-Silver et al. (2007) contend that the authors conflate inquiry-based approaches with discovery learning and problem-based learning. Clearly, the lack of a consensus on what constitutes inquiry and how to structure inquiry in the classroom results in ambiguity about inquiry (Anderson, 2002).

Despite these arguments, there are developed methods of structuring inquiry in the science classroom such as the 5E model of inquiry, the continuum of inquiry, and inquiry levels. The 5E instructional model of inquiry is a widely used method of structuring inquiry in the science classroom and includes 5 main steps; engage, explore, explain, elaborate, and evaluate (Bybee et. al., 2006). These steps provide the teacher a method of ordering an inquiry-based lesson by starting with a scientific investigation (engage, explore) and building upon that investigation in order to learn and apply science concepts (explain, elaborate). The teacher assesses students understanding through the evaluation step of this model.

The 5E model of inquiry structures inquiry based upon the order of a lesson while the continuum of inquiry structures inquiry based upon the support given to students by the teacher. The continuum of inquiry is based on the five characteristics of inquiry (i.e. learners engage in scientifically oriented questions), and the teacher can modify inquiry-based activities to be more student-centered or more teacher-centered (NRC, 2000). For example, in a very teacher-centered inquiry activity students might be given the research question and the procedure of how to collect and analyze data, then instructed on how the activity directly connects to the science content. In a moderately teacher-centered, inquiry-based activity the students might have to come up with their own method of how to collect and analyze data, but the teacher models how to make connections between the data and the science concepts. Using the continuum, the teacher has a variety of ways to modify activities to make them more or less student-centered.

Similar to the continuum of inquiry, Schwab (1962) originally described three levels for structuring inquiry, called “enquiry”. The purpose of identifying levels was to be specific enough to support science teachers in using enquiry but general enough to encompass all science content (Herron, 1971). At a level 1, students are provided the research question and the methods, but they do not know the answer ahead of time. A level 2 enquiry activity is characterized by providing students a research question but no methods of answering the question. Level 3 is the least structured where students are “confronted with the raw phenomenon” and develop a question and the method (Schwab, 1962, p.55). Herron further elaborated on these levels of enquiry, adding a level 0 to describe a non-enquiry activity where students are provided the question and methods, as well as one clear solution (Herron, 1971).

Recently these levels have been modified to include level 0 activities as inquiry activities (Cothran, Geiss, and Rezba 2000; Bell, et al., 2005) as students are still analyzing data to answer a research question. The four levels, called the Enquiry Levels Framework (ELF), correspond to Herron’s levels 0-3 and remain characterized by whether students are provided the question, methods and solution for an activity (Table 1). In ELF, c*onfirmatory* inquiry (level 1) typically comes after the content is taught, and students are analyzing data to *confirm* a relationship. By taking a confirmatory activity and placing it before content-oriented instruction, it becomes a *structured* inquiry activity (level 2) because students do not know the answer prior to conducting the investigation. A *guided* inquiry activity (level 3) provides students with a specific question, but students develop the procedure for answering the question. *Open* inquiry (level 4) places the most responsibility on students. Students develop their own question and procedures, and they do not know what results to expect in the investigation. The specific levels of inquiry investigated in this study align with the ELF method of structuring inquiry.

Table 1.
The Enquiry Levels Framework (ELF)

	What is provided by the teacher		
Level of Inquiry	**Question**	**Methods**	**Solution**
1 Confirmatory	x	x	x
2 Structured	x	x	
3 Guided	x		
4 Open			

Note. Adapted from Bell, R.L., Smetana L., & Binns I. (2005).

One benefit to ELF is the ability for science teachers to incorporate these levels in a variety of content and contexts, which may indicate practical usage for the classroom (e.g. Bianchi & Bell, 2008; Kluger-Bell, 1999; Wheeler & Bell, 2012). In a 5th grade classroom, Bianchi & Bell (2008) discussed how each level of inquiry could be utilized to develop students' deep conceptual understanding of density. Kluger-Bell (1999) reviewed how elementary teachers could implement a single foam activity using an open, guided, or structured inquiry approach. Wheeler & Bell (2012) provided a specific example of how to implement open inquiry in a high school chemistry classroom and model how this activity could be modified to a different level of inquiry and for different chemistry content. Yet, ELF, like other methods of structuring inquiry, may be influenced by the teacher.

Teacher Conceptions and Practices of Inquiry

A substantial body of research explores the science teacher's role in inquiry instruction. More specifically, there are many studies assessing teachers' beliefs of and understandings about inquiry in science education (e.g. Blanchard, Southerland & Granger, 2007; Lotter, Harwood, & Bonner, 2006; Van Hook et al., 2009). According to Mansour (2009), beliefs are defined as a "teacher's idiosyncratic unity of thought about objects, people, events and their characteristic relationships that affect his/her planning and interactive thoughts and decisions" (p. 26). In this paper, beliefs about inquiry are teachers' thoughts and decisions about their instruction of inquiry-based practices. While teachers' beliefs and knowledge about inquiry may differ, they are intertwined and cannot be assessed independently of each other (Mansour, 2009). Consequently, both teacher beliefs and understandings about inquiry, called teacher conceptions, are addressed in this study.

Within the body of inquiry literature a handful of studies assess how secondary science teacher beliefs, understandings, and practices about inquiry change as a result of professional development (eg. Kazempour, 2009; Lotter et al., 2006; Van Hook et al., 2009). In a case study by Kazempour (2009), the researcher analyzed one high school teacher's understanding of inquiry before and following a 2-week summer inquiry-based professional development. Results indicated the teacher's understanding of inquiry transformed from a very simplistic view to a more cyclical view as a result of the professional development. Further, the teacher changed his beliefs about students to view them as more capable of performing inquiry, which influenced his beliefs about teaching. These understandings and beliefs translated into the teacher's practice as evidenced by an increased use of student-centered, inquiry-based practices in the classroom.

Similarly, Van Hook et al. (2009) found a relationship between a change in teacher beliefs and teacher practices. A total of 27 upper elementary and secondary teachers along with 18 graduate scientists completed an intensive professional development program called PRISM focused on inquiry-based practices. During the professional development, teachers learned about the 5E model of inquiry, the continuum of inquiry, and co-planned an inquiry-based unit with a graduate scientist. During the academic year a teacher and scientist pair attended follow up sessions and co-planned and co-taught science classes. Results suggested that initially teachers believed hands-on, open, individually performed inquiry was the only type of inquiry. By the end of the academic year following the professional development the teachers recognized the inquiry continuum and understood the necessity for collaboration and discussion in inquiry. In a third study, Lotter et al. (2006) examined 9 secondary science teachers' understanding of inquiry before and after a 2-week summer professional development focused on a 7-step process incorporating inquiry. The researchers found modeling the 7-step process explicitly during the professional development helped teachers develop a better understanding of inquiry-based practices, and teachers incorporated inquiry in the lesson plans developed at the professional development. The previous literature thus indicates that inquiry-based professional development can help improve teachers' understandings and beliefs about inquiry and help facilitate implementation of inquiry in the secondary science classroom.

Despite this research on the teacher beliefs, understandings and practices of inquiry following professional development, to our knowledge, no research has explored teacher conceptions and practice of ELF following professional development. In fact, there is very little research focused directly on the Enquiry Levels Framework. A few studies incidentally investigate levels of inquiry (Lederman et al., 2008; Pine et al, 2006) by comparing inquiry-based activities to other instructional methods. However these studies do not identify their inquiry instruction by levels of inquiry and only examine the effect of inquiry on student outcomes. Lederman et al. (2008) investigated how a science unit taught through direct instruction, inquiry-based instruction, or a mixture of the two affected content knowledge and attitudes of middle school students in the U.S and Europe. While not identified as a level of inquiry, the inquiry-based instruction described in this study falls under structured inquiry. Results indicated there were no significant differences in students' content knowledge or attitudes between the three groups. In a similar study, Pine et al. (2006) examined how hands-on learning versus text-book learning affected 5th grade students' ability to perform inquiry skills such as observation and inference, controlling for cognitive ability. The four different scenarios completed by students in both the hands-on and textbook groups were all inquiry-based. Three of the scenarios would be classified as guided inquiry and one as structured inquiry. Results revealed no significant differences on inquiry skills between students completing inquiry through hands-on activities or textbook activities. These two studies imply that inquiry-based methods may not increase student outcomes when compared to other methods of science instruction; however, they don't account for the role of the teacher.

Only one study directly identified and examined levels of inquiry (Blanchard et al., 2010). In this study the researchers compared the effect of guided inquiry versus verification labs on middle and high school students' understanding of concepts, procedures and nature of science. They also analyzed classroom instruction of guided and verification inquiry using the Reformed Teaching Observation Protocol (RTOP) instrument. Results indicated students' achievement was highest in the guided inquiry classrooms where teachers received high RTOP scores. The lowest scoring students were in the guided inquiry classrooms, not the verification classrooms, where teachers received low RTOP scores. These results indicate that the teacher plays an important role in effectively implementing inquiry in the classroom. Further, ineffective implementation of guided inquiry may negatively affect student understanding.

Purpose

Blanchard et al. (2010) identified the importance of the teacher role in implementing levels of inquiry, but as verification labs are no identified as inquiry, this study investigated Herron's levels of inquiry not ELF. Atar (2011) calls for more research on teacher conceptions of inquiry. Therefore, the purpose of this investigation was to characterize secondary science teachers' conceptions and implementation of ELF following the Virginia Initiative of Science Teaching and Achievement (VISTA) Secondary Teacher Program (STP). Three research questions guided the investigation:

1. What are secondary science teachers' conceptions of inquiry and ELF?
    a. How do teachers understand inquiry and ELF?
    b. What are teachers' beliefs about inquiry and ELF?
2. How do secondary science teachers integrate and structure inquiry instruction for their students?
3. What patterns exist between secondary science teachers' conceptions about inquiry and their classroom implementation of inquiry?

Methodology

Theoretical Framework

This study was guided by a social constructivism framework. Social constructivism is founded on main assumptions: a) knowledge is constructed by people who are active participants in the process; and b) social interactions within an individual or between individuals play an important role in constructing knowledge (Ferguson, 2007). As new knowledge is gained, it can be tested and modified based on new experiences. As an example, in an inquiry-based activity on reaction rates, students work in groups to analyze data about temperature and the time of a reaction. During this process students are actively involved in the process of graphing data and interacting with other students and the teacher in order to draw conclusions about the graph. Students conclude that reaction time decreases as temperature increases, and the teacher may provide students opportunities to then apply this new relationship. The teacher may also support students' development of further questions to help develop and modify their understanding of reaction rate.

In this study the social constructivism helped focus the observations of the classroom on students' active involvement in inquiry and interactions during inquiry. Specifically, we looked for student-student interactions and student-teacher interactions as they relate to the characteristics of scientific practices.

Site and Participants

A subset of 3 secondary science teachers was purposefully selected from 11 teachers enrolled in the VISTA STP. These 3 teachers, George, Chris, and Karen[1], were selected because interview data indicated they implemented the levels of inquiry into their science instruction. At the time of the study, each teacher was a first- or second-year science teacher in a suburban public school surrounding a large metropolitan area.

The methods course. These teachers completed a semester-long science methods course as part of the VISTA STP. One week of the methods course occurred before the academic year

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[1] Pseudonyms are used to protect the identity of the teachers.

and focused on science teaching strategies, classroom management, laboratory safety, and curriculum development. During this time the teachers learned the definitions of inquiry and levels of inquiry as described by ELF. According to VISTA, inquiry is defined as “students asking questions, collecting and analyzing data, and using evidence to solve problems” (Maeng & Bell, 2012, p. 3). Because of the late hiring process, George and Chris were not part of the summer week and made up this portion of the course at the beginning of the fall semester. The content of these make-up classes were the same.

The course is designed for first and second year teachers and met for seven Saturdays once school started in the fall semester. During the Saturday classes the teachers analyzed learning from a student and teacher perspective. The teachers also had various assignments due throughout the course. These included a paper on their philosophy of teaching and a unit plan incorporating inquiry. In addition to meeting with the course instructors, each teacher also had a coach who mentored them within the classroom. These coaches were retired teachers who were available to the teacher for resources and support for the equivalent of 90 hours over the course of the academic year.

The participants and their schools. Prior to becoming a first-year chemistry teacher at a large suburban high school, Karen was a long-term substitute. At the time of the study, Karen was provisionally certified and was working toward her teaching licensure. Over 2,700 students attended the school in which Karen taught and was one of twelve high schools in the county. The school was only one of two in the county that required remediation for all tests (i.e. students who fail a test can retake the test), and was moving toward a no homework policy. The student population was diverse, with about equal numbers of Caucasian, Hispanic and African American students. Karen taught both honors chemistry and regular chemistry on an alternating day block schedule. The principal of the school also required that the objectives and learning goals be posted in the classroom.

George was a second year physics teacher who taught at a secondary school with 3000 students in grades 7-12 in a large suburban area. George graduated at the top of his class in physics and was a civil engineer for 4 years before becoming a teacher. There were five secondary and twenty high schools in the county. The student population at George’s school contained about a third Caucasian students and a third African-American students. The remaining 30% of the school population was evenly split between Asian and Hispanic students. Like Karen’s school, George taught on an alternating day block schedule. George taught both regular and honors physics.

Chris was a first year teacher and one of three biology teachers working in a small city high school located in a sprawling suburban area. Immediately prior to the study, he graduated from an out-of-state university teacher education program. His student teaching experience was in a seventh grade science classroom. The high school where Chris taught contained less than 800 students total; almost half of the student population was Hispanic, a third Caucasian, and a small portion African-American. Chris’s high school was the only one in the city, and it served both affluent and low income neighborhoods. While the school was fairly new, there was little technology in the classrooms. Like Karen and George, Chris also taught on an alternating day block schedule. He taught four regular biology classes, one inclusion biology class, and one English as a Second Language (ESL) biology class.

Data Collection

Data sources included surveys, semi-structured interviews, classroom observations, informal interviews, and relevant artifacts. These multiple data sources allowed for triangulation of the data and increased the trustworthiness of the findings. To provide support for face and content validity of surveys and interview protocols, each instrument was reviewed by a panel of science education and research, statistics, and evaluation experts. The panel's revisions were incorporated in the final versions of the instruments used in the present study.

Teacher Perceptions Surveys. Participants completed the Perceptions surveys prior to and following the VISTA STP course. These surveys assessed participants' understanding of multiple constructs emphasized during the STP. A subset of open-ended questions from the Pre- and Post-Perceptions surveys assessed the participants understanding of inquiry (Appendix A). Participants defined inquiry and explained what inquiry would look like in their classroom. The purpose of these questions was to determine how well participants' definitions of inquiry aligned with the VISTA definition of inquiry. The Post-Perceptions survey also assessed the extent to which the participants found the professional development helpful. All survey responses pertaining to inquiry was included in the data set.

Semi-structured interviews. Initial interviews were conducted with all three participants using the Teacher Perceptions Follow-up Interview Protocol (Appendix B). This interview lasted about thirty minutes and explored each participant's experience in the methods class, including their understanding of inquiry. A second interview, the Teacher Inquiry Interview, sought to gain further insight into the participant's meaning of inquiry and ELF (Appendix C). Another goal of this interview was to ascertain the frequency and types of inquiry the participant incorporated into instruction for later triangulation with observational data. This interview lasted about thirty minutes and occurred prior to classroom observations. Each interview was recorded, transcribed, and initial interpretation of their meaning of inquiry was added.

Classroom observations. The first author conducted two purposeful observations for each participant during the duration of the VISTA STP, for a total of 11 hours of classroom observations. The timing of the two observations intended to exemplify the implementation of inquiry within the classroom. These observations occurred when the participant specifically indicated they were teaching through inquiry. One of the observations consisted of observing the participant for two class periods in which they taught the same lesson to two different groups of students. The purpose of this back-to-back observation was to see how the participant implemented inquiry across classes and what types of interactions were present during this type of lesson. The second observation included only one class period of inquiry instruction. Due to scheduling conflicts, Karen was only observed for the back-to-back observation.

Field notes of each observation included details about the interactions between the participant and student, interactions between student and student, evidence of engagement in the activity, and the types of scientific practices (e.g. planning investigations, engaging in argumentation) incorporated into the lessons.

Informal interviews. Each participant responded to informal interview questions following each inquiry observation. This interview lasted between ten minutes and thirty minutes depending on the participant. These interviews sought to understand the participants' meaning of the implementation of their inquiry instruction. The main topics of the interview included the overall objectives for the lesson, the participants' perception of the lesson success, the origin of the lesson idea, and the participant's identification of the level of inquiry for the activity (Appendix D).

Artifacts. For each observation, the participant provided handouts and worksheets given to the students. The purpose of collecting these handouts was to see how the participant structured the activity, how the lesson aligned with the objectives, and how participant's identification of the levels aligned with their instruction. The participant also provided artifacts and other information pertaining to activities prior to and following the observed class period.

Data Analysis

The researchers employed a constant comparative approach to analyze the data (Boeije, 2002; Glaser, 1965). In a constant comparative approach the researcher develops categories grounded in the literature as well as the data. Each category contains confirming and non-confirming data, resulting in a range of data describing the category. Further, the data is gathered and constantly compared to previous data to determine any new factors which may influence the category. The process ceases when the new data does not provide any additional information about the category.

In the present study, initial categories about participants' understanding of inquiry and the levels of inquiry stemmed from the conceptual framework. Using participant data about their understanding helped develop a range of properties for the category. For example, all participants' understanding of inquiry before the VISTA STP contained some components of the literature definition; however, after the STP more characteristics of inquiry were present in their definition. Some participant understandings of inquiry also contained details not aligned with the VISTA definition of inquiry.

No research addresses teacher beliefs on ELF; thus, the categories pertaining to teacher beliefs developed out of the data. The categories and range of data formed as a result of interview, survey, and observational data. For example, teacher beliefs about the levels of inquiry appropriate for high school science arose from the data. The data collection and analysis concluded when multiple data sources continued to provide iterative data representative of this category.

Scientific practices grounded the category related to teacher practices of inquiry and ELF. Observational data indicated different teachers emphasized different scientific practices, providing the range of data describing this category. Social constructivsm also helped explain differences in the implementation of scientific practices for each teacher. For example, the type of interaction (i.e. student-student or student-teacher) observed in each participant's classroom related to the types of scientific practices observed. Further, the prevalence of one type of interaction over another tended to be characterized by students engaging in certain scientific practices.

Results

Based upon participants' responses to pre and post survey questions, the data indicated all participants understanding of inquiry improved following the VISTA STP. Follow up interviews showed all participants had partially aligned understandings of inquiry levels following the VISTA STP. George had the most aligned and sustained understanding of ELF. He was able to correctly identify and modify different inquiry scenarios during a follow up interview months after the VISTA STP instruction on inquiry levels. Interview and observational data indicated teacher beliefs about inquiry either facilitated or impeded the implementation of inquiry in the classroom. The perceptions of barriers may have influenced each participant's practice of inquiry; George did not perceive as many barriers to implementing inquiry as Karen and Chris. All three participants held similar beliefs about ELF, indicating structured inquiry was the most appropriate method of structuring inquiry in their classroom. Finally, each participant's implementation of ELF varied as characterized by the types of interactions and scientific practices evidenced during an inquiry-based observation. George's students engaged in more student-student interactions and more scientific practices than either Karen or Chris's students. These differences in implementation of ELF may be influenced by the participants understanding and/or beliefs about inquiry and ELF.

Participant knowledge of inquiry and levels of inquiry

Inquiry understanding. Pre-Perceptions Surveys indicated participants had incomplete understandings of inquiry and were unaware of how to structure inquiry prior to the VISTA STP. Post-Perceptions Surveys indicated participants understandings of inquiry became more aligned with the definition of inquiry (Table 2). In follow up interviews participants also used inquiry levels to define inquiry-based instruction.

Table 2.

Teachers' definitions of inquiry before and after the professional development (Perceptions Surveys).

	Before VISTA PD	After VISTA PD
Karen	Inquiry learning has students explore open ended question to using scientific method to learn new skills.	Students learning by exploring a question. Inquiry can be open or closed or somewhere in between. Student use scientific method to find answer to their question.
Chris	It draws on the curiosity of students to learn about unknown things. For the teacher, this means taking a very hands-off approach and letting students guide the learning process. Because of having to aim towards certain content and standards, it is difficult for a teacher to let students completely guide their activities.	Inquiry draws on the curiosity and problem solving skills of the students. The most open inquiry allows the student to decide the question to investigate as well as how to go about the investigation. In the classroom, a more closed degree of inquiry is generally used because of how much time and effort it takes to set up an inquiry-based activity. In these more closed inquiries, students are given a question, but they have to design and conduct the experiment as well as collect and analyze data.
George	The students are the ones who are inquiring about something that they are interested.	Have a problem or a phenomenon that is looked at through the scope of the scientific method to discover the truths about that topic.

Both Karen and Chris initially believed inquiry was solely open inquiry. Chris also agreed and implied this is a barrier to implementing inquiry. However, after learning about levels of inquiry through the VISTA STP, both Karen and Chris understood inquiry can be open or more structured. Chris also defined guided inquiry in his post-survey response and includes some of the key scientific practices in his definition. He perceived guided inquiry as a more practical approach to implementing inquiry in the classroom than open inquiry. While George's definition of inquiry was general before and after the VISTA STP, he discussed the need to limit the "scope" of inquiry in the classroom, which implied he better understood the need to structure inquiry. The use of "the scientific method" to describe inquiry may indicate he understood inquiry as primarily an experimental method of gaining knowledge. However, one of George's inquiry-based lessons was non-experimental in nature, signifying he understood "the scientific method" can be both observational and experimental.

All three participants indicated the VISTA STP included explicit instruction on how to incorporate inquiry into science instruction. As Chris indicated in his initial interview:

> We did a whole lot of stuff in the first couple of weeks of the class about defining what different levels of inquiry are appropriate for different ages and for different subject areas of science and different materials that we have to use. I'd say there was quite a bit of explicit definition there. (Teacher Perceptions Follow-up interview)

Chris readily acknowledged the explicit instruction of inquiry and ELF during the STP, which was aligned with his understanding of inquiry. Karen also indicated the professional development provided opportunities for the participants to develop and implement inquiry. Karen indicated more specifically how inquiry was explicitly taught during the STP:

> Inquiry instruction for me was a new topic. So this was a really great class for me to have before I had started my semester. It was interesting to try and design labs and activities for my students –that was one of the things she [the instructor] challenged us with – that were inquiry based. It caused me to actually think about how do you move them through some of our early objectives, particularly when we spend the beginning of the year on safety and a lot of the time on math. And we were actually tasked with doing an inquiry activity that we taught in the classroom. So to me actually having her challenge us with that and have us teach it to each other before we took it into the classroom was a great opportunity to experience that. (Teacher Perceptions Follow-up interview)

The additional opportunities to actively be involved in the practice of inquiry helped Karen better understand inquiry as an instructional tool.

Understanding of the Enquiry Levels Framework. Follow up interviews assessed each participant's explicit understanding of ELF. During the Perceptions Follow-up interview Chris discusses how he defines the levels of inquiry:

> Completely closed inquiry, level 0 they called it, where there's really no inquiry going on. Everything's given to the students, everything's told to the student, there's a certain definite answer that they're supposed to get. That's the typical cookie cutter lab where you know if you didn't get this answer then you did it wrong. And then there were, I believe, levels 1, 2, and 3 after that (Teacher Perceptions Follow-up interview)

Chris went on to define level 3 as "completely open inquiry", which he defined as students coming up with the question and experimental design. At inquiry levels 1 and 2 Chris indicated the teacher provides the question and tells the students "You need to come up with the experimental design" and continued by stating "Or maybe the other way around, 'Here's your procedure and you come up with how you're going to collect your data and how you're going to record and analyze your data'" (Teacher Perceptions Follow-up interview). Chris labeled the levels as 0,1,2 and 3 instead of 1,2,3, and 4, indicating he did not see confirmatory inquiry as inquiry. This aligns with Herron's original levels of inquiry but not ELF. Despite the misalignment, Chris still accurately described the support provided during closed and open inquiry. He was not clear about delineating levels 1 and 2 from each other; however, his identification of providing the procedure or not reflects the main difference between guided and structured inquiry.

George's definitions of the levels of inquiry were more general than Chris's but aligned with ELF rather than Herron's original levels. In the Teacher Inquiry Interview he specified that in the first level the teacher is "walking the students step by step through a process". George identified level two as where the teacher is "Still giving them maybe a rough outline of what you want them to do but being much more hands off' and identified the third level as "just giving them basically a list of materials and a problem...writing a procedure and a hypothesis and what the steps are to go through to come up with the answer." He concluded by indicating "Level four is basically a blank canvas...absolutely no teacher help, all guided by students" (Teacher Inquiry Interview). Clearly, George understood the support provided by the teacher decreased through the levels of inquiry. His definition of the first level of inquiry did not appear to detail the support provided by the teacher. However, when comparing his definition of level 1 and level 2, George recognized the need for providing students a procedure. Similar to Chris, George understood how the procedure can be provided or taken away by the teacher.

On the other hand, in Karen's definition of inquiry levels she talked about structuring inquiry in terms of providing or taking away data tables for students:

> I take turns taking things away. I take the cookbook lab the school uses or we've used in the department for quite some time but the materials are available. And I may not provide the procedure. Or I may not provide the data table. (Teacher Perceptions Follow- up Interview)

Karen discussed how she takes away the procedure from her students, which is an explicit modification method emphasized in ELF, but taking away the data table is not an aspect of structuring using the levels. This was not completely aligned with ELF. Nonetheless, Karen uses a variety of tools to modify lessons to make them more student-centered.

In addition, the participants had varied views of the levels when asked about different scenarios during the inquiry interview. Table 3 summarizes the participants' answers to whether a scenario was inquiry and if so, what level. The participants clearly identified whether a scenario was inquiry, as seen in their responses to scenario 2. This data supports the claim that all 3 participants had an aligned understanding of inquiry following the STP. George correctly identified each scenario according to ELF, and he was also able to give concrete examples of how to modify each scenario to provide more or less support for the students. In contrast to George, Chris' ability to define the levels continued to align more with Herron's levels than ELF. He confidently defined Herron's levels of inquiry in his Teacher Perceptions Follow-up interview immediately after the end of the methods course, but he struggled with identifying the inquiry scenarios on the Teacher Inquiry Interview a few months later. On the Teacher Inquiry Interview Chris grappled with whether the last scenario was inquiry, and he also struggled with ways to modify the scenarios, specifically scenario 3 involving computer simulations. Karen also struggled to define the scenarios, and her modifications of each scenario included changing the "procedure, hypothesis or data table" (Teacher Inquiry interview). Similar to Karen's follow up interview, while altering the hypothesis and data table were ways to modify inquiry activities, these methods did not align with the modifications using ELF.

Table 3

Comparison of teacher answers to the levels of inquiry for each scenario

Scenario (Correct Answer)	**Scenario 1 (Guided)**	**Scenario 2 (Not inquiry)**	**Scenario 3 (Structured)**	**Scenario 4 (Structured)**
Karen	Open	Not inquiry	Middle level	No or very low
George	Guided	Not inquiry	Structured	Structured
Chris	Extremely open	Not inquiry	Fairly guided	Inquiry? Extremely guided

Note: Scenario details are referenced in APPENDIX C. Correct answers are based upon ELF.

Teacher beliefs about inquiry and Enquiry Levels Framework

The researchers inductively developed an understanding of participants' beliefs about inquiry from observational data and informal interviews. These beliefs mainly centered on participants' beliefs about students' ability to perform inquiry. Participants either perceived students as facilitators or barriers to implementing inquiry in their classroom. Furthermore, participants discussed factors outside of their classrooms such as high stakes tests which they perceived as barriers to inquiry.

Students as facilitators. George's beliefs about students' doing inquiry differed from Chris and Karen's beliefs. For example, during one observation, George's physics students gathered data relating height and fall time of an object in order to determine the gravitational constant. He took the students outside to the football bleachers and instructed students to drop an object from three different heights and conduct three trials at each height. They were given a data table to enter their data and a general procedure, making this a structured inquiry lab. Students had to determine what heights to conduct their trials and how to collect the data. With some team work, all groups collected the necessary data with little guidance from George. He encouraged students to work with each other instead of relying on him in order to figure out what to do.

This type of self-organization and emphasis on student-student interactions was evident in both observed inquiry-based lessons George taught. When interacting with students George focused on getting students to think about what they were doing rather than students relying on him to solve the groups problem. During this lab George monitored students and asked one group "Are you guys okay with what is going on?" (Live Observation 2) When a student in the group responds "sort of", George probes the student by asking what they mean. Instead of trying to provide answers George is getting the students to think about what their problem is so they can solve it on their own. Clearly George's belief about his role as the teacher and his beliefs about the abilities of his students' translated to a student-centered approach.

Students as barriers. In contrast, Chris and Karen's beliefs about inquiry were much more infused with perceived barriers to using inquiry-based approaches in their classrooms. Karen's view of inquiry conveyed her perception that the students themselves can act as barriers to implementing inquiry:

> Students struggled with these [structured inquiry] labs at the beginning of the year, they just wanted to know what they had to learn and memorize it. I want them to understand. They have gotten the hang of it now, but they would have [raised a mutiny during] this lab at the beginning of the year. Doing inquiry changed the rules of the game on them mid-game. We should start doing inquiry in middle school so students don't come in like this. (Live observation 1 interview)

In her response, Karen indicated how students come in to high school just wanting the teacher to provide the correct answer. By introducing inquiry to these students in high school, teachers are asking students to change the way they have always learned, and she perceived this as a real challenge to overcome. In Karen's classroom students' active engagement was much different than what was observed in George's classroom. The majority of student-teacher interactions in Karen's class centered on procedural conversations. When the student-teacher interactions involved content-based conversation, Karen tended to provide students answers rather than probing and discussing. This aligns with her beliefs about students being barriers to an inquiry-based approach.

Chris's beliefs about his students' ability to perform inquiry also reflected his perceptions that students can act as barriers to inquiry instruction. After the first inquiry-based observation, Chris reflected on what went well and did not go well during the lesson. He responded "behavior management is always a struggle" (Live observation 1 interview). When asked about the level of inquiry, he also stated "very limited inquiry, but it's typical of what we normally do, I didn't change it" (Live observation 1 interview). Similar to Karen, the dominate interactions in Chris's classroom were student-teacher interactions; however, these interactions focused more on behavior than procedure. For example, when going outside to collect data for an inquiry-based activity Chris continually interacted with students about not running or making sure they were paying enough attention to write down the correct values. The focus of his interactions was not on the meaning of the data. When students interacted with each other they tended to be more social interactions. Thus, concerns with student behavior appeared to limit the types of interactions students engage in and how Chris implements inquiry in his biology classroom.

External factors as barriers. In addition to students as barriers, Chris and Karen also perceived high-stakes testing as an external barrier to implementing inquiry. These high stakes tests, called standards of learning (SOLs), are the most dominant state-wide policy that public school science teachers deal with. These standards-based high-stakes tests occur in Biology and Chemistry classes, which Karen and Chris teach. In these classes, administrators, teachers, and even students tend to focus on high-stakes testing over the course of the year. Karen communicated her conflict between inquiry and high-stakes testing:

> We take SOL [tests] very early – this year my understanding is the first week in May, so I have a whole six weeks [after the test]. So I am doing a lot of inquiry labs at the end of the year. With curriculum the way it is I'm having to [teach] certain things. Although I do inquiry, I don't do entire open inquiry. I do more guided inquiry during the school year. I am so looking forward to the end of the school year and that six week period where I can really give students open inquiry time. They'll have foundation in chemistry concepts and they can then do more inquiry based. (Teacher Perceptions Follow-up interview)

Due to the impending SOL tests, Karen did not feel able to incorporate open-ended inquiry into her curriculum until after the testing window. Karen also believed students should have a foundation in the content before performing open inquiry.

Beliefs about the Enquiry Levels Framework. When specifically assessing the participants' beliefs about ELF, there was a clear consensus among the three participants. They all believed the levels were a simple, practical method of implementing inquiry in their classrooms, and all participants believed structured and guided inquiry were the best levels to implement at the high school level.

When asked what he would implement from the methods course in the coming year, Chris indicated he would implement the levels of inquiry as a method of modifying his activities:

> I think I'm going to keep sticking with the inquiry based lab activities and how do you take a cookie cutter lab and make it into something where the students have to think with their own curiosity and make it an inquiry based lab with different levels. (Teacher Perceptions Follow-up interview)

Chris saw levels of inquiry as useful because he did not have to make brand new activities. He was able to use what he already had and could make small modifications in order to make it inquiry-based. Karen also perceived the levels of inquiry as a practical way to implement more inquiry-based activities into her classroom. During an informal interview following the first live observation, Karen indicated she "added the questions to the lab to make it more inquiry and put it at the beginning of the unit" (Live Observation 1 interview). By putting the activity at the beginning of the units Karen easily converted a confirmatory activity to a structured activity. She also indicated that adding a research question and moving the order of instruction to come after an investigation were simple changes she used to make an activity more inquiry-based.

All three participants held similar beliefs about which levels of inquiry were most appropriate for high school students. Specifically, they all believed structured and guided inquiry, rather than open or confirmatory inquiry, best suited students' abilities. When asked about levels of inquiry George taught throughout the year, he responded:

> I probably stick right about level 2 throughout the year. And that's mostly because the topic's changing, so I don't feel it's appropriate to change the level of how I am explaining a new topic because first year physics is hard enough as it is. So I just don't want them to feel like they're just thrown in and sink or swim (Teacher Inquiry Interview).

George believed structured inquiry was most appropriate for his students because the physics content is difficult. He appeared to believe he should emphasize content rather than process skills during inquiry instruction.

Chris also emphasized specific levels of inquiry and indicated that during the methods course he, along with other teachers, agreed on the most appropriate level of inquiry:

> At our round table discussions we kind of came up with the idea that level 1 and level 2 are pretty much are where are kids are at in terms of high schoolers and trying to use inquiry (Follow up Interview).

For Chris, level 1 and level 2 are structured and guided inquiry, which aligned with George's belief on what levels of inquiry should be used with high school students. However the foundation of Chris's beliefs about the most appropriate levels stem from different beliefs about inquiry in general. Contrary to George's concern about students' academic ability, Chris was more concerned about behavior management.

Inquiry instruction

For each observation where George, Karen, and Chris indicated they were using an inquiry-based approach, all participants indeed implemented inquiry in their classroom according to the simplified definition of inquiry. In other words, there was alignment between what they reported they were doing and what they were actually doing. In each observation the students answered a research question through the analysis of data, and all participants implemented either confirmatory or structured inquiry with their students. Even though the inquiry-based activities for all participants were structured or confirmatory, there were still differences in the types of interactions observed. In George's classroom there was more evidence of interactions associated with conceptual understanding and process skills, while the interactions in Karen and Chris's classrooms focused more on procedural and behavioral issues. Further, student-student interactions predominated in George's classroom, whereas student-teacher interactions were present more often in Karen and Chris's classrooms. Those student-student interactions present in Karen and Chris's classroom differed from the student-student interactions observed during George's classroom.

There were also differences in the scientific practices implemented during each participant's inquiry-based activity. During the inquiry-based observations George implemented more scientific practices than either Karen or Chris. However, how each teacher provided support for these practices varied. In George's classroom students analyzed and interpreted data in their individual groups while Chris modeled the process of analyzing data for students.

Types of Interactions. After learning about static electricity, George's students were given a procedure for manipulating tape and made observations of how tape attracts and repels different objects. The student-teacher interactions dominated the beginning of the inquiry activity and focused on the procedure. George helped students understand exactly how to stick the tape to each other and the table in order to gather observational data. As the activity progressed George purposefully decreased the number of student-teacher interactions by monitoring student progress from afar. This forced students to interact with each other about the concepts instead of asking George for the answers to the activity. As students made observations, they automatically connected their observations to concepts about them movement of electrons. The ability to interact with other students allowed students to connect their current understanding of static electricity with the new observational evidence, rather than passively accepting an explanation given by George.

In contrast to George's class, the interactions and focus during Karen's inquiry activity were much different. During a properties of gases lab, Karen had students gathering data to characterize behaviors of gases. Similar to George, the student-teacher interactions were initially procedural; however, throughout the activity Karen continued to interact with her students about content when George did not. The student-student interactions in Karen's classroom also tended to be procedural which limited the students' active engagement beyond gathering data. When students discussed content with each other there were clear misconceptions which Karen did not address. For example, students observed the increase in volume of a balloon attached to a Erlenmeyer when heated. Students explained this phenomenon was a result of an increased number of gas particles, when in fact no additional particles can enter the Erlenmeyer. These ineffective student-student interactions limited students' accurate knowledge acquisition through this inquiry-based activity.

Like Karen, Chris's classroom interactions were predominately student-teacher interactions. During a carrying capacity activity students went outside to simulate how many bears can be sustained in an environment over multiple seasons. Chris's only interaction with his students focused on the procedure or behavioral issues. For example, Chris continually reminded students to only pick up one piece of food at a time during the activity, asked students whether the correctly recorded the correct number, and kept students from arguing while waiting their turn. The only student-student interactions observed during this activity were social in nature and never about the content or concepts being taught.

Scientific Practices. The number of scientific practices incorporated into inquiry-based activities differed for each participant (Table 4). Karen's students carried out investigations, analyzed and interpreted data, and constructed explanations. Chris's carried out investigations, analyzed and interpreted data, and used mathematics and computational thinking. George's students asked questions, developed and used models, planned and carried out investigations, analyzed and interpreted data, used mathematics and computational thinking, constructed explanations, engaged in argumentation, and obtained, evaluated, and communicated their results. Furthermore, even though all participants incorporated carrying out an investigation and analyzing data into inquiry activities, the way each scientific practice was emphasized differed.

Table 4. Overview of inquiry observations

	Karen	**Chris**		**George**	
Scientific Practices	*Properties of Gases (structured)*	*Carrying Capacity (structured)*	*Experimental Method (structured)*	*Static Electricity (confirmatory)*	*Gravitational Constant (structured)*
Asking questions					x
Developing and using models				x	
Planning and carrying out investigations	x	x	x	x	x
Analyzing and interpreting data	x	x	x	x	x
Using mathematics and computational thinking		x			x
Constructing explanations	x			x	
Engaging in argument from evidence				x	
Obtaining, evaluating, and communicating results				x	

Note: Only during George's guided inquiry lab did students both plan and carry out an investigation. All participants implemented their inquiry-based activity during one block period with the exception of George's guided inquiry lab.

The following classroom observation illustrates how George's students participated in multiple scientific practices during a confirmatory inquiry activity about static electricity.

> *After finishing the homework the teacher gives directions about materials which are in the front of the room. For this inquiry activity students have a handout instructing them to take pieces of tape, stick them to the desk or to each other, make observations, and provide explanations of what is happening. To differentiate the sides of the tape, students are instructed to cut one side of each piece so it has a pointy shape, leaving the other side flat, or uncut. In the beginning the students focus more on these procedural issues than understanding the concepts/content of the lab. The teacher interacts with the students mostly about the procedure as they work. After a few minutes the students begin to understand the instructions. Students in one group, which consist of two males and one female, discuss with each other what is happening. They debate among themselves whether a piece of paper that is attracted to the tape has a positive or neutral charge. John attempts to explain the attraction: "protons and neutrons are in the nucleus so they can't transfer, therefore it must be electrons transferring."*

> *Kyle tended to dominate the discussion but was not always correct in his explanations. John was less dominating but appeared to have good explanations. The last question of the activity asked students for another name for the "flat and pointy" sides of the tape. Kyle thinks the question refers to synonyms so he answers "dull and sharp." John says, "I think it's positive and negative." As John and Kyle discuss this, Suzie takes two pieces of tape and places them close to one another to see what happens. John sees her doing this and says, "Try the flat with the pointy, they attract, see?" Suzie sees that, then tries the pointy with another point and they repel. The group then collectively decides positive and negative are what they are going to put down for the answer. (Live observation 1)*

This excerpt illuminates how students were engaged in argument from evidence, and obtained, evaluated and communicated results. This group of students seemed to have multiple explanations for their observation of the tape, and the student who could best justify their explanation, or provide the most evidence, was the explanation the group agreed on. Based on John's answer, Suzie then gathered more observational data in order to evaluate John's explanation. Throughout the observation all three students were effectively communicating and arguing with each other about the phenomenon. Students also created conceptual models of the process of static electricity during a whole group discussion at the end of the activity. The students drew and explain the movement of electrons and how current relates to the movement of electrons.

George's students participated in a structured inquiry activity for determining the gravitation constant, which by the ELF definition signifies the teacher supplied the research question. Yet at the end of the inquiry-based activity George provided students the opportunity to come up with their own research question to build upon this experiment. Between the static electricity activity and the gravitational constant activity George's students engaged in all scientific practices.

Students in Karen's properties of gases activity were engaged in the scientific practices of carrying out investigations, analyzing and interpreting data, and constructing explanations. Karen provided the students a handout where they recorded their different observations about gases from different stations around the room. Once students gathered their observational data they returned to their seats to analyze their data in order to answer questions about how gases behave. Karen's students also engaged in constructing explanations; however before beginning the activity she asked her students "Where will we get the explanations for the activity? Use your notes and textbook. You don't have to do the explaining at the stations" (Live observation 1). Even though students are engaged in multiple scientific practices, the way Karen has students analyze data and construct explanation is clearly different than George's implementation of the same scientific practices.

Like Karen, Chris also focused on students carrying out investigations, analyzing and interpreting data, and using mathematics and computational thinking. After students gathered data outside for the carrying capacity, Chris modeled with the whole class how to calculate carrying capacity from their data. Students participated in mathematical thinking for this activity, but it was clearly teacher-led and students were given little opportunity to practice this thinking on their own. Once Chris finished modeling, he told students, "You have three more questions to do. What we've talked about should help you figure these out. We have two minutes before the end of class, if you don't finish it in class, finish it for homework" (Live Observation 1). Students analyzed their data in response to teacher proposed questions on a worksheet, which they were able to complete within the two minutes. The limited time frame prevented students from fully engaging in analyzing data or using computational thinking.

In summary, both Chris and Karen emphasized data collection and data analysis as well as student-teacher interactions, while George incorporated a range of scientific practices along with more opportunities for student-student interactions. These differences in implementation may be influenced by each participant's understanding of inquiry and beliefs about inquiry.

Relationship between knowledge, beliefs, and practice

While the 3 participants' understanding of inquiry improved and aligned with the formal definition of inquiry after the VISTA STP, there were still some variations among teachers' specific understanding of ELF. George had the most accurate understanding of ELF as evidenced by his ability to identify and modify different inquiry scenarios. He was also able to incorporate the most scientific practices in his inquiry instruction. However, for Chris and Karen, their practices of inquiry did not align with their understanding of inquiry. This may be explained by their understanding of the definition of inquiry levels. The mis-alignment of understanding and practice for Chris was evident in his discussion of inquiry and its relation to teaching using inquiry:

> I've always thought of inquiry as involving a little bit of curiosity, want to know what's going on. But in terms of designing lessons for science inquiry, I would say it's more an experiment or an investigation (Inquiry interview)

The idea that curiosity and motivation characterized scientific inquiry, according to Chris, disappeared as he explained inquiry teaching. The translation of scientific inquiry into his classroom may be one reason he limited opportunities for students to engage with each other beyond data collection.

Both Karen and Chris perceived students as barriers to implementing inquiry and believed guided and structured inquiry were most appropriate for their classrooms. In combination, these beliefs may have contributed to the limited number of scientific practices and focus on student-teacher interactions observed in Karen and Chris's classrooms. On the other hand, George's student-centered approach to inquiry aligned with the presence of student-student interactions in his classroom. At the same time, his belief that structured and guided inquiry were most appropriate for high school students conflicted with his use of confirmatory and structured inquiry levels. These contradicting factors may be the reason more scientific practices were evident in his inquiry-based teaching.

In summary, the results indicated all participants gained a better understanding of inquiry after the VISTA STP and also understood inquiry levels as an instructional method of structuring inquiry in the classroom. While participants' understandings appeared similar, their beliefs about inquiry were most varied. Both Chris and Karen perceived external barriers to inquiry, including high-stakes testing and students' abilities, while George perceived no barriers to inquiry. Further, George also differed from Chris and Karen in his belief about student abilities during inquiry-based activities. However, all participants held similar beliefs about levels of inquiry. They believed structured and guided inquiry were most appropriate for high school students. While all participants implemented confirmatory and structured inquiry, observations indicated their implementation differed in the types of student interactions and the number of scientific practices incorporated into the inquiry activity. Chris and Karen incorporated a few scientific practices while George was able to incorporate all scientific practices. George also had fewer student-teacher interactions and more student-student interactions than Chris and Karen.

The difference in implementation inquiry levels may be influenced by the participants understanding and beliefs about inquiry and ELF.

Discussion

This study characterized 3 participants' changes in their conceptions of inquiry and their implementation of ELF after participation in the VISTA STP. Specifically, participants' understandings of inquiry improved after the professional development. They understood the different scientific practices associated with inquiry as well as the different levels of inquiry. However, their inquiry practices did not always align with these improved understandings. All participants incorporated either confirmatory and/or structured inquiry activities but emphasized different scientific practices and different types of student interactions to engage students in the investigation. These differences in implementation of confirmatory and structured inquiry may have provided students different experiences gaining scientific knowledge

Alignment of conceptions and practice

These findings both support and conflict with those of Wee et al. (2007), which indicated that a first year secondary science teacher's practices were not aligned with their understanding of inquiry. The teacher in that study was able to develop inquiry-based lessons incorporating scientific practices such as "high levels of evidence as priority, analyzing data, and justifying explanations" (p.80), yet these scientific practices did not translate into the classroom. These findings align with Chris and Karen's conceptions and implementation of inquiry. They both exhibited a deeper understanding of inquiry-based practices through their survey and interview responses and also failed to consistently translate their understanding of inquiry into the classroom. Conversely, George's deeper understanding of inquiry appeared to translate into the classroom through students' ability to communicate results and justify explanations. Therefore, other factors such as perceived barriers may influence the practice of inquiry.

Differences in Enquiry Levels Framework implementation

The two main barriers which influenced participants' implementation of inquiry in the present study included student abilities and external barriers. Using a social constructivist lens helped better understand how student abilities influenced participant's understanding of inquiry. In social constructivism, social interactions influence the process of gaining knowledge. The predominant student-teacher interactions in Karen and Chris's classroom were procedural or behavior management-based. Karen believed her students struggled with inquiry-based activities because they had not been previously exposed to inquiry. Chris believed the behavior of his students may not be conducive to inquiry-based practices; thus his implementation of inquiry emphasized student-teacher interactions and focused on data collection and analysis. These types of interactions may have influenced Karen and Chris's beliefs about student as barriers to inquiry-based instruction.

In contrast, George believed students struggled with the physics content, but he believed in a very student-centered approach to inquiry. George also interacted with students about procedures, but he also interacted with students about their conceptual understanding through his use of guiding questions. His inquiry-based activities were very structured and also incorporated student interactions which allowed for students to collect and analyze data as well as explain, communicate and argue results. The difference in the types of interactions George experienced with his students may be one explanation for why he did not perceive students as barriers to inquiry. These results support Kazempour (2009), who found that teachers' belief of student ability influenced their implementation of inquiry in the classroom. Thus, the interactions the teachers experienced with their students influenced their beliefs and consequently their practice.

The predominant external barrier teachers face when attempting to incorporate inquiry into the classroom is high-stakes testing (Anderson, 2002; Keys & Bryan, 2001). Both Karen and Chris taught classes which had end of year standards that appeared to be emphasized within each of their schools, but George did not. The focus on these high-stakes, multiple choice, content-based tests appeared to compel Karen and Chris to rush through inquiry-based activities. This may be another reason why these two participants encouraged student-teacher interactions and only incorporated specific scientific practices into their structured inquiry activities.

One alternative explanation for the differences in inquiry practices may be related to the teachers' varied science and teaching backgrounds. For example, George held a physics degree, worked as a civil engineer prior to teaching, and was in his second year of teaching upon entering the VISTA STP. He was clearly more comfortable than Chris and Karen with open-ended questions and facilitating student-student interactions during inquiry-based activities, possibly due to his content knowledge. Conversely, Chris had a background in education, not biology and Karen had only substitute teaching experience prior to becoming a chemistry teacher. In response to students' specific questions about content, Chris often stated he did not know the answer, suggesting his breadth of content knowledge did not extend far beyond the curriculum he was teaching. During inquiry activities, student-teacher interactions in Chris and Karen's classes typically focused on the procedure and gathering of data. Due to the possibility of multiple answers, Chris and Karen may not have been comfortable having students communicate and explain their results from an inquiry activity and therefore did not include these characteristics of inquiry. However, this is not the most likely conclusion when situated in the context of similar studies of beliefs and practices (e.g. Kazempour, 2009; Lotter et al., 2006; Van Hook et al., 2009).

Students and Enquiry Levels Framework implementation

Social constructivism may also help us understand how these differences in inquiry implementation influence student's active learning of science. According to social constructivism, both active learning and social interactions are essential for gaining knowledge. In a quasi-experimental study by Blanchard et al. (2010), students completing guided inquiry labs and verification labs were assessed on their understanding of science concepts. Classrooms were also observed and analyzed using the RTOP. The researchers concluded that student scores were higher in a guided inquiry classroom with a high RTOP score. Students in a guided inquiry classroom with a low RTOP score performed significantly worse than students in a traditional classroom. While not explicitly using a constructivist framework, the RTOP instrument assessed for student-teacher relationships and interactions. Therefore Blanchard et al. (2010) may imply that the interactions within a classroom may influence student outcomes.

The present study did not measure student outcomes; however, we can infer how students may be gaining knowledge differently based upon the types of interactions and active learning evidenced in the observations. Evidence of active learning for inquiry-based activities can be qualified by the types of scientific practices in which the students engaged. Since both Karen and Chris's inquiry-based activities engaged students in fewer scientific practices than George's inquiry-based activities, it is possible that students in George's classroom were gaining more scientific knowledge. This conclusion is supported by observational data which indicated Karen's clearly had misconceptions about gases which were not addressed. Misconceptions were not evidenced in George's classroom.

As indicated above, the types of interactions also differed between participant's inquiry-based activities, which may also be an indicator of differences in student learning. The interactions observed in Chis and Karen's classroom clearly did not focus on gaining a conceptual understanding of the concepts related to the inquiry-based activity. Conversely the interactions in George's inquiry activities incorporated opportunities for conceptual conversations. These conceptual conversations occurred with George as a facilitator, but more often solely between students. In social constructivism gaining of knowledge occurs when a more knowledgeable person interacts with a less knowledgeable person. Typically this occurs between a teacher and student; however, in George's classroom the social interactions between students provided more opportunities for knowledge acquisition. In a study by Naylor, Keogh, & Downing (2007), observational data indicate that argumentation between elementary students is possible in the absence of the teacher. If student-student argumentation is possible in the elementary grades, one conclusion from this study may be that typical student-teacher interactions observed with Karen and Chris may not provide students' as many opportunities for conceptual understanding as effective student-student interactions observed in George's classroom.

The myth of open inquiry

Additionally, while some researchers assert that open inquiry is the best approach to students doing inquiry (NRC, 2000; Settlage, 2007); the results of the present study suggest that with effective support from a teacher such as George, implementing inquiry using confirmatory and structured inquiry levels may provide students opportunities to develop all scientific practices and gain scientific knowledge. George's type of implementation of the levels of inquiry also contradicts a study of two physics teachers' inquiry practice (Dudu & Vhrumuku, 2012). The researchers characterized inquiry according to levels of inquiry, but also delineated inquiry into open and closed inquiry. They defined closed inquiry as "the teacher asks learners to follow step-by-step instructions; answer specific questions; be passive recipients of information; and use teacher and textbook explanations for observed phenomena" (Dudu &Vhrumuku, 2012, p. 580). Results indicated one physics teacher implemented "closed" inquiry practices while the other teacher implemented more "open" inquiry practices. However, the definition of "closed" and "open" inquiry, according to Dudu & Vhrumuku (2012) conflates structuring of inquiry and inquiry practices. Dudu & Vhrumuku make the assumption that when the teacher provides a step-by-step procedure, students are automatically passive recipients of information; however, the present study indicates otherwise. In George's classroom students are clearly involved in confirmatory and structured inquiry while actively participating in the scientific practices of argumentation and communication of results. Therefore, the results from the present study contradict the research of Dudu & Vhrumuku (2012). In fact, so-called closed inquiry-based activities such as confirmatory inquiry may provide opportunities for students to actively be involved in explaining and communicating results.

Implications

The results of the present study can inform the design of professional development to support teachers' use of ELF to structure inquiry instruction. Professional developers should consider including teaching about ELF to support integration of science practices into instruction. Yet only one of the three teachers in this study had student-centered beliefs about inquiry, reflecting his implementation of more scientific practices within confirmatory and structured inquiry. This suggests teacher beliefs are difficult to change and thus a conceptual change model may be an appropriate method of changing teacher beliefs to align with inquiry-based practices. Inquiry-based research focuses on studying how conceptual change is used in practice, as reviewed in Keys (2000). To our knowledge no research examines the role of conceptual change in an inquiry-based professional development model.

While the small sample size of the present study limits the transferability of the results to other secondary science teachers, future studies may examine how a conceptual change model used in an inquiry-based professional development influences secondary science teachers' beliefs about inquiry and ELF. Additionally, research indicates that teachers' conceptions of inquiry do not typically emphasize evaluation or communication of results in inquiry-based instruction (Atar, 2011; Kim, Tan, & Talaue, 2013). Thus, future research should focus on teachers who incorporate these scientific practices into inquiry investigations in an effort to understand how teachers can effectively use student-student interactions to engage students in evaluating and communicating their findings during confirmatory and structured inquiry.

Clearly, this study suggests a secondary science teacher in their first years of teaching can not only effectively implement inquiry activities incorporating all scientific practices but also implement these practices through confirmatory and structured levels of inquiry. Providing first year teachers the opportunity to learn about ELF may help improve inquiry-based teaching for secondary science teachers.

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APPENDIX A

Relevant Open Ended questions from Perceptions- Survey

Pre and Post Perceptions Survey:

1. Define Problem-based Learning:
2. Define Science inquiry:
3. Define Nature of Science:
4. Describe what teachers and students are doing in a typical lesson/activity that emphasizes PBL:
5. Describe what teachers and students are doing in a typical lesson/activity that emphasizes science inquiry:
6. Describe what teachers and students are doing in a typical lesson/activity that emphasizes nature of science:

Post Perceptions Survey:

7. If you have participated in professional development experiences that addressed topics covered in the VISTA Secondary Teacher Program, how does the VISTA Secondary Teacher Program compare to these previous professional development experiences (if any)?
8. What are the most important content and strategies that you have learned during the VISTA secondary methods course? (Please describe as many as apply
9. How will you use the content, materials, and/or strategies that you learned during the VISTA secondary methods course? (Please describe as many as apply).
10. Describe your interactions with your VISTA coach to this point.

APPENDIX B:

Relevant Questions from Perceptions Follow-Up Interview Protocol

Describe your overall impressions of the VISTA Secondary Teacher Program (STP) course.

1. How were you explicitly exposed to the key definitions of inquiry instruction, problem-based learning, and nature of science instruction?
   a. Do you feel you have a solid understanding of each of these constructs to implement them in your classroom? Why or why not?
   b. How did your participation in VISTA affect your thinking about these instructional approaches?
   c. Do you feel you had adequate opportunities to practice these approaches during the Methods course? Why or why not?
   d. Did the pace/order of the program instruction influence this in any way?
2. Describe your experiences learning about implementing technology to support inquiry-oriented science instruction during the VISTA Secondary Science Methods course.
3. Which components of the VISTA SSM course do you plan to implement in the coming year? In what ways? (give concrete examples).
4. Which components of the VISTA Secondary Science Methods course did you find to be most valuable? Why? What recommendations do you have to improve the course in future years?

APPENDIX C:

Teacher Inquiry Interview

1. Define science inquiry.
   a. Probe: Describe the levels of science inquiry.
2. On the following sheet of paper are four scenarios. Read each scenario and determine whether they are inquiry or not. (For each scenario, the interviewer asks the following questions):
   a. Probe: Does this scenario describe science inquiry? If so, why? If not, why not?
   b. Probe: If participant responds the scenario is inquiry: Which level of inquiry is it? Why?
   c. Probe: If participant responds the scenario is inquiry: How would you modify the activity to make it a different level. What is the inquiry level of the activity as described? Why? Repeat for all 5 scenarios.
3. How often do you incorporate inquiry activities into your teaching?
   a. Probe: Think of a unit in which you do the most inquiry-oriented teaching. What is this topic of this unit? How many lessons are inquiry? What levels of inquiry are the inquiry activities in this unit?
4. Do you try to scaffold the levels across the year?
5. Where do you get your materials/ideas for inquiry instruction?
6. How have you modified your materials/ideas?
7. Describe an inquiry lesson you have taught.
   a. Probe: What level of inquiry do you believe this activity was? Explain.
   b. Probe: What were the primary learning goals of this activity?[2]
   c. Probe: What were the roles of the students and the teacher during this activity?
   d. Probe: How did these roles facilitate the learning goals?
   e. Probe: How did this lesson demonstrate the characteristics of inquiry?
   f. Probe: What aspects of the inquiry activity were effective or ineffective in terms of the goals for the students? Why do you think so?

Scenario Questions

Directions: Read each of the following scenarios and determine whether it is inquiry or not. You will be asked to justify your answers.

1. In a chemistry class, students design an investigation to answer the question: What effect will temperature have on the reaction rate of aluminum foil and hydrochloric acid? The students work in groups pairs to develop a hypothesis and procedure to answer the question. The teacher approves each group's procedure, and the groups perform their experiment to gather data. After they finish collecting data the students analyze their data and develop a conclusion. Each group presents their results to the class.
2. In a biology class, students are given a leaf collection project where they collect and press 30 different leaves. The instructions indicate each leaf must be mounted on a piece of paper and have an identification label. The students combine the pages into a notebook and turn it in to the teacher.
3. In a physics class, students use a computer simulation to determine the relationship between mass and velocity. The teacher gives the students instructions of how to use the program. They are also instructed to use specific masses in order to measure the velocity. After gathering the data from the simulation students analyze the data to determine the relationship between mass and velocity.

4. In an earth science class, students work in groups of three to define and describe the effects of El Nino by using information from the Web. They gather data from the national weather website and regional data websites on El Nino, and with the teachers help analyze the data to find trends. Each group presents their findings on a poster, which are displayed in the hall.

APPENDIX D:
Informal Interview Topics

1. What lessons will you do after the observed lesson today?
2. Overall how did you feel the lesson went?
3. Where did you get the activity from?
4. What level of inquiry do you think this lesson was? Was that what you planned for?