

## ABSTRACT

Title of Document: INFLUENCE OF SUBJECT MATTER  
DISCIPLINE AND SCIENCE CONTENT  
KNOWLEDGE ON NATIONAL BOARD  
CERTIFIED SCIENCE TEACHERS'  
CONCEPTIONS, ENACTMENT, AND  
GOALS FOR INQUIRY.

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The present study investigated differences in the continuing development of National Board Certified Science Teachers' (NBCSTs) conceptions of inquiry across the disciplines of biology, chemistry, earth science, and physics. The central research question of the study was, "*How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*"

A mixed methods approach was used that included an analysis of the National Board portfolio entry, *Active Scientific Inquiry*, for participants (n=48) achieving certification in the 2007 cohort. The portfolio entry provided detailed documentation of teachers' goals and enactment of an inquiry lesson taught in their classroom. Based on

the results from portfolio analysis, participant interviews were conducted with science teachers (n=12) from the 2008 NBCST cohort who represented the science disciplines of biology, chemistry, earth science, and physics. The interviews provided a broader range of contexts to explore teachers' conceptions, enactment, and goals of inquiry. Other factors studied were disciplinary differences in NBCSTs' views of the nature of science, the relation between their science content knowledge and use of inquiry, and changes in their conceptions of inquiry as result of the NB certification process. Findings, based on a situated cognitive framework, suggested that differences exist between biology, chemistry, and earth science teachers' conceptions, enactment, and goals for inquiry. Further, individuals teaching in more than one discipline often held different conceptions of inquiry depending on the discipline in which they were teaching.

Implications for the research community include being aware of disciplinary differences in studies on inquiry and exercising caution in generalizing findings across disciplines. In addition, teachers who teach in more than one discipline can highlight the contextual and culturally based nature of teachers' conceptions of inquiry. For the education community, disciplinary differences should be considered in the development of curriculum and professional development. An understanding of disciplinary trends can allow for more targeted and relevant representations of inquiry.

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CONCEPTIONS, ENACTMENT, AND GOALS FOR INQUIRY.

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## DEDICATION

To Dr. Robert Chance for his unwavering support and encouragement over the years.

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# Chapter 1: Problem Statement

## *Introduction*

Despite widespread agreement in the science education reform community that inquiry should be an integral part of science teaching and learning, research indicates that little inquiry is actually taking place (American Association for the Advancement of Science, 1992; Lotter, Harwood, & Bonner, 2007; National Research Council, 1996; Wells, 1995). Even with considerable time and resources invested in articulating and promoting a vision of reform for science education inquiry is oftentimes missing from the science classroom (AAAS, 1992, NRC, 1996, NSTA, 1995). Central to this study was the role inquiry holds in that vision and how teachers in different subject matter disciplines think about and enact inquiry.

Research has identified barriers perceived by science teachers to implement inquiry in their classrooms (Brickhouse, 1990; Keys & Bryan, 2001; McGinnis, Parker, & Graeber, 2004; Wallace & Kang, 2004). Time constraints, external examinations, student maturity and ability, local school culture, and other factors have been cited by teachers as barriers to using inquiry teaching in their classrooms. While identifying these barriers has provided valuable insights, little has changed at the classroom level. Inquiry remains inconsistently enacted, and when enacted it often differs from the intentions of reform documents and curricula designers (Abd-El-Khalick, 2004, Anderson, 2002; NRC, 1996).

Professional development is often described as a key element in promoting teachers' use of inquiry in the classroom. Studies have shown that professional development can result in changes to teachers' conceptions of inquiry (Crawford, 2007;

Luft, 2001; Songer, Lee, & McDonald, 2003). However, professional development often does not result in changes in classroom practice (Lee, Hart, Cuevas, & Enders, 2004; Lotter, Harwood, & Bonner, 2007).

With the current emphasis on inquiry within the science education community, this study aimed to build on a professional development experience that has been shown to increase teachers' understanding about inquiry: the National Board (NB) certification process (Lustick & Sykes, 2006; Park & Oliver, 2008). The National Board certification (*Adolescent and Young Adult: Science* certification area) provides a uniform, rigorous, and substantial data source to study teachers' conceptions of inquiry.

During the 2006-2007 school year I was a NB candidate in the *Adolescent and Young Adult: Science (AYA Science)* certification area (chemistry). In November 2007 I was awarded NB certification. The NB certification experience and my personal interest in teaching with inquiry led me to wonder how the NB certification could help us understand how teachers think about inquiry. The following description of the certification process is provided to situate the study.

#### *NBPTS Background*

Established in 1987 with a grant from the Carnegie Corporation of New York, the National Board for Professional Teaching Standards (NBPTS) certified its first cohort of teachers in 1993. Today more than 74,000 teachers have achieved certification with over 9,600 new recipients in 2008.

According to the NPBTS website, National Board Certified Teachers (NBCTs) advance the quality of teaching and learning by:

- Maintaining high and rigorous standards for what accomplished teachers should know and be able to do.
- Providing a national voluntary system certifying teachers who meet these standards.
- Advocating related education reforms to integrate National Board Certification in American education and to capitalize on the expertise of National Board Certified Teachers (NBPTS, 2009a).

There are currently 25 available certificate areas ranging from early childhood to young adulthood across a variety of subject areas. Within each certificate area there are further divisions. For example, this study focused on the *AYA Science* certificate area, which consists of Biology, Chemistry, Earth/Space Science, and Physics specialty areas. *AYA Science* certification can be obtained in one of these four areas.

The certification process is rigorous and time consuming. Only about 40 percent of candidates achieve certification the first year; about 65 percent do so by the end of the three-year cycle. In addition, teachers spend from 200 to 400 hours to prepare and complete the certification process (NBPTS, 2009a). This rigorous, extensive certification process provides a rich data source for exploring teachers' ideas about teaching and their science content knowledge.

#### *National Board Core Propositions and Standards*

The National Board has identified five areas, termed *Core Propositions*, which provide a vision of accomplished teaching. These are:

Proposition 1: Teachers are committed to students and learning.

Proposition 2: Teachers know the subjects they teach and how to teach those subjects to students.

Proposition 3: Teachers are responsible for managing and monitoring student learning.

Proposition 4: Teachers think systematically about their practice and learn from experience.

Proposition 5: Teachers are members of learning communities.

Of the five, this study primarily examined Proposition 2 and 4.

In addition to the *Core Propositions*, NB provides a set of standards for each certificate area. Standards are generated by a committee of teachers, distributed to the education community for review and comment, and are then approved by the NBPTS Board of Directors. In this manner, the standards represent a consensus view of what constitutes accomplished teaching in that certificate area. Of the twelve *AYA Science* standards, “*Understanding Science*,” “*Fostering Science Inquiry*,” and “*Reflecting on Teaching and Learning*” are most relevant to this study. Teachers are encouraged to continually refer back to the standards as they think and write about their teaching.

#### *Portfolio and Assessment Center Exercises*

The *AYA Science* certificate process consists of the construction of a portfolio documenting candidates’ teaching and a series of assessments focused primarily on knowledge of teaching and content. The portfolio is weighted as 60% of a candidate’s score and the Assessment Center exercises make up the remaining 40%. The majority of teachers’ time is spent preparing the portfolio although many teachers spend considerable time preparing for the Assessment Center exercises.

The *AYA Science* portfolio consists of four entries: *Teaching a Major Idea in Science*, *Active Scientific Inquiry*, *Whole Class Discussion in Science*, and *Documented Accomplishments: Contributions to Student Learning*. The focus of this study is the portfolio entry *Active Scientific Inquiry*. The entry requires that the candidate:

- Plan and teach an inquiry science lesson or lesson sequence.
- Generate a 20-minute video engaging students in active scientific inquiry.
- Describe, analyze, and reflect upon their lesson and video in a thirteen-page document.

The guidelines, instructions, and rubric by which the entry will be assessed are specific and detailed. From a research perspective, this provides a consistent and uniform set of conditions for portfolio creation. All participants are provided with identical instructions, requirements, and scoring rubrics. While teaching environments do vary considerably, teachers' interpretation and work on their portfolio tells us a lot about the conceptions they hold for inquiry teaching and learning.

Assessment Center exercises are composed of six sections that examine content knowledge specified in the NBPTS standards. Candidates are given 30 minutes to respond to each exercise. Assessments are administered at an authorized testing facility via computer. The Assessment Center exercises for *AYA Science* are:

**Exercise 1: Data Analysis**

**Exercise 2: Interrelationships**

**Exercise 3: Fundamental Concepts**

**Exercise 4: Change Over Time** (Biological, Physical, and Earth Sciences specialty areas)  
-OR-

**Exercise 4: Changes in Systems** (Chemistry specialty area only)

**Exercise 5: Connections in Science**

**Exercise 6: Breadth of Knowledge**

In this study, Exercise 3: Fundamental Concepts was used to provide a measure of teachers' science content knowledge. For Exercise 3:

*Teachers will be asked to demonstrate a depth of content knowledge in their specialized field. They will be given a visual, mathematical, or graphical representation of a concept and will give a description of the concept, analyze relationships, and discuss consequences of changes (NBPTS, 2009b, p. 3).*

In addition, Exercise 6: Breadth of Knowledge was used to provide a measure of teachers' understanding of science content knowledge across the disciplines of biology, chemistry, earth science, and physics.

*Teachers will be asked to demonstrate knowledge across the science disciplines and describe a major idea in science. They will then explain a concept in each of the three major sciences not in their specialty and relate the concepts to the major idea (NBPTS, 2009b, p. 3).*

### *Summary*

Teachers achieving National Board certification have completed a rigorous, reflective, and uniform professional development experience. They have planned, enacted, described, analyzed, and reflected on their teaching and on students' learning in their portfolio entries. In addition, through Assessment Center exercises, they have been assessed on their science content knowledge in both their specific discipline and in more general science concepts (e.g. data analysis, other science disciplinary knowledge, etc).

The portfolio entry, *Active Scientific Inquiry*, along with Assessment Center scores, provides rich data for studying NBCSTs' conceptions of inquiry, especially when

supported by participant interviews and the Views of Science-Technology-Society (VOSTS) questionnaire.

### *Research Questions*

Using National Board Certification in *Adolescent and Young Adult: Science* as a rigorous and uniform treatment, there were three primary questions addressed by the present study. First, factors influencing teachers' conception, enactment, and goals of inquiry were explored to address the research question: *"How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?"*

Second, the influence of teachers' science content knowledge on their conceptions of inquiry was addressed. *"How does science subject area content knowledge influence teachers' enactment of inquiry-based teaching and learning?"*

Finally, building upon findings from the above questions, the current study investigated changes in teachers' conception and enactment of inquiry as a result of the NB certification process. While the portfolio and Assessment Center exercises provided considerable data, to develop a richer and fuller understanding of the factors that influence teachers' conceptions of inquiry required additional sources. In the case of this study, interviews and the VOSTS questionnaire provided such data.

*"How did the National Board certification process alter teachers' conceptions of inquiry?"*

Research findings in this study contribute to the literature on professional development and teacher practice of inquiry. In addition, the present study may guide improvements in the design and implementation of professional development efforts and potentially lead to more effective experiences for teachers.

### *Theoretical Framework*

The current study originally adopted a sociocultural perspective in the planning and design of instrumentation and protocols. Lemke (2001, p. 296) described the sociocultural perspective as

*“Viewing science, science education, and research on science education as human social activities constructed within institutional and cultural frameworks.”*

Others have used a sociocultural perspective to study science teaching. McGinnis and Simmons (1999) studied teachers’ perspectives of teaching science-technology-society (STS) issues in the classroom. The sociocultural framework allowed them to study teachers’ beliefs about how controversial STS issues were influenced by local cultures. Regarding teaching with inquiry, Wallace and Kang (2004) noted that it is important to take into account how teachers’ beliefs about inquiry have developed as a result of the social context and culture of the classroom. These studies have shown that the sociocultural perspective is an appropriate framework for studying science teaching.

The sociocultural perspective is well suited for studying how teachers think about and enact inquiry in their classrooms. Both the development of teachers’ conceptions of inquiry and how they use it in the classroom are strongly influenced by their interactions with others. Therefore, an emphasis on these interactions was expected to represent a theoretically productive approach.

As the study progressed and data analysis took place, however, it was recognized that a more specific theoretical framework was needed to assist in identifying and organizing results from portfolio analysis and themes emerging from participant interviews. In particular, there was a need to take into account the context of teachers’

practice and the communities in which they interacted. A situated cognitive perspective was selected to provide a framework with sufficient explanatory power for this analysis.

Situated cognition, located within a sociocultural research paradigm, posits that learning takes place within a social context and culture and that the two are intimately related (Brown, Collins, & Duguid, 1989). According to Lave and Wenger (1991), learning is dependent upon context, is socially negotiated, and takes place through enculturation into communities of practice. In this sense, the situative perspective emphasizes systems of interactions rather than individual behavioral or cognitive processes (Greeno, 1997).

As Borko (2004) states, teacher learning takes place in a variety of contexts: the classroom, school communities, professional development activities, and interactions with colleagues. In this study of NBCSTs, the NB certification process, in particular the construction of the portfolio entry *Active Scientific Inquiry*, provides an opportunity to study the context in which teaching with inquiry takes place. In addition to portfolio analysis, participant interviews allowed for further exploration of contexts and an opportunity to investigate the discourse communities that influence NBCSTs' conceptions, enactment, and goals for inquiry.

Teaching with inquiry takes place within the social context of the classroom, school, and larger education community. How teachers think about and enact inquiry is influenced not only by these contexts, but also by the communities in which they interact and have interacted in the past. Examples of these discourse communities include NBCSTs' experiences as students, previous scientific research experiences, and interactions with other teachers.

While not as much research has been done with teachers, Putnam and Borko (2000) present a description of how the situative perspective can be used to study teacher learning. Three central ideas of the situative perspective are that learning is situated in a social or physical context, social in nature, and distributed. Building on recent research, they conclude by stating that the situative perspective, with its view of cognition as social, situated, and distributed, offers a framework for studying teaching and teacher learning.

Of particular interest to this study are the social context of teaching with inquiry and the discourse communities in which teachers participate. Viewing NBCSTs' conception, enactment, and goals through a situative lens provides a productive and relevant framework to analyze their teaching with inquiry.

#### *Rationale*

Currently, gaps exist in our understanding about influences on teachers' conceptions and enactment of inquiry. Specifically, we know little about how teachers' discipline (biology, chemistry, earth/space science, physics) influences their conception of inquiry. Considerable work has been done at the departmental level (e.g., English, Science, Social Studies, etc.) and in secondary schools (Grossman & Stodolsky, 1995) but it is not clear that this generalizes to within departments and specifically to science. Further, the influence of subject area content knowledge on inquiry teaching has been documented in the literature (Alexander, 1992; Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989) but there is a dearth of mixed methodology studies with a developed quantitative aspect investigating the link between domain knowledge and inquiry teaching. The current study seeks to explore these factors and place them in

context with teachers' conceptions of inquiry as a result of a professional development experience.

The above factors do not exist in isolation; context is crucial. To merely identify the existence of factors does not elucidate their interaction with teachers' conceptions of inquiry, decisions they make, and life in the classroom. Recent research has indicated that the NB certification process does result in significant gains in teachers' understanding of inquiry (Lustick & Sykes, 2006; Park & Oliver, 2008). Based on evidence that teachers are learning from the NB process, the present study used a mixed methodology to identify the factors and to place them in the context of teacher change and classroom practice.

To provide a clear and consistent discussion format, the rationale is divided into three sections based on the research questions.

#### *Influences on teachers' conceptions and enactment of inquiry*

Considerable research has been done on inquiry and teacher beliefs (Brickhouse, 1990; Kane, Sandretto, & Heath, 2002; Nespor, 1987; Pajares, 1992) and conceptions (Wallace & Kang, 2004; Lotter, 2005; Lederman, et al., 2002) about inquiry. However, as Windschitl (2004, p. 481) stated,

*“... little is known about how teachers conceptualize inquiry, how these conceptions are formed and reinforced, how they relate to work done by scientists, and if these ideas about inquiry are translated into classroom practice.”*

The NB certification process provides a rich data set to explore NBCSTs' conceptions of inquiry and describe how the certification process led to changes in teachers' conception of inquiry.

*Influence of science discipline on teacher's conceptions and enactment of inquiry.*

At the secondary level, minimal research has been done on the influence of the teachers' subject area (biology, chemistry, earth/space science, physics) on their enactment and conceptions of inquiry. A thorough review of the literature yielded few results. Of these, none provided a theoretical or practical basis for understanding how science subject area influences teachers' conceptions of inquiry at the secondary level. An understanding of subject area specific conceptions of inquiry can inform our theoretical understanding of inquiry teaching. It can also offer insights into how teachers from different disciplines think about and enact inquiry teaching.

High school teachers often define themselves by the departments in which they teach; for example, social studies, English, or science (Grossman & Stodolsky, 1995). This is also case within departments; perhaps to even a higher degree in science. While it is common for teachers to teach two subject areas, teachers tend to identify more with a specific subject. This subject area focus has important implications for understanding how teachers think about inquiry. For example, if biology and physics teachers have differing conceptions about the importance of alternate explanations in inquiry, this could provide insights into their conception of inquiry and have implications for professional development, curriculum development, and classroom practice.

Research scientists often use different methodologies and have different approaches to and conceptions of scientific inquiry. For this study, it was thought that similar differences exist between science subject areas and that differences in conceptions of inquiry also exist. This study sought to identify and explore the extent to which

differences between subject areas exist and how this ultimately influences teachers' conceptions and enactment of inquiry.

*Influence of teachers' science content knowledge on inquiry teaching.*

Subject area content knowledge has been shown to influence teaching with inquiry (Alexander, 1992; Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989). According to Anderson (2002), an insufficient body of research has been carried out on how teachers' content knowledge influences their instruction. However, case study research has suggested that it is important (Smith, 2007). Further, studies in mathematics education support the idea that content knowledge is necessary to implement inquiry-oriented instruction (Loucks-Horsley, Hewson, Love, & Stiles, 1998; Schneider & Krajcik, 2002). The current study sought to strengthen our understanding of the importance of content knowledge as it relates to inquiry teaching. Specifically, it aimed to identify aspects of inquiry that are related to teachers' subject matter content knowledge.

*What Leads to Change in Teachers' Conception of Inquiry?*

Identifying the influence of subject area and science content knowledge has limited potential for extending our knowledge of inquiry teaching. We must look at the context in which the factors operate to develop a fuller view of their influence on teachers' practice. While analysis of the portfolio entry, VOSTS questionnaire responses, and Assessment Center scores can help us understand the relationships between the science subject area content knowledge and teacher conceptions, it is necessary to talk directly with teachers to explore the context in which they think about inquiry.

Research has found that *AYA Science* candidates do learn from the NB certification process (Lustick & Sykes, 2006; Park & Oliver, 2008). Using a quasi-experimental design, Lustick and Sykes found that greatest gains were made in the areas of scientific inquiry and assessment. This conclusion was supported by teacher comments about the portfolio process. In a case study of three NB candidates, Park and Oliver (2008) also found that teachers improved their understanding of inquiry instruction. Both studies indicate that teachers were learning and that the change could be measured by both quantitative and qualitative instruments.

Using semi-structured interviews to provide context and clarification, three sub-questions were examined. First, the elements leading to any changes were explored. Second, critical points where change occurred were identified. Finally, how the changes are represented in current practice will be examined.

*What elements of the professional development experience led to the change?*

It has been hypothesized that much of the learning that took place during the NB process was influenced by the availability of a detailed description of inquiry in the NB standards and portfolio instructions (Lustick & Sykes, 2006). As Lustick and Sykes noted, teacher learning occurred in areas where the biggest difference existed between teachers' practice and NB standards. Given the diverse meanings of inquiry (Anderson, 2002; Crawford, 2007), it is possible that NB documents provided a vision of inquiry that clarified and expanded teachers' ideas and led to changes in their conceptions and enactment of inquiry.

*When did the change take place?*

Knowledge of when teachers' conceptions of inquiry change can help identify critical points in the certification process and may generalize to other professional development activities. Therefore, this knowledge has important implications for our understanding of teacher change and for professional development. It is even possible that the change may have taken place well after the portfolio was completed (Lustick & Sykes, 2006), something that can only be identified through participant interviews.

*How is this change represented by the teachers in their current practice?*

For change to have an impact on student learning, it must have some permanence in teachers' practice. In the present study, semi-structured interviews will be used to describe any changes that took place in teachers' practice as a result of the NB certification process.

Even for teachers who did not change their conception of inquiry, changes to practice are possible. For example, one participant in a pilot study that preceded and informed the current study stated that there was no change to her conception about inquiry. However, in discussing her teaching she stated that she now used inquiry more frequently because she was more comfortable in its use. For her, the portfolio process *“got me started with inquiry labs and I have been incorporating more of the activities into my courses over the past two years.”*

*Meaningful Questions*

The NB certification process offers an accessible and data-rich opportunity to study conceptions and enactments of inquiry. However, access aside, what makes the current study meaningful?

As a researcher, a high school science teacher, and a recently NB certified teacher, my experience has been that inquiry teaching is demanding and difficult. As others have pointed out (Crawford, 2000; Sandoval & Daniszewski, 2004), teaching with inquiry requires teachers to take on new and sometimes unfamiliar roles. I have experienced this in my own practice as a chemistry teacher. At the same time, inquiry can result in more motivated students (Crawford, Krajcik, & Marx, 1999; Gibson & Chase, 2002; Palmer, 2009).

Evidence indicates that teaching science using inquiry is as effective as more traditional teaching methods, as measured by standardized tests. According to research comparing inquiry-based learning to National Assessment of Education Progress (NAEP) science test scores, students involved with a project-based science curriculum, closely related to inquiry-based instruction, scored significantly higher than, or the same as, the national average (Schneider, Krajcik, Marx, & Soloway, 2002).

In addition to the evidence that inquiry is as effective as other teaching methods when measured by the NAEP exam, it has been shown that students involved with inquiry have a more positive attitude towards science over time. Based on a longitudinal study on the impact of inquiry-based science on middle school students' attitudes towards science, Gibson and Chase (2002) concluded that students who took part in a summer inquiry-based science camp maintained a higher interest and more positive attitude than students who had applied to the camp but were not accepted. Others reported similar findings (Crawford, Krajcik, & Marx, 1999; Hand, Wallace, & Yang, 2004; Palmer, 2009).

In this regard, the current study can further our knowledge of the influences on teachers' conceptions of inquiry and the context in which it exists. This, in turn, can lead to more effective professional development and curriculum for inquiry-based teaching, and ultimately, improved student learning.

My own experience in attending and presenting workshops about inquiry has led me to believe that science teachers' conceptions about inquiry are often limited and undefined. For example, teachers understood the idea of having students ask questions, design experiments, and collect and analyze data as described in national reform documents. Often, as noted by Holliday (2004), these teachers believed that inquiry was to be taught implicitly, with minimal guidance. This conception resulted in many teachers feeling that inquiry would not work in their classroom and disengaging from the professional development experience.

An understanding of the factors that influence teachers' enactment and conception of inquiry are central to reform-oriented professional development efforts. Professional development can lead to changes in teachers' conceptions about inquiry (Abd-el-Khalick & Lederman, 1998; Luft, 2001; Lustick & Sykes, 2007; Park & Oliver, 2008; Supovitz & Turner, 2000). However, limited resources, and pressure created by high stakes testing often result in diminished opportunities for professional development. It is therefore essential that available opportunities be designed and conducted to be as effective as possible.

### *Significance*

Studying the NB certification process provides an opportunity to access a rich source of data about teachers and inquiry. Because of its richness and depth it is possible

to investigate several factors influencing teachers' conception and enactment of inquiry that have been understudied in the field. This takes on further significance since NBCSTs represent an important and growing source of influence and leadership in schools; a source that could play an important role in reform efforts in science education. Therefore, expanding our knowledge of how they think about inquiry can inform us of the role they might play in science education reform efforts.

Much of the research on inquiry has been on pre-service teachers (Crawford, 2007; Windschitl, 2004) or small groups of volunteers specifically interested in learning more about inquiry (Luft, 2001; Wallace & Kang, 2004). These populations, while accessible, offer limited generalizability. The current study extends our knowledge by studying a population of experienced teachers who have engaged in a professional development experience for a variety of personal and professional reasons.

### *Teachers' Conceptions of Inquiry*

As discussed earlier in the Rationale section of this proposal, gaps exist in our knowledge of how teachers conceive of inquiry. A central goal of the current study was to generate new knowledge to expand our understanding of teachers' conceptions of inquiry. The significance is twofold. First, the study sought to enhance our theoretical understanding of teacher practice as it relates to inquiry. Second, findings from the study will guide professional development and curriculum that can more effectively enable teachers to teach inquiry in a manner consistent with the vision of the national reform documents.

### *NBCSTs as Teacher Leaders*

NBCSTs represent an important and growing influence in leadership in schools; one that could have an impact on science education reform efforts. This study is significant as it increases our understanding of how highly accomplished science teachers think about inquiry.

An intended outcome of the NB certification is the creation of teacher leaders within schools. As stated in the Carnegie Task Force (1986, p.55), which led to the establishment of the National Board, NBCTs are to:

*... provide active leadership in the redesign of the schools and in helping their colleagues to uphold high standards of teaching and learning.*

Recent research supports this notion. In a study of interview data from 15 NBCTs, it was found that NBCTs became involved in a variety of leadership activities, many newly available as a result of being certified by NBPTS. Further, these teachers were more focused in their leadership goals (Sato, Hyler, & Monte-Sano, 2002).

Darling-Hammond (1996) said that change starts within schools. Therefore our understanding of how NBCSTs think about inquiry offers insights into a potentially important source of science education reform leadership in schools. Given that many meanings teachers give to inquiry are often different from the intent of reform documents (Matson & Parsons, 2006; Wheeler, 2000; Windschitl, 2003), NBCSTs may offer an effective means to promote reform in science education at the school level. Our knowledge of their conceptions of inquiry can guide efforts to leverage this human resource.

### *A Significant Data Source*

The comprehensive nature of the NB certification process, including an entire portfolio entry on teaching an inquiry lesson or unit, provided access to data that would otherwise take considerable time and resources to obtain. This includes:

- A uniform, well-established and documented treatment.
- A rigorous treatment. It is estimated that teachers will spend between 50 and 100 hours on the portfolio entry *Active Scientific Inquiry*.
- Descriptive, analytical, and reflective commentary by teachers (13 pages) about their inquiry teaching based on video of themselves and students engaging in inquiry.
- An assessment of teachers' content knowledge that has been shown to be valid and reliable.

In addition, participants in the study completed the VOSTS instrument and took part in interviews, adding to the available information. Together, this represented access to a data set not previously studied in the literature.

An important aspect of this data source is that participants did not necessarily seek certification out of an interest to learn more about inquiry. Teachers undertake NB certification for a variety of reasons including professional growth, financial incentives, and prestige. In this sense, the data represent a group of teachers with varying degrees of experience, motivation, and conceptions about inquiry. It is thought that this results in more diverse views about inquiry and provides a representative array of teachers' conceptions of inquiry.

### *Purpose*

Using a mixed methodological approach (Greene, 2001), the present study was designed to expand our understanding of how experienced teachers conceive of inquiry. Based upon multiple and varied data sources, a sociocultural framework was used in the design of the study and analysis of data.

First, the study investigated the factors that influence teachers' conceptions of inquiry. These included subject area (biology, chemistry, earth/space science, physics) and subject matter content knowledge. Second, the study built on the factors considered in question one and sought to describe how teachers' conceptions of inquiry change as a result of the National Board certification process.

### *Beginning of Study Researcher Positionality*

In many ways I think and write about science teaching from three distinct perspectives: as a National Board certified high school science teacher who taught science in the US Peace Corps in Africa and a former research chemist. Each of these roles brings unique insights and ideas. At the same time, each role comes with its own set of experiences and notions that need to be examined and monitored.

For the past seven years, I have taught high school chemistry and have tried to make scientific inquiry a significant part of my teaching. Over that time I've faced many of the barriers described in the literature (Abd-El-Khalick, 2004; Brickhouse, 1990; Welch, 1981) and developed strategies to get around them. Currently, in my seventh year of high school chemistry teaching, I struggle daily with the everyday practical pressures

of teaching, limited time and resources, and my still-developing ability to plan and implement inquiry in my classroom.

As a chemistry teacher, inquiry appeals to me because of the higher-level skills involved, the access inquiry gives students to science concepts, and the interest and motivation it creates. For many of my English Language Learner (ELL) students it gives them a chance to be successful while developing vocabulary and writing skills. I attempt, and often succeed in engaging students in an inquiry experience once or twice a week. At the same time I am aware of the pressures and constraints experienced in the context of a high school setting.

During and after college I worked for the Food & Drug Administration, first as a technician and later as an Analytical Chemist developing analytical methodologies (e.g. Carson & Breslyn, 1996). During that time, I was involved in many research studies and had a chance to work with scientists from around the world. As a result, I have my own conceptions about research, the nature of science, and how scientific inquiry is done. While this gives me a useful perspective and understanding of scientific research, it is limited to one experience in one research context.

My experience as a Peace Corps Volunteer teaching science in the far north of Ghana, West Africa, is also an important influence on how I view teaching and science education. In Ghana, high stakes tests serve as the means to decides who moves on in the educational system. This creates a very competitive, exam-focused learning environment, especially at the secondary level. As a new teacher I struggled to prepare my students for their exams and at the same time provide them with a useful and

authentic view of how science is done. It was in this context that I started my teaching career.

Today, while teaching high school chemistry in the United States, I am confronted with many of the same issues. Pressures created by testing, curricular constraints, and students with limited experiences with inquiry all present challenges. Much like my experience in Ghana, I continue to try to maintain a balance. My research grows out these experiences and a desire to understand how teachers think about and enact inquiry and how professional development can support their efforts.

Over the past seven years of teaching, I've developed my own conception of inquiry. However, like all teachers, my personality, the context in which I teach, and my students, are unique. What may be important to me, work for my students, and be supported by my school may not be the case for other teachers. As a researcher, it means I need to step back and be careful not to impose my ideas, experiences, and expectations on others.

### *Terms*

Adolescent and Young Adult: Science ( <i>AYA Science</i> )	One of 25 National Board certification areas. <i>AYA Science</i> includes students ages 14-18 and is awarded in four specialty areas (biology, chemistry, earth/space science, and physics).
Assessment Center Exercises	A series of six computer-based assessments (Data Analysis, Interrelationships, Fundamental Concepts, Change Over Time, Connections in Science, Breadth of Knowledge). The exercises make up 40% of a candidate's total score.
National Board Certified Teacher (NBCT)	A teacher who has achieved certification from the National Board for Professional Teaching Standards

National Board for Professional Teaching Standards (NBPTS or NB)

NBPTS is an independent, nonprofit, nonpartisan and nongovernmental organization. It was formed in 1987 to advance the quality of teaching and learning by developing professional standards for accomplished teaching, creating a voluntary system to certify teachers who meet those standards and integrating certified teachers into educational reform efforts (NBPTS, 2009c).

The five central tenets of accomplished teaching, according to NBPTS. They are:

NBPTS Core Propositions

- Teachers are committed to students and their learning.
- Teachers know the subjects they teach and how to teach those subjects to students.
- Teachers are responsible for managing and monitoring student learning.
- Teachers think systematically about their practice and learn from experience.
- Teachers are members of learning communities.

Adolescent and Young Adult Standards

Thirteen standards that form the basis for portfolio construction. Standards are also used as a basis for assessing portfolios.

Portfolio

*AYA Science* candidates must submit four portfolio entries: three describing and analyzing their classroom practice and one documenting their accomplishments.

Portfolio Entry Two: *Active Scientific Inquiry*

Portfolio Entry Two consists of 13 pages of description, analysis, and reflection about engaging students in scientific inquiry. The written commentary is centered on a 20-minute video showing teacher and students at different stages of the inquiry activity.

### *Limitations*

There are several important limitations for this study. The first relates to participant selection. Although considerable effort was expended to randomly select participants for participant interviews randomly, it is possible that respondents are not fully representative of the population of NBCSTs from the 2007 and 2008 cohort years. This is primarily a result of the volunteer nature of the selection process.

Further, it is possible teachers who were more confident in their use of inquiry were more willing to participate in the study. This could result in a sample skewed towards participants with a more developed conception of inquiry. At the same time, it is not anticipated that this will constrain potential conclusions. Data from this sample would still be expected to exhibit differences across the factors being investigated, perhaps to an even greater degree, as teachers may be more willing and able to discuss their conceptions of inquiry.

The use of NBCSTs limits the generalizability of the study. NBCSTs represent teachers who want to advance in the profession and are confident in their abilities and chances at achieving certification. In short, they are a motivated and goal-oriented group of participants with professional and financial incentives to succeed. As a result, a rich source of data on experienced teachers' conception of inquiry is available for study. This extends the range of contexts in which inquiry has been studied and adds new knowledge to the field.

A third limiting factor may be how NBCSTs are influenced by the nature of the certification process. In essence, candidates are trying to meet the requirements set forth by NBPTS to achieve certification. This is actually a strength of the current study; their portfolio entry provides an image of how teachers' conceptions and enactment of inquiry based on their understanding of reform documents and NB's version of inquiry (which is closely aligned with reform documents). This is then augmented by the VOSTS instrument and participant interviews to develop a profile of their own conception of inquiry.

A final limitation may lie in the instrumentation being used. The portfolio inventory was developed by the author, and while it has an interclass reliability coefficient of 0.84, the instrument has not undergone the extensive validation that other instruments in the study have (e.g. VOSTS, NB Assessment Center exercises). This limitation therefore required the use of multiple data sources to strengthen validity.

### *Assumptions*

The first assumption was that there are measurable differences in the factors being studied (influence of subject area and content knowledge). For this to be the case, instrumentation must have been sensitive enough to detect these differences.

Second, it was assumed that change was actually taking place as a result of participants' involvement in the NB certification process. For research on the factors influencing teachers' conception and enactment of inquiry, this assumption was not as relevant. However, for determining how the National Board certification process alters teachers' conception of inquiry, it was necessary for change to take place. Previous research indicates that learning about inquiry does take place as a result of the NB certification process (Lustick & Sykes 2006; Park & Oliver, 2008); however, it is possible that the learning will not be sufficient to alter teachers' conceptions.

An additional assumption was that the instruments used in the study will be able to measure the constructs they are intended to. Further, it was assumed that the instrumentation will also be sensitive enough to detect differences at a resolution necessary to draw meaningful conclusions. This takes on added importance since there were three different instruments being used in the study.

## Chapter Two: Literature Review

### *Introduction*

A rich literature on inquiry, the nature of science, and teachers' conceptions has been established over the past several decades (Brickhouse, 1990; Keys & Bryan, 2001; Lotter, 2005; Lederman, et al., 2002; McGinnis, 2000; McGinnis, Parker, & Graeber, 2004; Wallace & Kang, 2004). This literature formed the foundation on which this study was grounded.

First, the term inquiry is defined. A clear and consistent definition of inquiry is essential for analyzing teachers' portfolio entries and generating an accurate profile of their conceptions of inquiry. Inquiry is often depicted as consisting of process skills (the inquiry) and understandings about science (the nature of science). Both process skills and understandings about science are discussed. In addition to defining inquiry, a substantial part of the section involves discussing the literature on the nature of science (NOS).

Having defined inquiry, the theoretical perspective used in this study is presented. The framework of situated cognition supports the analysis and interpretation of both the quantitative and qualitative data by taking into account the social contexts surrounding teaching and the communities in which teachers participate or have participated.

Extending from a situative perspective, teachers' conceptions about inquiry, the nature of science, and science teaching are considered. Specific elements include defining what is meant by "conceptions," approaches for measuring and documenting teachers' conceptions, and the validity and reliability of the data collected and conclusions made.

Finally, with an understanding of how to access and measure teachers' conceptions of inquiry it is possible to explore the factors influencing these conceptions. The main factors explored in this review are the influence of discipline (biology, chemistry, earth/space science, and physics), teacher science content knowledge, and previous scientific research.

### *Inquiry and the Nature of Science*

Much has been written about the history of inquiry from its beginnings with Dewey (Dewey, 1910, as cited in National Research Council, 2000), to its resurgence in response to Sputnik in the 1960s, and recently its central role in current reform documents (NRC, 1996; AAAS, 1993; NSTA, 1995). DeBoer (2004) provides a thorough and current account of the evolution of inquiry in science education. The history of inquiry offers insights into both the theoretical and practical aspects of inquiry and its place in science education today. While the history and role of inquiry in science education reform are important topics, the purpose in this section of the literature review is to develop a working definition of inquiry to inform and guide the current study.

Inquiry is often framed as consisting of both process skills and understandings about the nature of science (e.g. NRC, 1996). Process skills include designing investigations, collecting and analyzing data, etc. Understandings about the nature of science consist of aspects of the philosophy and sociology of science, such as of the tentative nature of theory or the role of creativity in experimentation. Together the process skills and understandings are intended to provide an accessible, authentic image of how scientists go about studying the natural world. According to the NSES (NRC, 1996), scientific inquiry:

*refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p.23)*

In the NSES inquiry is presented as *Abilities Necessary to do Scientific Inquiry* and *Understandings about Scientific Inquiry* (NRC, 1996). *Abilities* are primarily process skills while *Understandings* deal with the nature of science. NBPTS address the nature of science in *Standard II: Understanding Science*. It is in *Standard VII: Fostering Scientific Inquiry*, where the process skills of inquiry are presented. There are a total of twelve standards in the *AYA Science* certification area. Inquiry and NOS therefore make up a considerable portion of the NB science standards.

In the present study inquiry was also separated into process skills (the NSES *Abilities to Do Inquiry*) and understandings of the nature of science (the NSES *Understandings*). The NB portfolio entry two, *Active Scientific Inquiry*, provided data on teachers' conceptions and enactment of the process skills involved in inquiry. Data on teachers' understandings of the nature of science, which are not emphasized in the NB portfolio, were accessed using the Views of Science-Technology-Society instrument (Aikenhead & Ryan, 1992). While the ability to do scientific inquiry and understandings about NOS were separated for the purpose of data collection and analysis, it is important to keep in mind that they interact to form teachers' visions of inquiry. In this study, participant interviews were used to explore this interaction and provided additional data about teachers' conceptions of inquiry.

## *Inquiry*

Defining inquiry is not a trivial task. Much of the meaning is context-specific and it is not always possible to know what the speaker intended (Anderson, 2007). The confusion about the meaning of inquiry may in part have a negative influence on its use in the classroom. Deboer (2004) states

*... but perhaps the most important reason why inquiry teaching has not enjoyed more success is because its essential nature is often misunderstood.*

Even in the research literature there are considerable differences in how inquiry is described. It often goes by different names: discovery learning (Wise & Okey, 1983), project-based science instruction (e.g., Blumenfeld, Krajcik, Marx, & Soloway, 1994), and “minds-on” inquiry (Duschl & Gitomer, 1997). The *National Science Education Standards* offer a useful vision of inquiry for this study. The standards were developed over several years with considerable input from policy makers, researchers, teachers, parents, and others involved in science education (Collins, 1998). Considering the thorough and inclusive process used to develop the standards, they can be seen as a consensus document representing a vision of inquiry for K-12 science education.

For science grades 9-12, the NSES Content Standard A (NRC, 1996, p. 173-176) provides guidance as to the abilities students need to do inquiry. These six areas are listed as headings in the standard and each is described briefly.

### Abilities Necessary to do Scientific Inquiry

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.

- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

A criticism of the NSES was that it did not offer teachers a clear definition of inquiry (Anderson, 2007). In addition, it lacked abundant examples and practical information for enacting inquiry in the classroom. The publication of *Inquiry and the National Standards: A Guide for Teaching and Learning* (NRC, 2000) was published as a follow-up publication with a more practical emphasis on inquiry in the classroom. Viewed together, the two publications provide both a description of inquiry and practical examples of inquiry being implemented at the classroom level.

Anderson (2007) described three different ways the term inquiry is used in the NSES.

- *Scientific Inquiry* – the ways scientists study phenomena and come to conclusions.
- *Inquiry Learning* – the process by which students engage in inquiry.
- *Inquiry Teaching* – how teachers use inquiry in classroom instruction.

While these categories are not explicitly listed in the NSES, the distinction is useful. In relation to Anderson's categorization of inquiry, the present study used portfolio analysis to focus on teachers' conceptions of *Inquiry Learning* and *Inquiry Teaching*. The VOSTS questionnaire was employed to look at teachers' conceptions of *Scientific Inquiry*. Participant interviews were used to clarify and probe both data sources and to further investigate teachers' conceptions of inquiry.

Underscoring the importance placed on inquiry in science education, the NBPTS selected *Active Scientific Inquiry* as one of the four portfolio entries required for certification in *AYA Science*. Much like the AAAS and NRC documents, the National

Board *AYA Science Standards* document represents a consensus view of inquiry (NBPTS, 2007). National Board Candidates are instructed to carefully read and frequently refer to the *AYA Science Standards* while preparing their portfolio entries. For portfolio entry two, *Active Scientific Inquiry*, the most relevant of the thirteen standards is *Standard VII: Fostering Science Inquiry*.

The secondary science standards, in particular *Standard VII*, are also a consensus view of the components of accomplished teaching, and, not surprisingly, contain many of the same themes as the *Abilities for Doing Inquiry* in the NSES document. Like the NSES, *Standard VII* places an emphasis on:

- asking questions and formulating hypotheses.
- making observations and recording and interpreting data.
- using technology in investigations.
- reaching conclusions based on data.
- communicating their results about their findings.

For example, according to the description in *Standard VII*, a good inquiry activity (NBPTS, 2007, p. 40):

*... allows active participation and student control over manipulating variables, posing questions, and using technology and data analysis. Accomplished teachers also select activities that engage students in using and improving their research and communication skills, such as writing laboratory reports and preparing presentations with graphs and visual displays.*

Because of the widespread acceptance of the NSES and their similarity to the National Board *Standards for Secondary Science*, the inventory instrument developed for

this study was based on the NSES *Abilities for doing Inquiry*. Based on the literature reviewed here, use of the NSES vision of inquiry allowed for the construction of a manageable and credible inventory tool to measure teachers' conceptions, enactment, and goals of the abilities necessary to do inquiry. Further, it allowed for a comparison of teachers' conceptions of inquiry with the consensus reform view.

### *Nature of Science (NOS)*

There seems to be general agreement on what students should understand about NOS (AAAS, 1989, Brickhouse 1990; NRC, 1996; Lederman, 2007). This includes ideas about the tentative nature of scientific knowledge, subjectivity and objectivity, science as a human activity, the role of theory and observation, creativity and imagination, the role of culture, and the nature of progress in science.

Over time, views on the nature of science have changed and some points still remain contentious. However, these are not necessarily relevant to K-12 students (Lederman, 2007). Lederman argues that there is agreement on the elements of the nature of science that are relevant to pre-collegiate education. These are: scientific knowledge is tentative, empirically based, and subjective, involves human inference, imagination and creativity, and is socially embedded. In addition, he includes the relationship between laws and theories and between observation and inferences as important aspects of the nature of science.

Osborne, Collins, Ratcliffe, Millar, & Duschl (2003) found similar aspects to be appropriate for school science in a Delphi study of the 23 international participants that included science educators, scientists, historians, philosophers, and others experts. In their study they asked, "What should be taught to school students about the nature of

science?” Nine themes emerged about the nature of science that were considered to be essential for the pre-collegiate science curriculum. The nine themes were *Science and Certainty, Analysis and Interpretation of Data, Scientific Method and Critical Testing, Hypothesis and Prediction, Creativity and Science and Questioning, Cooperation and Collaboration in the Development of Scientific Knowledge, Science and Technology, Historical Development of Scientific Knowledge, and Diversity of Scientific Thinking.*

In the development of the Views of Science-Technology-Society (VOSTS) instrument, Aikenhead and Ryan (1992) focused the section on the nature of scientific knowledge around eleven themes. These include the *nature of observations, scientific models, classification themes, tentativeness in science, hypothesis, theories & laws, scientific approach to investigations, precision & uncertainty, logical reasoning, fundamental assumptions for all science, epistemological status of scientific knowledge, and paradigms vs. coherence of concepts across disciplines.* Here again there is considerable overlap with the other researchers cited above.

Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) also developed an instrument to measure views of the nature of science. Based on open-ended questions, the Views of Nature of Science (VNOS) questionnaire captures qualitative data about teachers' views of the nature of science. The instrument is intended to provide information about the empirical nature of science, the scientific method, general structure and aim of experiments, role of prior expectations in experiments, validity of observationally-based theories and disciplines, tentative nature of science, difference and relationship between theories and laws, nature of scientific theories, function of scientific theories, logic of testing scientific theories, creative and imaginative nature of science.

Because of the open-ended nature of the instrument it is necessary to conduct follow-up interviews to clarify and probe teacher responses.

Both the VNOS and VOSTS have important theoretical and practical considerations, which are considered later in this review of the literature. However, the aspects of the nature of science measured by both instruments are consistent and both have been shown to capture meaningful data in the context of the current study. Because the VOSTS requires considerably less time for participants to complete, is a lower inference instrument, and yields comparable results, the VOSTS was used in the current study.

### *Summary*

In this section, inquiry has been defined to include both process skills and understandings about the nature of science. Further, aspects of each have been detailed and the literature explored. These definitions served to guide the construction and selection of instrumentation to measure teachers' conceptions of inquiry, investigate factors influencing them, and to explore how the NB certification process contributes to their change in participants' conceptions and enactment of inquiry.

### *Situative Perspective*

The situative perspective (Brown, Collins, & Duguid, 1989; Greeno, 1997; Lave & Wenger, 1991; Putman & Borko, 2000) has been found to be a productive framework for exploring contextually and socially rich settings. Because the current study focuses on teachers' conceptions, enactment, and goals for inquiry teaching, both context and culture are important constructs. Three studies involving the situative perspective and

inquiry are presented here to illustrate how the theoretical framework of situated cognition informs data collection and analysis in the current study.

*Crawford, 2007*

Five prospective science teachers were studied during their fieldwork experience teaching high school science (Crawford, 2007). The purpose of the study was to examine how their beliefs and knowledge related to their enactment of inquiry teaching. Over the one-year fieldwork experience, teachers were interviewed, observed, and artifacts collected. Using a multiple case methodology situated in teachers' practice, data collection and analysis focused on understanding how participants learned to teach with inquiry.

In addition to the constructs of teacher knowledge and beliefs, situated learning and cognitive apprenticeship were used to interpret the learning environment of prospective teachers in the study. For Crawford, this theoretical perspective was appropriate because it addressed the interactions of the prospective teachers, their teacher mentors, and university staff involved in the program. Being situated within the authentic context of the high school, prospective teachers are seen as taking part in a cognitive apprenticeship as they learn to teach science.

Several aspects of Crawford's work are relevant to the current study. First, her use of the situative perspective demonstrated that it is appropriate and effective for studying the complex and dynamic setting of a high school science classroom. Secondly, the application of situated cognition to the constructs of beliefs and knowledge is relevant to the current study. Crawford found there is a connection between participants' beliefs

and their actual teaching with inquiry. This suggests that NBCSTs' conceptions about inquiry also influence their practice.

Caution is necessary in translating findings to experienced teachers such as NBCSTs in the current study. First, unlike most new teachers, NBCSTs are not grappling with issues of classroom management. In addition, they do not have the constraint of having to work within the context and culture of another teacher's classroom as do the prospective teachers in Crawford's study. Therefore, the current study extends our understanding about experienced teachers' conceptions and enactment of inquiry in a more typical classroom environment.

*Friedrichsen & Dana, 2005*

This study of four highly regarded biology teachers (Friedrichsen & Dana, 2005) investigated participants' orientations towards science teaching. Orientations were defined as teachers' knowledge and beliefs as they related to teaching science. To access these orientations, researchers used a combination of interviews, classroom observation, and a card sorting task. A particularly relevant finding was that teachers' beliefs about students and learning are situated in the physical and social contexts of the school. This finding is consistent with other research on teacher learning and supports the use of the situative framework to study NBCSTs' conceptions, enactment, and goals for teaching with inquiry.

In describing influential contextual factors, Friedrichsen and Dana highlighted the importance of the concept of time, something found to be important in the current study. Time was found to be a major constraint in what teachers believed was possible to

accomplish. As a result, teachers' beliefs about time influenced their science teaching orientations, a factor I found in the current study.

Like Crawford, Friedrichsen and Dana included classroom observations in their study. Their work is informative because it was not feasible to conduct classroom observations in the current study of NBCSTs. Specifically, their study establishes a connection between teacher orientations, enactment, and the situative framework. Unlike Crawford's study which consisted of prospective science teachers, the use of highly regarded biology teachers is of a higher relevance to the current study and provides support that the situative perspective will be effective for studying NBCSTs.

*Schwartz, Lederman, and Crawford, 2004*

In a study of thirteen preservice secondary science teachers, Schwartz, Lederman, and Crawford (2004) investigated the development of participants' conceptions of NOS as a result of a science research internship. Preservice teachers were placed with a scientist at the university where the study took place. The authors note that, based on the situative perspective, it is often assumed that learners will develop an understanding of NOS by taking part in experiences situated in authentic scientific contexts. Their study explores factors that helped participants develop their understanding of NOS during the internship.

Building on previous research, Schwartz, Lederman, and Crawford found that simply being involved in authentic scientific experiences was not sufficient to develop participants' conceptions of NOS. Explicit opportunities for participants to reflect were necessary in addition to providing an authentic context. Further, they found that more

reflective participants were more likely enhance their understanding of NOS during the internship.

The study initially seems to contradict the situative perspective; in particular, the idea of cognitive apprenticeships. Even when situated within an authentic research setting, participants did not learn about NOS without explicit opportunities to reflect upon the experience. However, when these opportunities existed, participants did develop in their understanding of NOS. Since the current study involved inquiry and NOS, these findings support the notion that the National Board certification process will result in changes in teachers' conceptions of inquiry due to a strong reflective component of the NB certification process.

### *Summary*

The articles described here provide support for using the situative perspective to study NBCSTs' use of inquiry. They highlight the role of physical and social contexts in teachers' beliefs and orientations towards inquiry, point to the role of discourse communities and cognitive apprenticeships in learning to teach with inquiry, and underscore the importance of reflection in teacher change. Perhaps most importantly, they provide examples of how the situative perspective has been used in the study of inquiry, science teaching, and NOS.

### *Teachers' Conceptions and Enactment of Inquiry and the Nature of Science*

The term *conception* is used frequently in research on inquiry teaching. Often it is used alongside words like *beliefs*, *views*, *orientations*, and *ideas* when describing inquiry teaching and learning. *Inquiry* itself often has different meanings depending on the person and context in which it is used (Anderson, 2002). These meanings can be

thought of as the speaker's conception of inquiry in that specific context. This section examines the construct of *conception* as it relates to inquiry, both the process skills (the inquiry aspect) and understandings (the nature of science aspect). In addition, the relationship between teachers' conceptions and enactment is explored and research on teacher learning in the context of the NB certification process is presented.

#### *Conceptions, Beliefs, Views, Orientations, and Ideas about Inquiry*

Common to research on inquiry are terms such as *conceptions, beliefs, views, orientations, and ideas*. A closer look at how each is used in the literature guided the development and design of the investigation and the communication of findings.

In an in-depth study of three secondary science teachers, Lotter (2005) built upon a model consisting of a limited number of *core conceptions*. The idea of *core conceptions* is a useful theoretical construct that can be used to describe the factors that influence their science teaching. According to Lotter these are teachers' knowledge and beliefs about science, the learning process, students, and effective instruction. For Lotter, the term *conception* is made up of both knowledge and beliefs.

The Views of Nature of Science questionnaire (Lederman, et al., 2002) is reported to provide a meaningful and valid tool to assess conceptions of the nature of science. In this case, the terms *views* and *conceptions* are synonymous. *Belief* is not used. Research literature on the nature of science is consistent in its use of the terms *conceptions* and *views* (e.g. Akerson & Hanuscin, 2006; Schwartz, Lederman, & Crawford, 2004; Trumbull, Scarano, & Bonney, 2006).

In a study of how pre-service teachers conceptualize inquiry, Windschitl (2004, p. 481) states:

*Despite the ubiquity of the term ‘inquiry’ in science education literature, little is known about how teachers conceptualize inquiry, how these conceptions are formed and reinforced, how they relate to work done by scientists, and if these ideas about inquiry are translated into classroom practice.*

In this description, *conceptions* and *ideas about inquiry* are synonymous.

Friedrichsen and Dana (2005) use the term *orientations* in their study of highly regarded biology teachers’ science teaching orientations. *Orientations* are defined as “*teachers’ knowledge and beliefs about the purposes and goals for teaching science.*” Their definition of *orientations* is similar to Lotter’s description of *conceptions*, consisting of knowledge and beliefs.

The construct of *belief* has been the focus of a wide body of research and teachers’ beliefs are seen to play an important role in instructional choices (Nespor, 1987; Pajares, 1992). Kane, Sandretto, & Heath (2002) called beliefs “*theories in action.*” Jones & Carter (2007) defined beliefs as being “*integral to larger belief systems that include self-efficacy, epistemologies, attitudes and expectations.*” Because of the substantial body of research on inquiry, the construct of *belief* can provide theoretical guidance for the present study and is carefully considered in the literature review.

Wallace & Kang (2007) found that teachers often hold two different belief systems about inquiry teaching. This literature suggests that NBCSTs may also hold different conceptions about inquiry depending on the context. In an earlier study Wallace & Kang (2004) found two major belief strands about inquiry in a multiple within-case study of six experienced high school teachers. Operating from a sociocultural perspective, they found teachers’ beliefs about factors constraining their use of inquiry

tended to be more public and originated from school culture. Beliefs that promoted inquiry tended to be more private and centered on what teachers believed about successful science learning.

Wallace and Kang's findings also support the assertion that teachers can have more than one conception of inquiry based on the contexts in which they teach. In the current study science disciplines are the primary context investigated. Therefore, teaching classes in more than one disciplinary context can result in different conceptions and enactment of inquiry, something found in the current study.

Investigating experienced secondary science teachers, the work of Wallace & Kang aligns well with the current study, suggesting NB teachers also hold conceptions that can exist both publicly and privately. In addition, their work also supports the possibility of multiple conceptions based upon science discipline. As a result, instrumentation was designed to access and measure these multiple conceptions.

### *Summary*

In the current study, the term *conception* is used to describe the meanings teachers give to *inquiry*. Based on its usage in the literature, *conception* has a broader scope, including beliefs and knowledge. However, like the other terms used, it is contextual. Therefore the meanings teachers give in their own teaching and those used in the context of the National Board certification process must both be considered. Further, multiple conceptions are likely for teachers teaching in more than one discipline. It is therefore necessary to be sensitive to the context in which teachers are describing their conceptions of inquiry.

### *Conceptions and Enactment of Inquiry and the NB Certification Process*

In the context of the NB certification process, Lustick and Sykes (2006) found that teachers learn from the construction of their portfolio. In their study of 120 candidates for the *AYA Science* certificate they found quantitative evidence that portfolio preparation had a significant impact upon candidates' learning. Of the thirteen NB standards they found that the greatest learning occurred in the areas of inquiry and assessment. This research supports the use of NBCSTs as a productive source of data for understanding teachers' conceptions, enactment, and goals for teaching with inquiry.

Lustick and Sykes used both qualitative and quantitative data to explain why the greatest improvement took place in inquiry and assessment. Using interview comments, they found that inquiry was a new form of teaching for many NB candidates. Based on interview data Lustick and Sykes hypothesized that the learning took place largely because the portfolio guidelines and requirements provide a framework for teachers to plan, design, and implement inquiry in the classroom. Quantitative data also supported their claim. Based on gains in pre and post scores, teachers are "*learning to align their practice more closely with National Board's conception of scientific inquiry and teaching.*"

Viewing these findings through an *official* and *personal* conceptions perspective, portfolio creation is largely in the realm of the *official*. Teachers are using documents provided by the NB, which represent the consensus view of inquiry, to produce their portfolio. To a large degree they are trying to reproduce the reform vision of inquiry. The notion is supported by the finding that the NB portfolio process often results in

teachers aligning their practice with the reform vision of inquiry (Lustick & Sykes, 2006).

Inquiry was only one of the thirteen NB standards investigated by Lustick and Sykes. Because of the amount of time spent assessing the other standards, the focus on inquiry was necessarily limited. A larger limitation in the study is the measurement of teacher learning based on pre and post measurements using rubrics and procedures created by the NB to score portfolios. Since the study was designed to detect changes in teachers' learning from the portfolio process, evidence of learning was measured using NB rubrics and procedures. As a result, teacher learning aligns with the NB conception of inquiry. In other words, it represents the *official* view of inquiry. Largely absent from the study are teachers' *personal* views of inquiry, something explored through participant interviews in the present study.

A further limitation, as it relates to this study, is that the differences between biology, chemistry, earth science, and physics teachers were not investigated. Therefore, while the knowledge that learning is taking place supports the assertion that portfolio construction is an active process where teachers are spending considerable time and effort to document and reflect upon their teaching, it does not contribute to understanding differences across science disciplines.

Since learning was measured using the same metrics used in the NB certification process, there was a reliance on the NB vision of inquiry. This may also have influenced the conclusions reached about teacher learning and inquiry. Due to the larger numbers of biology and chemistry teachers in the *AYA Science* certificate it is likely the teacher learning described applies primarily to teachers in those disciplines. Again, disciplinary

differences were not a part of the design and analysis of the study so it is not possible to know what influence this may have had.

Additional support that the *AYA Science* portfolio construction process represents a rich source of information about teachers' conceptions and enactment of inquiry can be found in Park and Oliver's multiple-case study of three NB candidates. Park and Oliver (2008) investigated how the NB certification process influenced the pedagogical content knowledge (PCK) of three high school chemistry teachers working towards certification. The study found that inquiry-oriented instruction was one of the five main aspects of PCK development affected by the NB process. This work supports the findings of Lustick and Sykes that teacher learning can occur through portfolio creation. Further, it adds support through the analysis of additional data sources such as classroom observations, interviews, teacher reflections, and field notes.

#### *Measuring Teachers' Conceptions and Enactment of Inquiry*

As described earlier, inquiry can be thought of as processes or abilities and understandings about the nature of science. Therefore measurement must take into account both aspects. In the current study, the processes or abilities were measured through analysis of the NB portfolio while the understandings were measured using the VOSTS instrument. Semi-structured interviews were then used to clarify, expand, and further develop an understanding of teachers' conceptions of inquiry. This section describes the literature on NB portfolios, instruments used to assess teachers' views on the nature of science, and the use of semi-structured interviews to assess teachers' conceptions of inquiry teaching and learning.

### *Analyzing Portfolios*

Portfolios provide a rich source of information on NBCSTs' conceptions, enactment, and goals of inquiry. Recent research has shown that materials provided to candidates by NBPTS to guide portfolio construction can be a source of teacher learning (Kowalski, Chittenden, Spicer, Jones, & Tocci, 1997; Rotberg, Futrell, & Lieberman, 1998). Further, portfolios represent an image of NBCSTs' best efforts to portray and highlight their use of inquiry. However, the very nature of the NB portfolio process can result in NBCSTs trying to mirror the vision of inquiry found in the NB standards, portfolio guidelines, and rubrics. For these reasons some researchers have questioned whether portfolios accurately represent the character of the teacher in such high-stakes environments (Placier, Fitzgerald, & Hall, 2001; Snyder, Lippincott & Bower, 1998).

In current study, the portfolio entry *Active Scientific Inquiry* is used to access teachers' conceptions of the abilities or process skills necessary for inquiry. Further, it is theorized that the portfolio represents teachers' *official* conception of inquiry, developed from their expectation of what is required of them to achieve NB certification. In this respect it does not represent their *personal* conception of inquiry, something that will be measured by participant interviews in the current study.

It is assumed that the NB portfolio primarily represents an *official* conception of inquiry found in the reform documents. These documents, specifically the NSES (NRC, 1996), were used to develop the inventory instrument used to assess portfolios. For science, grades 9-12, the NSES Content Standard A (p. 173-176) provides guidance as to the abilities students need to do inquiry.

- Identify questions and concepts that guide scientific investigations.

- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

Portfolios are effective and productive means of studying teachers' thinking and enactment of inquiry. Viewing the NSES as a consensus or *official* conception of inquiry, the above six topics were used to develop the inventory instrument used in this study. The dimensions of each topic were further developed using the descriptions provided in the NSES.

#### *Teachers' Conceptions of Nature of Science and its Measurement*

Numerous instruments have been developed to measure students' and teachers' views of the nature of science (Lederman, Wade, & Bell, 1998). Based on the goals of the current study and validity and reliability considerations, two instruments were most appropriate for the present study. The *Views of the Nature of Science Questionnaire*, Version C (VNOS-C) and a section of the *Views on Science-Technology-Society* (VOSTS).

#### *The Views of Nature of Science Questionnaire, Version C (VNOS-C)*

The VNOS, an open-ended questionnaire, can provide rich, descriptive data on teachers' views of the nature of science. There are several versions available; however,

the VNOS-C was selected based on its depth and appropriateness for secondary science teachers. VNOS-C is made up of ten questions assessing teachers' views on the nature of science.

Content and face validity were established for the instrument using an expert panel made up of three science educators, a science historian, and a scientist. Building on the validity of previous instrument (VNOS-A and VNOS-B), the VNOS-C was found to produce valid results when used in conjunction with follow-up interviews (Lederman et al., 2002). The authors of the instrument suggest that a large number of participants be interviewed for researchers new to using the instrument. The number can be lowered as the researcher becomes more familiar with the instrument.

The open nature of responses provides rich data about teachers' conceptions about the nature of science. This was evident in the pilot of the current study where participants wrote an average of 1300 words in response to the ten questions. However, it was evident from the data that follow-up interviews would be necessary to make valid distinctions about teachers' views of the nature of science.

The use of an open-ended questionnaire overcomes several criticisms of standardized instruments. First, with standardized items it is assumed that participants will perceive the question in the same way as the researchers (Aikenhead & Ryan, 1992; Lederman & O'Malley, 1990). Second, the biases of the developers are often reflected in the development of the instrument (Lederman et al., 1998). Open-ended questions allow participants to provide views that are less constrained than with a standardized, forced-choice instrument.

The very open nature of the VNOS instrument has several drawbacks. First, there is a considerable amount of inference involved in analyzing the meaning of participant responses. In many cases the instrument does not provide a clear indication of whether participants have naïve or informed views. In these cases a follow-up interview is necessary. From a practical standpoint the instrument takes longer for participants to complete and longer to analyze than standardized instruments.

#### *Views of Science-Technology-Society Questionnaire (VOSTS)*

The VOSTS (Aikenhead & Ryan, 1992) is a multiple-choice instrument made up of 116 questions. Of these, 24 are related directly to aspects of the nature of science. A major difference between the VOSTS and other instruments was in the student-centered, empirical development of the instrument. As a result, the instrument retains a high degree of validity.

The content validity of the VOSTS was established through the use of literature on the nature of science and by looking at the theoretical models used to validate earlier standardized instruments (Aikenhead & Ryan, 1992). Further, the instrument developers used empirical data from student responses to guide development. The VOSTS has also been used to assess conceptions of the nature of science held by pre and in-service teachers (Botton & Brown, 1998; Huann-shyang, 2002; Tairab, 2001, Zoller, Wild, & Beckett 1991).

There are several advantages, both pragmatic and theoretical, in using the VOSTS in the current study. From a practical standpoint the forced-choice nature of the instrument takes less time to administer than free-response instruments. The analysis is also simplified, as results require much lower inference about participants' responses.

Consequently less time is needed for follow-up interviews. From a theoretical standpoint the VOSTS allows for the use of parametric statistical procedures, something not easily accomplished with free-response instruments.

Several disadvantages also exist. First, the use of a multiple-choice format results in responses that are not as extensive and rich as a free-response instrument. While interviews can be used to access this information, this itself essentially results in a free-response instrument. Second, the authors of the VOSTS do not provide clarification on what constitutes an adequate view of the nature of science. This places limitations on the interpretation that can be made from data (Lederman, 1986). Finally, the instrument was developed in the context of North American participants and should only be considered valid in that context (Lederman, 1992).

### *Interviews and Teachers' Conceptions of Inquiry*

In conjunction with data from portfolio and nature of science analyses, the present study used semi-structured interviews to access teachers' conceptions of inquiry. Building on the framework of *official* and *personal* conceptions developed earlier in the literature review, interviews can broaden our understanding and allow us to answer new questions.

Interviews provide rich sources of data that would be difficult or impossible to access using survey or portfolio analysis methodologies. Further, they can establish trust through more personal contact, gain access to more subtle shades of meaning, and are flexible enough to follow new lines of thought and ask probing questions.

The current study used a semi-structured interview technique. This method of data collection can capture teacher thinking about teaching that is not available through

other means such as direct observation (Patton, 1990). Others researchers have used semi-structured interviews (Luft & Roehrig, 2007), interviews involving educational scenarios as prompts (Lustick & Sykes, 2006) and interviews centered on scenarios about science learning (Hewson et al., 1995).

In a study of one hundred and twenty NB candidates, Lustick and Sykes (2006) used phone interviews to reproduce a modified version of the NB portfolio. For the interviews teachers were provided with a six-minute video, student artifacts, and several hypothetical teaching situations. Relevant to the current study is the use of hypothetical teaching situations to encourage teacher thought about science teaching. In addition, the use of phone interviews was shown to produce rich and meaningful data in a context similar to the present study.

Once complete, interviews were transcribed and assessors trained for the study scored participants' responses across the thirteen NB standards for *AYA Science*. The interview protocol was successful in identifying statistically significant changes in teacher learning, specifically in the areas of inquiry and assessment. However, inter-rater reliability was measured at 0.458 between the three assessors. This represents a low to moderate reliability in social research. Nonetheless, the work of Lustick and Sykes demonstrated that it is feasible to measure teacher learning and change resulting from the NB certification process using interviews.

Using a semi-structured interview Luft and Roehrig (2007) developed the Teachers Beliefs Interview (TBI) to use with beginning secondary science teachers. The interview protocol was designed to investigate teachers' epistemological beliefs about science teaching. The instrument was further developed and refined through an iterative

process and led to the development of maps that enabled the researchers to follow the development of science teachers. The semi-structured interviews were based around eight questions designed to access the beliefs of the teacher and provide opportunities to probe their beliefs about science teaching. Their work provides a detailed description of the process used to develop and refine an interview protocol, providing insights useful for enhancing the interview protocol used in the current study.

Hewson et al. (1995) used interviews to study teachers' conceptions of teaching science. Using the *Conceptions of Teaching Science Interview* protocol, interview data for twelve experienced secondary science teachers (biology, chemistry, and physics) was collected, coded, and placed in a grid for analysis. Themes emerging from the analysis were explored through a detailed interpretative summary.

The interview protocol consisted of ten events or scenarios for teachers to consider and discuss. The events represented instances where science learning may have been taking place both in and out of the classroom. Teachers are asked to interpret each event and state whether the thought science teaching was taking place. The resulting interview data was then analyzed to determine their conceptions of science teaching.

Based on a constructivist framework, Hewson et al. (1995) maintained conceptual structures representing teachers' conception of science teaching are made up of classroom events, instructional concepts, socially approved behaviors, and explanatory patterns. Further, knowledge of subject matter, the learner, instruction, and context were all related to teachers' conception of science teaching. The importance of context emerged as both a limitation and a strength in the study.

Of importance are the limitations involved in using a protocol such as the *Conceptions of Teaching Science Interview*. Perhaps most noteworthy is the often ambiguous nature of the ten events discussed in the interview. The structure of the interview allows teachers to choose the context in which the events are discussed. While the authors consider this a strength of the protocol, resulting rich data for analysis, it can lead to multiple contexts and make comparisons problematic. Further, with a sample size of ten teachers, the limitation is compounded. While the study did not address teachers' conceptions of inquiry, it does highlight the importance of the context from which teachers are speaking.

The current study placed an emphasis on context through the design of the interview process. Specifically, it considered the context in which NB teachers are discussing inquiry. The two primary contexts were whether they are describing inquiry from the NB perspective (the *official* context) or as it relates to their own day-to-day teaching (the *personal* context). Further, portfolio, Assessment Center scores, and the VOSTS instrument, provided multiple and varied data sources to support data interpretation.

### *Summary*

A review of the literature provided guidance for studying teachers' conceptions of inquiry. Through the use of portfolio analysis, survey data analysis of participants' beliefs regarding nature of science, and a detailed interview data analysis, the current study employed a variety of data sources and instrumentation to answer the research questions. The analysis of portfolio entries provided data on how teachers think about and enact the abilities necessary to do inquiry. The VNOS questionnaire and VOSTS

instrument accessed teachers' understanding of the nature of science. Finally, semi-structured interviews explored the factors influencing teachers' conceptions of inquiry and their interrelationships. Further, they provided data on how the NB process allowed teachers to modify and articulate their vision of inquiry.

### *Factors Influencing Teachers' Conceptions of Inquiry*

Three factors influencing teachers' conceptions of inquiry are explored in this section. These were selected for study due to their importance and gaps in the research literature. The domain knowledge of science by disciplines (biology, chemistry, earth/space science, physics) is the least researched factor, possibly due to the compartmentalization of research on inquiry. While there is more research on subject matter content knowledge in general, its relation to inquiry is limited. Finally, the literature on previous scientific research experiences and their relation to inquiry teaching is explored.

### *Science Discipline*

Schwab (1968) used the terms *syntactical* and *substantive* to describe the structure of a discipline. *Syntactical* knowledge refers to the methods of a discipline that are used to construct knowledge; for example, the use of theories to generate new knowledge or theory building based on experimentation and evidence. The concepts of a discipline and their relationships are described as *substantive* knowledge. In the current study it was speculated that differences in both syntactical and substantive knowledge will result in different approaches and conceptions of inquiry teaching.

Grossman & Stodolsky (1995) argued that in order to analyze reform efforts in secondary schools we must develop a better understanding of the subject matter

differences. Using survey and interview data Grossman found that high school teachers are members of subcultures with different beliefs, norms, and practices. Although the findings are not specific to science and do not involve disciplines, this study does suggest that differences may exist at the discipline level.

Domain knowledge provides a useful construct to explore the differences between the disciplines. Alexander and Judy (1988) defined domain knowledge as the knowledge held about a specific field of study. In the literature it has been called *domain specific knowledge*, *subject matter knowledge*, and *content specific knowledge* and is made up of declarative, procedural, and conditional knowledge (Alexander, 1992).

Some fields consist of more extensive knowledge and tend more towards fundamental principles than other fields (Schwab, 1968). For example, in physics, tasks tend to be well structured with more readily verifiable knowledge. A potential reason that well-defined domains, like physics, have been the subjects of numerous studies about student misconceptions is because a student's response can be verified as correct (Alexander, 1992). Reasoning along these lines, it is expected that NB teachers will hold different conceptions about inquiry related to how their discipline is structured and how knowledge is tested and verified.

Alexander calls for more research into ill-structured domains of knowledge. Research on teachers' conceptions of inquiry across different disciplines adds to the literature by describing the differences in discipline influence teachers' conceptions, enactment, and goals of inquiry.

Using portfolio, VOSTS and interview data, the current study extended these findings to the level of discipline in secondary science teaching, focusing explicitly on

inquiry teaching. While there is minimal research in this area, research done at the departmental level indicates that differences may be found (Grossman & Stodolsky, 1995).

### *Science Content Knowledge*

In an article proposing a research agenda for inquiry teaching and learning, Keys and Bryan (2001) call for more research into the knowledge base necessary for inquiry teaching. They state:

*Studies of teacher knowledge, including pedagogical content knowledge, nature of science knowledge, curriculum knowledge, and student knowledge, will be essential for developing preservice and in-service education for inquiry.*

Of the four domains of knowledge discussed in the proposed research agenda, the authors conclude that that the knowledge base needed for teaching inquiry may be an important and underdeveloped area of research on inquiry teaching and learning. The current study adds to this literature by quantitatively investigating how teachers' science content knowledge relates to the way they think about and implement inquiry and aspects of the nature of science.

T. M. Smith, et al. (2007) maintain that limited research has been conducted on the relationship between science teachers' content knowledge and instruction. However, he notes that the relationship has been shown to be positive in mathematics. To explore the relationship, Smith analyzed data from the National Assessment of Educational Progress (NAEP) instrument for eight grade science teachers. Based on a statistical analysis, a relatively strong association was found between teachers' use of reform-oriented instruction and content-oriented professional development. These findings

highlight the importance of content knowledge for teaching with inquiry and suggest that the current study will be able to describe how science content knowledge relates to different aspects of inquiry teaching.

In a study of ten in-service elementary teachers during a summer program, D. C. Smith & Neale (1989) found improvements in teachers' substantive knowledge. However, the improvements did not take place with respect to their pedagogical content knowledge. Based on their findings the authors state that teachers must have a "*deeply principled conceptual knowledge of the content,*" otherwise the development of PCK is not likely to take place. This research suggests that there is a connection between teachers' content knowledge and practical teaching knowledge. In the current study, content knowledge was compared to teachers' conception and enactment of inquiry. In other words, a comparison of teachers' content and pedagogical knowledge about inquiry was made.

During the pilot study that preceded and informed the present study, science content knowledge was also found to be of importance. In an interview with a biology teacher, content knowledge was described as the most important aspect of the certification process. In preparing for the NB Assessment Center exercises, she studied college texts and expanded and updated her biology content knowledge. As a direct result, she then structured her portfolio entry two, *Active Scientific Inquiry*, around enzymes and the importance of proteins. For her, enhanced science content knowledge enabled changes to her teaching.

Brickhouse (1990) also noted the importance of content knowledge in her study of three high school science teachers and their use of inquiry. Songer, et al. (2001) found

low content knowledge to be one of seven observed challenges to inquiry pedagogy in a study of barriers to using technology-rich science instruction in an urban setting. It is clear that subject matter content knowledge has an important influence on teachers' use of inquiry. The current study sought to explore how specific aspects of teachers' conceptions and enactment of inquiry relate to content knowledge.

### *Previous Scientific Experience*

Teachers' past research experience also appears to influence their use of inquiry teaching. A number of studies support this idea, however they do not address the specific aspects of inquiry and the nature of science that are related to previous investigative experiences.

In a multicase study of pre-service teachers, Windschitl (2003, 2004) found that the single most important factor in their use of inquiry teaching was whether they experienced an authentic inquiry experience as a professional or an undergraduate. Others (Bencze & Bowen, 2001, van Zee, Lay, & Roberts, 2000) have also suggested the importance of experience with inquiry in teacher pre-service education.

The focus on pre-service teachers limits the generalizability of Windschitl's study. In order to more fully investigate this phenomenon, it is necessary to collect data from a larger and more diverse group of teachers; for example, teachers who have been teaching for some time, those entering the profession through nontraditional paths, or teachers of different subject areas. The current study adds to the theoretical knowledge base by extending research to a different population of teachers.

In a study using interpretive case studies of four "highly regarded" high school biology teachers, Friedrichsen & Dana (2005) found that in addition to teachers' beliefs

about learners and the context of their classrooms, prior work also influenced their teaching orientation. In the study, three of the four participants had previous scientific research experiences (Naturalist with the National Park Service, Research Technician in a research laboratory, Research Assistant in a biology laboratory during a master's degree). For these teachers, the experiences were identified as important influences on their teaching goals and strategies.

The use of exemplary teachers in the study allows for a more meaningful comparison to the NB teachers in the current study. Because of the similarity between participants, it is expected that prior experiences will have some influence on teachers' conception and enactment of inquiry teaching. The current study focused specifically on teachers' conceptions of inquiry teaching rather than science teaching orientations in general. Based on the work of Friedrichsen & Dana it was expected that previous research experiences would be influential.

Building on the recognized importance of previous investigative experiences, the current study examined how these experiences influence specific aspects of teachers' conceptions of inquiry and the nature of science.

The literature provides a basis for developing working definitions of inquiry, the nature of science, and teachers' conceptions. Because teachers' conceptions and enactment of inquiry take place in the complex and interrelated contexts of the school and classroom, it is essential that appropriate methodologies and instruments are selected. The literature reviewed here provides support for the development of these research tools.

### *Summary*

Science content knowledge and previous scientific experiences have been found in the literature to influence teachers' use of inquiry. In addition, subject matter discipline has also been seen to influence teaching. However, little research exists in the field of science education and inquiry. The literature provides a starting point for investigating factors that may influence NBCSTs' conceptions, enactment, and goals for inquiry.

## Chapter 3: Methodology

### *Overview*

Teachers' conceptions of inquiry can be thought to arise from both cultural and personal beliefs (Wallace & Kang, 2004). Viewing the current study from a sociocultural perspective informed by the use of a situated cognition framework provided a means to describe and explain factors influencing teachers' conceptions, how they developed, the process by which change takes place, and potential barriers.

The framework of situated cognition was used in the methodological development of this study of National Board Certified Science Teachers. Three central questions were investigated. First, *"How does a National Board Certified Science Teacher's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?"* Second, teachers' science content knowledge was related to their use of inquiry to address the research question, *"How does science subject area content knowledge influence teachers' enactment of inquiry-based teaching and learning?"* Finally, building on question one, the process by which conceptions change was investigated by asking, *"How did the National Board certification process alter teachers' conceptions of inquiry?"*

Because teachers may hold more than one conception of inquiry, it is important to understand the sociocultural context in which teachers conceptualize inquiry. This includes a social and physical context along with consideration of the communities in which teachers work and live. In their study of six experienced high school science teachers, Wallace & Kang (2004, p. 939) stated:

*Our goal was to explore the integration of cultural beliefs and individual beliefs as they impact decisions about inquiry-based science teaching.*

The current study also held a similar goal of investigating how the social and individual contexts of teaching influence teachers' use of inquiry. Combined with interviews, the instrumentation provided rich data from multiple and varied sources.

In this section, the research settings and participants will be described, a procedural framework and instrumentation will be presented, and data analysis will be addressed. Finally, participant confidentiality and a timeline for the study will be provided.

### *Research Setting*

The current study consists of a number of elements being used in a variety of settings. These include teachers' NB certification experiences, completion of the VOSTS instrument and, finally, phone and e-mail interviews. Each of these settings has unique characteristics that relate to both the participating teachers and the type of data being collected. This section will detail each setting with an emphasis on its relation to the research questions.

#### *Portfolio Entry Two: Active Scientific Inquiry*

Prior to the study, NBCSTs have engaged in a one-year time span effort involving planning, teaching, writing, and finally submitting their portfolio. Portfolio construction was completed prior to participants being invited to take part in this research.

Portfolios are created in the context of teachers' schools and classrooms. NBCSTs' portfolio construction consists of planning, teaching, and reflecting on their

own teaching and students' learning. The content of teachers' portfolios, their teaching and student work, are generated in the context of their classroom and school. In most cases, teachers analyze the content and write the portfolios in their homes or offices at school.

For entry two, *Active Scientific Inquiry*, teachers must videotape themselves teaching a lesson in which their students engage in inquiry. The videotape is limited to 20 minutes and is made up of three sections which can be from different days in the inquiry activity. However, all three segments must be from the same class. Sections include students planning an investigation, collecting data, and analyzing and interpreting the results. It should be noted that the classroom setting included the presence of a video camera.

Teachers may also participate in support groups with other teachers undergoing the certification process and teachers who have already achieved certification. However, NBPTS has strict guidelines about viewing portfolios of former candidates (NBPTS, 2009d). NBPTS also provides extensive support in the form of the *Standards for Accomplished Teaching* (NBPTS, 2007) detailed portfolio construction guidelines, and rubrics used to score entries. These provide detailed, science specific information to teachers as they plan, teach, and write their portfolio entry.

The creation of teachers' portfolios takes approximately one year (Lustick & Sykes, 2006). Teachers normally do most of the work starting in the fall semester with a submission deadline of March 31<sup>st</sup> set by NBPTS. It is been noted that teachers spend up to 400 hours on the four entries that make up the portfolio (NBPTS, 2009a).

### *Assessment Center Exercises*

The *AYA Science* portfolio focuses on accomplished teaching and does not provide a measure of teachers' science content knowledge. To do so, the NB administers a series of six 30-minute Assessment Center exercises, usually after teachers have submitted their portfolios. Candidates have a timeframe in which they are able to take these required assessments.

Computer-based assessments are conducted at testing centers located around the United States. A tutorial is available on the web to help candidates become familiar with the software used to administer the exercises. The setting is typical of testing centers administering tests such as the GRE or Praxis. Testing centers provide a quiet, comfortable, computer-based testing environment with an emphasis on a consistent protocol and test security.

### *Interview*

Interview data collection was conducted by phone at a time convenient to the participant. Phone data collection allows for a sample from across the US, accounts for teachers' busy schedules, and is appropriate for the data being analyzed. E-mail was used for follow-up questions and areas that needed minor clarification. On average, each participant took part in two follow-up conversations, either by phone or e-mail.

For the semi-structured phone interviews, teachers were often at their school on a planning period or at their homes. Permission to record the conversation was requested at the beginning of the interview. The interview setting was not uniform across participants; however, this is not thought to have influenced data collection.

### *Participants*

Participants were selected from a national population of National Board Certified Science Teachers (NBCSTs) from the 2007 and 2008 certification cohorts. One pilot participant was from the 2006 cohort.

All participants had successfully completed NB certification in *Adolescent and Young Adult: Science*. In addition, participants held a bachelor's degree, possessed a valid state teaching license, and had completed a minimum of three full years of teaching at the time of their participation in the NB process. Participants were selected using a stratified random selection procedure based on their science discipline (biology, chemistry, earth science, or physics).

National Board Certified Science Teachers (NBCSTs) represent the population for this study. They have successfully completed a rigorous, reflective, and uniform professional development experience. Because of a substantial and uniform treatment, NBCSTs are an ideal population for study. From this population, a subpopulation of NBCSTs with certification in *Adolescent and Young Adult: Science* from the 2007 and 2008 cohort was selected. All participants in this group completed the NB portfolio entry *Active Scientific Inquiry*. In addition, all received identical portfolio instructions and assessment exercises during the certification process.

There are three parts in this study, each building on the findings of the previous phase. First, a pilot study was conducted with three participants to test instrumentation, interview protocols, and analytical techniques. Second, quantitative data was collected through the analysis of 48 NB portfolio entries, *Active Scientific Inquiry*, from the 2007

cohort. Based on results from the quantitative analysis, twelve NBCSTs were interviewed from the 2008 cohort.

Maturation effects are not thought to threaten the validity of the study since teachers' conceptions have been found to be stable over time (Pajares, 1992). As a result, participants' conceptions are not expected to change between the treatment and data collection.

### *Procedural Framework*

The pilot study consisted of three NBCSTs selected from the 2006 and 2007 NB certified cohorts selected using stratified random sampling. This sampling method ensured equal numbers of participants from the different science domain disciplines (biology, chemistry, and physics). Earth science was not included in the pilot due to a limited pool of accessible candidates.

#### *Phase I: Portfolio Analysis*

The first phase of the procedural framework consisted of the analysis of 48 portfolio entries. Portfolio analysis took place over three months during the summer and fall of 2008. Portfolios were read a total of four times and an Interclass Correlation Coefficient (ICC) was calculated after the final reading.

First, portfolios were read and scored using the Portfolio Inventory Instrument (PII) developed and tested in the pilot study. Scores were later used in the statistical analysis of how teachers' enactment and goals of inquiry differ across science disciplines after the last reading of portfolios was complete. Once the initial analysis was complete, a refinement of the PII was conducted to address any ambiguities within the

instrumentation. Emerging themes of participants' enactment and goals of inquiry were assigned initial codes during analysis. As coding progressed these themes were refined.

A second reading of portfolios took place and PII scores were then compared with those from the first reading. Any discrepancies between the two scoring sessions were investigated and when necessary changes were made to clarify the PII tool. Also in the second reading, emerging themes of teachers' enactment and goals of inquiry were further refined and consolidated. During the third reading a similar process was conducted resulting in further refinement of data collection and themes.

A fourth reading was conducted to produce the final scores that were used in the statistical analysis. In addition, major themes in each participant's enactment and goals of inquiry, as evidenced in participants' portfolios, were finalized. Afterwards, ten portfolios were selected at random and scored. These scores were compared to corresponding scores from the fourth reading and an ICC was conducted to document consistency in scoring portfolios.

### *Phase II: Participant Interviews and VOSTS Questionnaire*

Based on the results from the first phase of the study, modifications were made to the interview protocol to be used in Phase II of the study. A procedural framework for Phase II of the study is presented in Figure 1 and is based on the sequence of events that take place once a NBCST agrees to participate. The framework provides the reader with both an understanding of how the study progressed and how the instrumentation supported data collection and analysis.

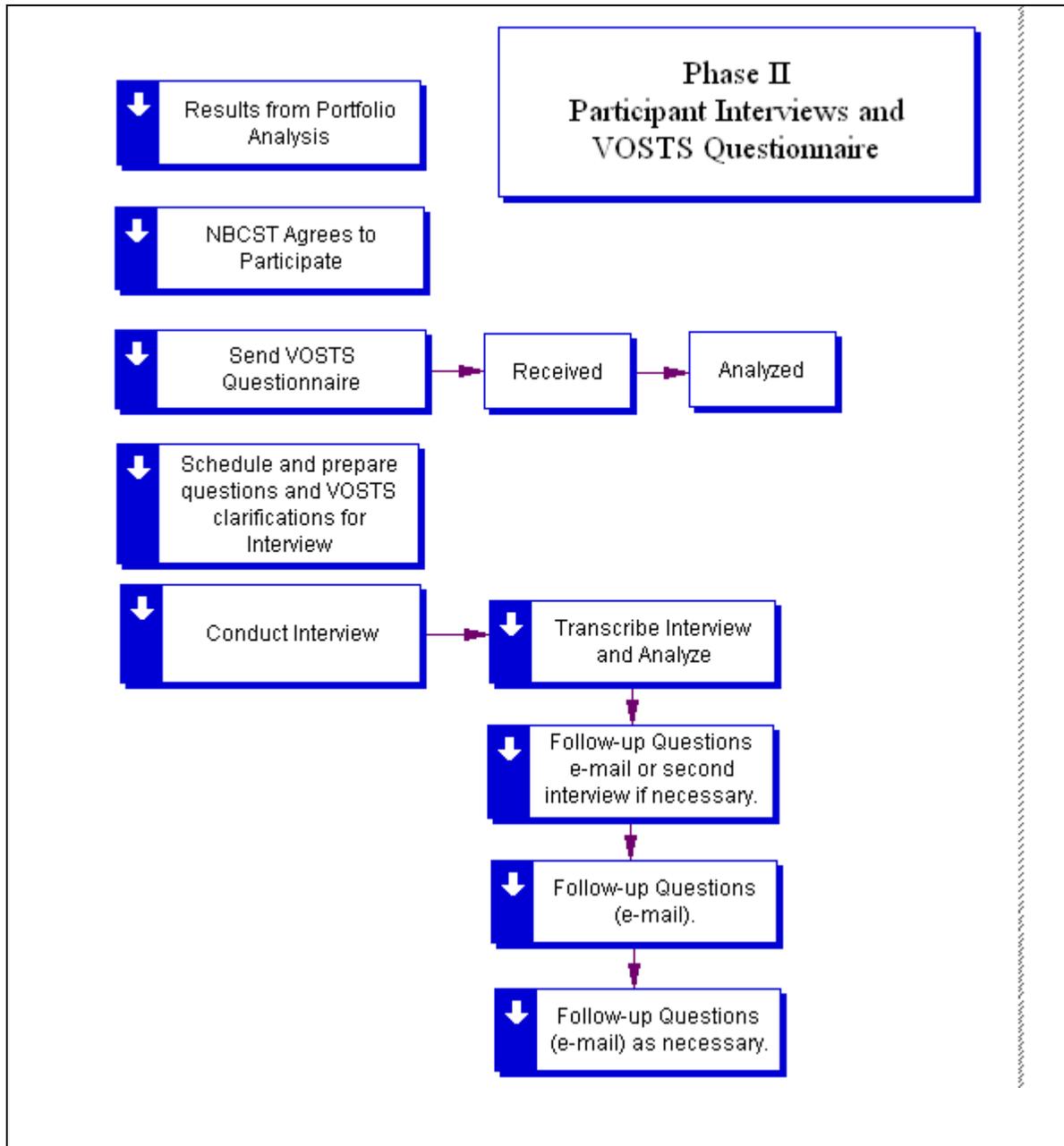


Figure 1. Procedural workflow for proposed study.

Two distinct data sources were used in Phase II. Participants were asked to complete the *Views of Science-Technology-Society* instrument (Aikenhead & Ryan, 1992). In the pilot study, the VOSTS nature of science questions took 20 to 30 minutes to complete.

Second, participants were interviewed to clarify and extend VOSTS survey responses. Interviews took between thirty and sixty minutes. A second interview was conducted when necessary. Follow-up questions were sent to all participants via e-mail and additional follow-up by e-mail and phone were conducted where appropriate.

### *Instrumentation*

Instruments used in the study provide data that are relevant to multiple research questions. Therefore, each instrument is described individually with a focus on its relevance to the study, usage, and validity and reliability.

#### *Portfolio Inventory Instrument (PII)*

Each portfolio was analyzed using an inventory developed by the study author (Appendix A). The Portfolio Inventory Instrument (PII) assesses the degree to which teachers engage their students in inquiry as defined by the National Research Council's (NRC, 1996) *Abilities Necessary to do Inquiry*. The inventory instrument was found to provide a consistent measure of teachers' enactment and goals of inquiry with an Intraclass Correlation Coefficient of 0.84 indicating good agreement between ratings. Since the instrument was based on the NSES, a consensus document developed by science educators and experts, the instrument is expected to have a high degree of face and content validity.

The instrument was designed to measure teachers' enactment of inquiry as described in their written commentary for the portfolio entry: *Active Scientific Inquiry*. Videotape footage was not analyzed in this study.

Written commentary for portfolio entries provided substantial data (13 typewritten pages) about teachers' conceptions and enactment of inquiry. The portfolios being analyzed were not simply teachers' reflections on what they remember about the inquiry activity. Instead, teachers had to describe and analyze what was taking place in video footage of their own teaching submitted with their portfolio. Teachers selected what they perceived to be the best example of inquiry teaching and learning from a larger set of video footage. For many teachers this entry involved looking through video from several different classes, often taken over several days. Based on the depth of the data, the portfolio analysis instrument is thought to provide a valid and reliable measure of teachers' conceptions and enactment of inquiry.

*Views of the Nature of Science Questionnaire, Version - C (VNOS-C)*

In the pilot study the VNOS-C questionnaire was provided to each participant via e-mail and was completed electronically. Teachers were asked to answer questions as thoroughly as possible, save the document on his or her computer, and return a copy via e-mail.

Developers of the VNOS recommend that it be administered under controlled conditions (Lederman et al., 2002). They estimate that the questionnaire takes 45 to 60 minutes but state time limits should not be imposed due to the open-ended nature of the instrument. In the pre-pilot and pilot study most participants took over 60 minutes. Two participants reported taking over 120 minutes.

Most often, teachers complete the questionnaire on their home computer at a time convenient to them. They are asked to refrain from consulting outside sources to assist in answering the questions and informed that there are no wrong or right answers. This is

important since in this setting teachers may have access to the Internet, which would make it difficult to determine their understanding of the nature of science. Due to the widely varying geographical location of participants, it was not feasible to administer the questionnaire under strictly controlled conditions.

### *Views of Science-Technology-Society (VOSTS)*

The VOSTS (Aikenhead & Ryan, 1992) is a multiple-choice instrument made up of 116 questions. Of these, 24 are directly related to aspects of the nature of science. A major difference between the VOSTS and other instruments was in the student-centered, empirical development of the instrument. As a result, the instrument retains a high degree of validity.

Questions from the VOSTS relating to the nature of science were provided to participants via e-mail. In pre-pilot and pilot testing with five individuals (both study participants and others) the instrument took between 20 and 30 minutes to complete. Since the questions are of a forced-choice nature, there is little inference involved in assessing responses. It is important to note that there are no correct responses and therefore no answer key. Responses cover a wide range in sophistication regarding ideas about the nature of science and can be compared to current expert consensus views.

### *Choosing an Instrument*

In the pilot phase of this study the VNOS-C was used to assess teachers' conceptions of the nature of science. Data were collected from three participants, a biology, chemistry, and physics teacher.

The VNOS-C presented several challenges for the current study. These included the amount of time for teachers to complete the questions, achieving a high degree of validity regarding teachers' meanings, and limitations on the type of statistical analysis that can be performed.

First, teachers have reported spending longer than the 45-60 minutes cited by the instrument's developers. Two participants in the pre-pilot and pilot took two hours to answer the questions. It is thought that this may be partially due to the population under study. NBCSTs may be more experienced writers as a result of the NB certification process or may be more experienced teachers. This could have led to lengthier participant responses. Either way, from a practical standpoint, the time factor is cause for concern, especially considering the difficulties experienced in recruiting participants.

Second, while the authors of the instrument call for low inference during analysis, I found analysis challenging. As suggested, follow-up interviews were essential in the pilot study to achieve valid inferences from the data. However, this limited the time available in the interviews for other aspects of the study. Even with follow-up interviews the analysis was challenging.

Finally, due to the categorical nature of the VNOS instrument (naïve vs. informed views), statistical analysis is questionable. This is not the case with the VOSTS where parametric statistical analysis is feasible (Aikenhead & Ryan, 1992).

Comparing VNOS and VOSTS pre-pilot and pilot data it was found that both instruments yielded similar information. As a result, the VOSTS was chosen to collect data on teachers' conceptions of the nature of science.

### *Assessment Center Scores*

After NBCSTs have submitted their portfolio to NB, they are required to complete a series of six computer-based assessments (Data Analysis, Interrelationships, Fundamental Concepts, Change Over Time, Connections in Science, and Breadth of Knowledge). Scores on the six assessment exercises make up 40% of a candidate's total score towards certification.

Science content knowledge scores are generated when teachers complete their Assessment Center exercises. These are reported as raw scores with a value between 1.000 and 4.000. Points are awarded in increments of 0.125. Teachers receive these scores, along with their scores for their portfolio entries, in November or December.

There were several advantages in using Assessment Center scores to assess science content knowledge. First, the instrument is administered using a standardized protocol in an environment specifically designed for testing. Second, because of the security of the test items teachers will have seen the questions before. Finally, NBPTS has over 15 years of experience in writing and administering the assessments. Because of the consequences involved with testing, considerable effort has gone into establishing the reliability and validity of the test instruments.

There were also several important disadvantages. First, as a researcher I did not have access to the assessments with the exception of a set of retired prompts available on the NBPTS website. Second, the Assessment Center exercises were designed specifically for making decisions about accomplished teaching as defined in the NBPTS *AYA Science Standards* and not necessarily intended for research. Finally, scores represent one set of

tests given on one day, something that needs to be noted when considering the validity of the results.

Despite these disadvantages, the assessments offered a unique opportunity to make quantitative comparisons and theorize about the relationship between science content knowledge and teachers' enactment and conceptions about inquiry.

### *Interviews*

Based upon results from the statistical analysis of portfolios, semi-structured interviews took place by phone with e-mail for follow-up and clarification. A second interview was conducted if additional time was needed or to explore potentially useful themes or ideas further uncovered after transcription and analysis of the interview. Prior to interviews, participants received an e-mail with a general outline and topics to think about in preparation for the interview. The interview protocol underwent considerable modification during the pilot study. Changes include the addition of examples to stimulate discussion, questions about inquiry and professional development, and an increased emphasis on the context in which inquiry teaching takes place. In addition, by using the VOSTS instrument, less time was spent discussing and clarifying their understanding of the nature of science. As a result, more emphasis could be placed on teachers' conceptions, enactment, and goals for inquiry.

Based on a sociocultural perspective, perhaps the most substantial change was modifying the protocol to probe teachers' *official* and *personal* conceptions of inquiry. This is accomplished by asking teachers what they think NB wants to see in an inquiry activity for portfolio entry, *Active Scientific Inquiry*. After establishing their *official* conception, they are then asked to describe their *personal* conception. Supporting probes

explore both questions in detail using examples, exploring what is possible in their classroom, and a discussion of how closely the two conceptions align.

Interviews were transcribed immediately and analyzed allowing data collection and analysis to build upon each other in a grounded theory fashion (Charmaz, 2005).

Transcription and analysis were used to inform future participant interviews and make modifications to the interview protocol where necessary.

### *Data Analysis*

Data analysis is described in three sections based on each research question.

Both quantitative and qualitative analyses are listed together where appropriate.

*Question One: Differences in teachers' conception of inquiry between disciplines.*

A one-way analysis of variance (ANOVA) was conducted to determine if any differences existed between groups (biology, chemistry, earth science, and physics) in their enactment of inquiry as seen in their NB portfolio entry, *Active Scientific Inquiry*. Participants' enactment of inquiry was measured for thirteen separate aspects of inquiry using the PII and an ANOVA was conducted for each aspect. For significant differences the Tukey post hoc comparison statistical test was used.

Based on the portfolio analysis, primary themes for of each participant's enactment and goals of inquiry were identified. A frequency table was created with participants grouped by discipline to show trends. Both totals and percentages were reported.

Data from the VOSTS questionnaire were tabulated and participant responses on a set of five VOSTS questions were rated. Ratings were based on a system developed by

Peters (2006). In this system, participants' responses are compared to a panel of experts on the nature of science. Participants are rated as having *Appropriate*, *Appropriate/Plausible*, *Plausible*, *Appropriate/Naïve*, and *Naïve* views of the nature of science. Based on the ratings, descriptive statistics were generated for each discipline. A complete explanation of the rating system and how it was developed is presented in Chapter Four.

Participant interviews, informed by the results of previously discussed analysis, were conducted to provide additional information about how participants' conceptions, enactment, and goals differed across science disciplines. Exploration and statistical analysis of 48 portfolios, along with findings from the pilot study, allowed for well-developed and targeted interview questions.

Interview text was analyzed in an analytically inductive manner to generate profiles for each participant. Each profile consisted of sections that included *Participant Context*, *General Conception of Inquiry*, *Enactment of an Inquiry Lesson*, *Goals of Inquiry*, and *Change*. After all profiles were completed a cross-case analysis was conducted to explore how teachers' conceptions, enactment, and goals for inquiry differed across disciplines.

*Question Two: Relationship between Assessment Center scores (science content knowledge) and conception of inquiry.*

Linear regression was used to determine the relationship between content knowledge scores and each item on the portfolio analysis (independent variable: content knowledge). Spearman's Rho was calculated for each pair of variables. Correlation

coefficients were then presented. Scatterplots were generated for significant results to allow visual inspection of the data.

*Question Three: How did the National Board certification process alter teachers' conceptions of inquiry?*

Participant interviews were conducted to explore how participants' conceptions and enactment of inquiry changed as a result of the NB certification process. Interview data for each participant were explored in an analytical inductive manner to identify emerging themes among participants. Using profiles described in Question One, a cross-case analysis was conducted to investigate how teachers' use of inquiry changed as a result of the NB certification process.

#### *Confidentiality and Data Collection and Storage*

Teachers' information will remain private and will not be made available publicly. Information will not be recorded in such a manner that participants can be identified, either directly or through identifiers linked to participants. The sources will not be publicly available. Written materials disguise the identity of the participants and the location of the person being interviewed. Participants were not identified by name in the transcripts or research report (names have been changed).

Audio tapes and notes gathered during the course of the research are stored by code number at the researcher's home and will be kept in a securely locked metal cabinet. The researcher will be the only person with access to the data, both hard copies and electronic.

Data will be stored in a locked secure metal file cabinet and on a computer hard drive at the researcher's home for 6 years after the study (until 2015). Hard copy data will then be destroyed via a shredder and electronic data will be erased on the hard drive of the researcher's computer.

## Chapter Four: Factors Influencing Teachers' Conceptions, Enactment, and Goals of Inquiry: A Quantitative Analysis

There are a number of potential factors suggested by the literature that influence teachers' conceptions, enactment, and goals for inquiry. The science discipline in which they teach, their understanding of the nature of science (Lederman, 2007), and their subject matter content knowledge (Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989) are all thought to play a role. In this mixed-methods study each factor is explored from both a quantitative and qualitative methodological perspective.

This chapter consists of a presentation and analysis of the quantitative data for the study. Qualitative results will be presented in Chapter 5. Quantitative data and statistical analysis are described in three sections, corresponding to research questions for this study.

The first section explores the research question, "*How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*"

First a statistical comparison of the four traditional disciplines is made using the *Portfolio Inventory Instrument (PII)* developed for this study to analyze data from the 48 *Active Scientific Inquiry* portfolio entries. Second, based on the analysis of these 48 portfolio entries, descriptive statistics are presented describing how NBCSTs' goals for inquiry vary with their discipline. Portfolios analyzed are from NBCSTs who achieved certification in 2007.

In the second section, results from the Views of Science-Technology-Society questionnaire for twelve NBCSTs are presented. The twelve NBCSTs who completed

the VOSTS questionnaire were also interviewed for the qualitative section of this study. Portfolios analyzed are from NBCSTs who achieved certification in 2008.

Research into high school departments (e.g. social studies, English, science) has shown that teachers often define themselves by their department affiliation (Grossman & Stodolsky, 1995). However, no research was found focusing specifically on differences between science disciplines. As a result, no research on disciplinary difference for the use of inquiry was available to inform this study. Further, within the science disciplines Lederman (2007) identified understanding whether teacher views of the nature of science were discipline specific as an area of critical research.

Finally, in the third section results from the analysis of content scores and enactment of inquiry are presented. Content scores are based on the National Board Assessment Center exercises while NBCSTs' enactment of inquiry was obtained using the PII. This final section addresses the research question, "*How does science subject area content knowledge influence teachers' enactment of inquiry-based teaching and learning?*"

Subject area content knowledge has been shown to influence teaching with inquiry (Alexander, 1992; Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989) but there is a dearth of mixed methodology studies with a developed quantitative aspect investigating the link between domain knowledge and inquiry teaching.

### *Influence of Discipline*

Table 1 describes the number of NBCSTs involved in the portfolio analysis section of this study. The study design planned for four groups of twelve. However, two

portfolios were incorrectly labeled as earth science, which were actually chemistry and physics. The error was discovered during portfolio analysis and there was not sufficient time to obtain additional earth science portfolios. As a result, the earth science category only has ten NBCSTs while chemistry and physics each have thirteen.

The unequal sample sizes do not have an overall effect on the statistical analysis with the exception of the Earth Science group. For this group a smaller sample size may have made it more difficult to achieve statistically significant results in the analysis of portfolio items. However, since the sample sizes were similar it is assumed that this did not lead to major differences in the analysis.

All 48 NBCSTs completed the portfolio entry *Active Scientific Inquiry*, which was analyzed using the PII (Appendix A). Table 1 lists the numbers of participants for each discipline.

Table 1

*Disciplines of Participants*

Discipline	n
Biology	12
Chemistry	13
Earth Science	10
Physics	13
Total	48

*Influence of Discipline on Enactment of Inquiry*

To answer the research question, “*How does a NBCST’s science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*” data on teachers’ enactment of inquiry were obtained through the analysis of the NB AYA Science portfolio entry *Active*

*Scientific Inquiry*. A total of 48 portfolio entries were analyzed using the PII developed for this study. The inventory rated each portfolio on 13 items related to teachers' descriptions of their enactment of inquiry. Scores from the portfolio analysis were based on a rating scale from 1 to 5. A score of 1 indicated the enactment of that aspect of inquiry was limited in the portfolio. A score of 5 indicated the item was fully present in the teacher's enactment of inquiry. The inventory instrument was found to provide a consistent measure of teachers' enactment of inquiry with an Intraclass Correlation Coefficient of 0.84 indicating good agreement between ratings.

Prior to data collection it was determined that for the ANOVA a sample size of 48 participants (12 in each of the four disciplines) would be necessary to achieve a significance of .05, a power of 0.8 with an effect size of 0.5. According to Cohen (1988) an effect size of 0.5 is considered large.

A One-Way ANOVA was conducted for each item on the PII. For significant results the Tukey post hoc comparison was used to identify where the differences existed.

Variables are frequently categorized as nominal, ordinal, interval, and ratio as originally described by Stevens (1946). Based on this categorization, the rated data generated by the PII in this study is ordinal data. Therefore, it does not meet the assumption for ANOVA that data is at the interval or ratio level. However, social scientists often use parametric techniques, like the ANOVA, to analyze ordinal data. For example, Seelig (1991) argued that parametric statistical techniques are appropriate for the analysis of Likert-scaled responses. He stated that respondents most often perceive the Likert scale to represent a continuum and therefore responses can be viewed as interval data. The same reasoning applies to the analysis of rank data for the PII.

Furthermore, in the current study PII items are rated on a scale of 1 to 5. Because there are a substantial number of steps in the scale, this increases the likelihood for variance between ratings and further supports the use of the ANOVA.

Statistical analysis detected violations to the assumption of homogeneity of variance in several items analyzed. While the current data set does not meet the assumption of homogeneity of variance in several instances, the balanced sample sizes minimize the effect. In general, with equal or nearly equal sample sizes the ANOVA is robust to the violations of homogeneity of variance (Hinkle, Wiersma, & Jurs, 1998).

Reanalyzing the data using the Kruskal-Wallis, a nonparametric analog of the ANOVA, produces nearly identical results. A major advantage of the Kruskal-Wallis test is that it does not assume normality (Hinkle, Wiersma, & Jurs, 1998), a concern with the data in this study. However, a drawback is that statistical power is often lower making a parametric test more attractive. Results from the analysis using the Kruskal-Wallis test are presented in Table 2 along with the ANOVA results. In every case there is little difference between the two tests. This supports the use the ANOVA for the analysis of PII data.

Since the use of ANOVA to analyze rank data has been accepted as an appropriate statistical technique in the social sciences, compelling arguments for its use exist, group sizes are balanced, and the analysis of data in this study using a non-parametric technique produces similar results, the ANOVA was selected to analyze the differences between biology, chemistry, earth science, and physics teachers' enactment of inquiry.

Results for the One-Way ANOVA are provided in Table 2. The first column, *Item*, refers to individual items on the PII instrument. Statistics for each discipline are

also listed with standard deviations appearing in parentheses below means. The F-ratio and significance level for each analysis is presented for each comparison of groups. An additional column has been added with results from the Kruskal-Wallis nonparametric test.

Table 2

*ANOVA Summary for Portfolio Inventory Items across Disciplines*

Item	Biology	Chemistry	Earth Science	Physics	F	p	Kruskal - Wallis
Item 1A	3.00 (1.28)	1.69 (1.03)	2.00 (1.70)	1.38 (1.65)	4.31	.010	.013
Item 1B	3.00 (1.13)	1.69 (0.86)	1.70 (0.95)	1.38 (0.65)	7.70	< .001	.003
Item 2A	4.50 (0.80)	3.69 (1.11)	3.80 (1.55)	3.77 (1.17)	1.26	.299	.249
Item 2B	4.83 (0.58)	4.15 (0.80)	4.80 (0.42)	4.62 (0.65)	2.95	.043	.33
Item 3A	1.92 (1.38)	2.46 (1.71)	1.80 (1.32)	2.92 (1.80)	1.28	.294	.397
Item 3B	1.75 (1.29)	2.54 (1.81)	2.40 (1.27)	4.23 (1.30)	6.73	.001	.002
Item 4A	3.25 (0.62)	3.15 (0.90)	3.20 (1.23)	4.23 (0.73)	4.39	.009	.010
Item 4B	3.17 (0.58)	3.15 (0.56)	3.30 (0.68)	3.69 (0.63)	2.20	.101	.122
Item 5A	1.67 (1.37)	1.08 (0.28)	1.10 (0.32)	1.31 (0.63)	1.43	.247	.508
Item 6A	4.17 (1.53)	2.46 (1.20)	2.60 (1.65)	2.92 (2.02)	2.74	.055	.083
Item 6B	2.58 (1.62)	2.16 (1.07)	1.50 (0.71)	2.31 (1.65)	1.25	.304	.376
Item 6C	3.25 (1.71)	3.15 (1.28)	2.70 (1.34)	2.38 (1.76)	0.86	.471	.452
Item HYPO	4.58 (0.74)	2.62 (1.61)	3.10 (2.03)	1.77 (1.24)	8.15	< .001	.001

Note: standard deviations appear in parentheses below means.

For significant results the Tukey post hoc test was performed. The Tukey test is appropriate for this analysis since the research questions were asked beforehand. Post Hoc tests were conducted for all items with significant p values ( $p < .05$ ).

Coding examples are provided for each item. However, it was often necessary to read through the entire portfolio entry to accurately score the item as evidence existed in multiple locations in the text of the portfolio entry. These examples are offered to give a general understanding of how items were coded.

Item 1A: *Degree to which teacher supports students' efforts to develop a research question.*

An analysis of variance showed that there was a significant difference,  $F(3,44) = 4.31, p = .010$ , between groups for teacher's support of student questioning. Post hoc analyses using the Tukey criterion for significance indicated that portfolio item scores for biology teachers ( $M = 3.00, SD = 1.28$ ) were significantly higher than for chemistry ( $M=1.69, SD= 1.03$ ) and physics teachers ( $M = 1.38, SD = 0.65$ ).

Coding example: *"To help students think of potential research questions, the class investigated a forested storm-water holding pond behind the school."* was coded as a five. There is evidence students received considerable support in developing their research question.

Coding example: *"I prompted each group with leading questions towards better testable questions and hypotheses when needed."* would be coded as a 3. There is some evidence of discussion about improving questions and hypotheses but not in a structured or comprehensive manner.

Item 1B: *Degree to which students choose own question to investigate.*

An analysis of variance showed that there was a significant difference,  $F(3,44) = 7.70$ ,  $p = < .001$  between groups for students' ability to choose the research question. Post hoc analyses using the Tukey criterion for significance indicated that portfolio item scores for biology teachers ( $M = 3.00$ ,  $SD = 1.13$ ) were significantly higher than for chemistry ( $M = 1.69$ ,  $SD = 0.86$ ), earth science ( $M = 1.70$ ,  $SD = 0.95$ ) and physics teachers ( $M = 1.38$ ,  $SD = 0.65$ ).

Coding example: *“By allowing them to choose the focus of their lab, students are able to choose a topic that interests them and makes the scientific investigation more meaningful.”* would be coded as a five. Students have considerable choice in the topic they will investigate.

Coding example: *“Individuals were allowed to come up with a variable about the process of photosynthesis and a way to test it.”* would be coded as a three. There is evidence that students are given a select a variable to test related to a specific topic.

Item 2B: *Degree to which students conduct scientific investigations.* Despite a value of  $p = .043$  from the ANOVA, no significant differences were detected between groups using the Tukey post hoc test.

Item 3B: *Evidence that teacher encourages and supports use of mathematics in students' investigations, where appropriate.*

An analysis of variance showed that there was a significant difference,  $F(3,44) = 6.73$ ,  $p = .001$ , between groups for students' use of mathematics. Post hoc analyses using the Tukey criterion for significance indicated that portfolio item scores for physics teachers ( $M = 4.23$ ,  $SD = 1.30$ ) were significantly higher than for biology ( $M = 1.75$ ,  $SD = 1.29$ ), chemistry ( $M = 2.54$ ,  $SD = 1.81$ ), and earth science teachers ( $M = 2.40$ ,  $SD = 1.27$ ).

Coding example: “*They were to create graphs to show those relationships, linearize [manipulate the variables of the x and y axis to create a straight line graph] them, if need be, and obtain an equation from that graph.*” would be rated as a five since there is considerable evidence of the use of mathematics in the investigation.

Coding example: “*The goals involving skills were met by the students collecting data in an organized manner, using measurement skills of distance and time, graphing results in the form of a bar graph, and analyzing their results.*” would be rated as a three since there is some use of mathematics in the investigation. While a bar graph is generated, there is little other discussion of mathematics in the portfolio entry.

Item 4A: *Students’ work culminates in an explanation or model of the phenomena (physical or math).*

An analysis of variance showed that there was a significant difference,  $F(3,44) = 4.39, p = .009$ , between groups for students’ work culminating in a model of the phenomena. Post hoc analyses using the Tukey criterion for significance indicated that portfolio item scores for physics teachers ( $M = 4.23, SD = 0.73$ ) were significantly higher than for biology ( $M = 3.25, SD = .62$ ), chemistry ( $M = 3.15, SD = 0.90$ ), and earth science ( $M = 3.20, SD = 1.23$ ) teachers.

Coding example: “*My goal is for students to understand how to develop the big concept of operating a rover and communicating effectively with a planetary rover.*” would be rated as a four since there is evidence students are investigating and modeling interplanetary communications.

Coding example: “*The students were required to present a basic graph of the data and to show the actual model with the correct variables and appropriate units.*” would be

rated as a three since there is some evidence that modeling is involved in the investigation. Here the graph is being used to show a model but is not developed further within the portfolio entry.

Item HYPO: *Degree to which students generated and tested hypotheses in their investigations.*

An analysis of variance showed that there was a significant difference,  $F(3,44) = 8.15$ ,  $p < .001$ , between groups for students' use of a hypothesis in their investigation. Post hoc analyses using the Tukey criterion for significance indicated that portfolio item scores for biology teachers ( $M = 4.58$ ,  $SD = 0.74$ ) were significantly higher than for chemistry ( $M = 2.62$ ,  $SD = 1.61$ ) and physics ( $M = 1.77$ ,  $SD = 1.24$ ) teachers.

Coding example: *"I had them give me example so hypotheses they might use and we discussed that they could only choose one variable in their hypothesis."* would be rated as a five since there is considerable evidence of the use of hypotheses in the portfolio entry.

Coding example: *"Each group had to decide on a single hypothesis to test. They must write their hypothesis and then test it."* would be rated as a four since the use of hypothesis was present but not developed in the portfolio entry.

#### *Influence of Discipline on NBCST Goals and Enactment of Inquiry*

In addition to analysis using the PII, portfolios were also classified into five categories based on the NBCST's goal for the inquiry lesson. These goals are stated explicitly in each portfolio and supported by the description of the NBCST's inquiry lesson in the text of their portfolio.

Teachers' goals and enactment for inquiry were categorized based on their portfolio entry *Active Scientific Inquiry*. In the instructions for the portfolio entry,

NBCSTs are encouraged to identify their goals for the inquiry activity. In addition to NBCSTs' stated goals, the text of the portfolio entry was also analyzed to identify their primary and secondary goals for inquiry. Due to the relatively small sample size there is not sufficient power for meaningful inferential statistical analysis. Results are therefore presented as descriptive statistics.

Categories were developed using an inductive analytical approach based on reading and analysis of portfolios. Four major themes emerged: *Students Conducting Scientific Investigations*, *Science Content Knowledge*, *Critical Thinking/Problem Solving*, and *Modeling*. A fifth category, *Other*, was created for portfolios that could not be easily categorized.

*Students Conducting Scientific Investigations (SCSI)*: For many teachers in this study, inquiry involves students conducting scientific investigations. Investigations typically consist of students asking a question, stating a hypothesis, designing procedures that involve the manipulation of variables (and often specific mention of a control group), coming to a conclusion, and communicating findings to their teacher and peers. Learning science content may also take place; however, it is not the primary purpose.

*Science Content Knowledge*: Participants within this theme emphasize the acquisition of content knowledge as the primary role of inquiry. While students may develop their own procedures, select variables to investigate, or work with mathematical equations, the predominant theme in their conception of inquiry is the development of subject specific content knowledge.

*Modeling*: The theme *Modeling* most often involves the generation of mathematical equations to describe a physical phenomena. In general, students are

presented with a problem or system. They then design a procedure and decide what data to collect. Based on the data, they conduct an analysis, often involving graphing, to generate a mathematical model in the form of an equation to describe the phenomena and predict its behavior. This category also includes a focus on modeling natural systems, for example weather patterns, with an explicit goal of creating a model that could be used to explain and predict natural phenomena. Modeling was not seen in courses other than physics in this study as a major goal or enactment of inquiry.

*Critical Thinking/Problem Solving:* Here the focus is on the actual process of solving a problem through logic or reasoning. It differs from the other categories in that there is little or no emphasis on testing of variables, obtaining content knowledge, or generating models of phenomena. Learning how to approach and solve a problem or think critically is the primary goal and enactment for this theme.

*Other:* There were four individuals placed in the *Other* category. These include, for example, science process skills such as use of laboratory equipment, making measurements, or following a pre-established set of procedures.

In Table 3: Primary Goals of Inquiry, the number and percentage of participants for each theme are presented.

Table 3

*Primary Goals and Enactment of Inquiry*

Discipline	SCSI	Content	Modeling	Problem Solving	Other
Biology	10 (83%)	1 (8%)	--	--	1 (8%)
Chemistry	4 (31%)	8 (62%)	--	--	1 (8%)
Earth Science	6 (60%)	1 (10%)	--	1 (10%)	2 (20%)
Physics	2 (15%)	4 (31%)	6 (46%)	1 (8%)	--

*Primary and secondary goals and enactment of inquiry.*

Primary goals provided useful information on what NBCSTs want students to acquire from an inquiry experience. Both their stated goals and the text of their inquiry portfolio entry provided substantial data for assigning NBCSTs to categories. However, in many cases secondary goals were also present. These provide a more nuanced description of NBCSTs' goals for inquiry. Goals are presented in separate tables for each discipline.

In Table 4, six out of the ten participants with the primary goal for inquiry as *SCSI* do not have secondary themes. This means that there was not enough evidence from portfolio analysis to warrant assigning a secondary goal designation. Three of the twelve participants have *Biology Content Knowledge* as a secondary goal.

Table 4

*Biology NBCSTs' Primary and Secondary Goals and Enactment of Inquiry*

<b>Biology NBCST ID #</b>	<b>Goals of Inquiry</b>
Bio #01	<b>SCSI</b>
Bio #02	<b>SCSI</b>
Bio #03	<b>SCSI</b> <i>Content</i>
Bio #04	<b>SCSI</b> <i>Content</i>
Bio #05	<b>Process Skills</b> <i>Content</i>
Bio #06	<b>SCSI</b>
Bio #07	<b>SCSI</b>
Bio #08	<b>Content</b> <i>SCSI</i>
Bio #09	<b>SCSI</b> Procedures
Bio #10	<b>SCSI</b> Content
Bio #11	<b>SCSI</b>
Bio #12	<b>SCSI</b>

In Table 5, eight participants held a primary goal for inquiry as *Chemistry Content Knowledge*. Of these five do not have secondary themes. This means that they approach inquiry focused almost entirely on *Chemistry Content Knowledge*.

Table 5

*Chemistry NBCSTs' Primary and Secondary Goals and Enactment of Inquiry*

<b>Chemistry NBCST ID #</b>	<b>Goals of Inquiry</b>
<b>Chem #01</b>	<b>Content</b> Procedures
<b>Chem #02</b>	<b>Content</b>
<b>Chem #03</b>	<b>Content</b> SCSI
<b>Chem #04</b>	<b>Critical Thinking</b>
<b>Chem #05</b>	<b>Content</b>
<b>Chem #06</b>	<b>SCSI</b>
<b>Chem #07</b>	<b>Content</b>
<b>Chem #08</b>	<b>Content</b>
<b>Chem #09</b>	<b>SCSI</b> Content
<b>Chem #10</b>	<b>SCSI</b> Content
<b>Chem #11</b>	<b>SCSI</b> Content
<b>Chem #12</b>	<b>Content</b>
<b>Chem #13</b>	<b>Content</b> SCSI

In Table 6, five participants did not have secondary goals. Four of the five participants held a primary goal for inquiry as *Earth Science Content Knowledge*.

Table 6

*Earth Science NBCSTs' Primary and Secondary Goals and Enactment of Inquiry*

<b>Earth Science NBCST ID #</b>	<b>Goals of Inquiry</b>
<b>Earth #01</b>	<b>SCSI</b>
<b>Earth #02</b>	<b>SCSI</b> Content
<b>Earth #03</b>	<b>Process Skills:</b> <b>Measurement</b>
<b>Earth #04</b>	<b>Content</b> <i>SCSI</i>
<b>Earth #05</b>	<b>SCSI</b> Content
<b>Earth #06</b>	<b>SCSI</b>
<b>Earth #07</b>	<b>Observations</b> Content
<b>Earth #08</b>	<b>Problem Solving</b>
<b>Earth #09</b>	<b>SCSI</b> Content
<b>Earth #10</b>	<b>SCSI</b>

In Table 7, only three participants do not have secondary themes. Of the three participants two have *Physics Content Knowledge* and one has *Critical Thinking*. *SCSI* did not appear as a secondary theme for any physics participant.

Table 7

*Physics NBCSTs' Primary and Secondary Goals and Enactment of Inquiry*

<b>Physics NBCST ID #</b>	<b>Goals of Inquiry</b>
<b>Phys #01</b>	<b>Content</b>
<b>Phys #02</b>	<b>Content</b>
<b>Phys #03</b>	<b>Modeling</b> Content
<b>Phys #04</b>	<b>Modeling (Math)</b>
<b>Phys #05</b>	<b>SCSI</b>
<b>Phys #06</b>	<b>Modeling (Math)</b>
<b>Phys #07</b>	<b>Content</b> Critical Thinking
<b>Phys #08</b>	<b>Modeling (Math)</b>
<b>Phys #09</b>	<b>Modeling (Math)</b>
<b>Phys #10</b>	<b>Problem Solving</b>
<b>Phys #11</b>	<b>Content</b>
<b>Phys #12</b>	<b>Content</b>
<b>Phys #13</b>	<b>Modeling</b> Content

In order to provide a comparison between the four disciplines in this study, results are presented together in Table 8. Each cell in the table represents an individual NBCST.

Table 8

*Primary and Secondary Goals and Enactment of Inquiry*

<b>Biology NBCSTs</b>	<b>Chemistry NBCSTs</b>	<b>Earth Science NBCSTs</b>	<b>Physics NBCSTs</b>
<b>SCSI</b>	<b>Content Procedures</b>	<b>SCSI</b>	<b>Content</b>
<b>SCSI</b>	<b>Content</b>	<b>SCSI Content</b>	<b>Content</b>
<b>SCSI Content</b>	<b>Content SCSI</b>	<b>Process Skills: Measurement</b>	<b>Modeling Content</b>
<b>SCSI Content</b>	<b>Critical Thinking</b>	<b>Content SCSI</b>	<b>Modeling (Math)</b>
<b>Process Skills Content</b>	<b>Content</b>	<b>SCSI Content</b>	<b>SCSI</b>
<b>SCSI</b>	<b>SCSI</b>	<b>SCSI</b>	<b>Modeling (Math)</b>
<b>SCSI</b>	<b>Content</b>	<b>Observations Content</b>	<b>Content Critical Thinking</b>
<b>SCSI</b>	<b>Content</b>	<b>Problem Solving</b>	<b>Modeling (Math)</b>
<b>Content SCSI</b>	<b>SCSI Content</b>	<b>SCSI Content</b>	<b>Modeling (Math)</b>
<b>SCSI Procedures</b>	<b>SCSI Content</b>	<b>SCSI</b>	<b>Problem Solving</b>
<b>SCSI Content</b>	<b>SCSI Content</b>	--	<b>Modeling (Math)</b>
<b>SCSI</b>	<b>Content</b>	--	<b>Content</b>
<b>SCSI</b>	<b>Content SCSI</b>	--	<b>SCSI</b>

### *NBCSTs' Conceptions of the Nature of Science*

The nature of science is often considered to be closely related to inquiry (Lederman, 2007). However, the NB portfolio entry, *Active Scientific Inquiry* places little emphasis on the nature of science. Although it is included in the NB Standards document (NBPTS, 2007), portfolio instructions and scoring rubrics make no mention of the nature of science. As a result, aspects of the nature of science are seldom addressed in NBCSTs' portfolios, as seen in the analysis of portfolios in this study.

To better understand participants' views on the nature of science, a subset of items from the Views of Science-Technology-Society (VOSTS) questionnaire was administered to twelve NBCSTs. The VOSTS is an established instrument (Aikenhead & Ryan, 1992) and items have been used extensively in research on students' and undergraduates' views of the nature of science. It has also been used to study pre-service and in-service teachers (Botton & Brown, 1998; Rubba and Harkness, 1996; Zoller, Donn, Wild, and Beckett, 1991). The VOSTS has the advantage of being a low inference instrument with participants selecting a response that best matches their views on the item. Participants were able to complete the subset of items within 20 to 30 minutes.

An alternate instrument, the View of Nature of Science (VNOS) was also tested during the pilot of this study. However, participants required an average of one hour to complete the instrument. In addition, due to the subjective nature of classifying participants' understanding of the nature of science, it was necessary to conduct a follow-up interview. Because participants were practicing teachers and the study took place during the school year, it was decided to use the VOSTS questionnaire, which placed less of a burden on participants.

Participants' responses to VOSTS questionnaire items provide support for the research question, "*How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*"

The data presented should be considered exploratory in nature. This is primarily due to the small sample size (n=12) and the limited number of items analyzed. For example, in his study Peters (2006) used over 200 participants. Due to sample size in the current study it is not possible to conduct statistical analyses; therefore, results are presented as frequencies and broader trends discussed.

Participants completing the VOSTS questionnaire were NBCSTs who achieved certification in 2008. There were three NBCSTs for each certificate area. Table 9 describes the certificate area of NBCSTs and the courses they taught during the 2008-2009 school year.

Table 9

*NBCSTs Completing the VOSTS Questions*

<b>Participant</b>	<b>Certificate Area</b>	<b>Currently Teaching (2008-09)</b>
Amy	Biology	Biology
Scott	Biology	Biology
Tom	Biology	Biology, Physics
Peter	Chemistry	Chemistry
Allen	Chemistry	Chemistry, AP Biology
Anita	Chemistry	Chemistry, Science Research
Donna	Earth Science	Earth Science
Sarah	Earth Science	Earth Science
Cathy	Earth Science	Earth Science, Honors Chemistry, Astronomy, Pre-AP Biology
Diane	Physics	Physics
Carl	Physics	Physics
Jane	Physics	Physics, Biology

*Findings.*

Responses from the VOSTS questionnaire in this study were not appropriate to analyze statistically, primarily because of the small sample size. Although procedures for analyzing VOSTS data have been proposed by Rubba and Harkness (1996) and Vazques-Alonso and Manassero-Mas (1999) these require larger sample sizes than were available for this study where the sample consists of twelve participants. As a result, data from this study are presented as descriptive statistics.

Based on the work of Peters (2006) a column providing an interpretation of each response was added to Tables 10, 12, 14, 16, and 18. There are five possible rankings for each response: *Appropriate*, *Appropriate/Plausible*, *Plausible*, *Appropriate/Naïve*, and *Naïve*. In Peters' study, fourteen college biology faculty served as experts and completed a set of VOSTS questionnaire items. For each item, experts rated indicated their agreement on a scale of one to ten (ten being the highest) for each possible response. Using descriptive statistics, each response was assigned a rating. For example, to be rated as *Appropriate*, "at least two of three descriptive statistics (mean, median, mode) of expert ratings had to be rated at 8 or greater, and at least 80% of the expert ratings had to be between 7 and 9." Ratings were assigned to the other four responses in a similar manner.

These ratings are used here to aid in the analysis of participant responses. The use of only biology faculty is a limitation in using Peters' designations. It is possible that biology NBCSTs in the current study may be more likely to hold similar views of science as college biology faculty. However, none of the items selected contain biology content or themes. Further, as written, the items are discipline neutral. For example, the item dealing with scientific models mentions heat, the neuron, DNA, and the atom as possible models. Therefore it is assumed that the use of college biology faculty as experts will not introduce a bias towards biology teachers in this study.

An advantage of using the VOSTS questionnaire is that participants can only choose from a specific set of responses. This limits the amount of interpretation necessary in data collection and analysis. Further, by using the established categories, for example *Naïve*, *Plausible*, or *Appropriate*, it is possible to compare participants'

responses to an expert consensus. However, it should be noted that views on the nature of science are tentative and subject to change. Therefore their classification should not be taken as absolute and immutable.

Data from five questionnaire items are presented in this study. Items were selected to address a variety of aspects of the nature of science (Nature of Scientific Knowledge: Scientific Models, Nature of Scientific Knowledge: Tentativeness of Scientific Knowledge, Nature of Scientific Knowledge: Precision & Uncertainty in Scientific/Technological Knowledge, Social Construction of Scientific Knowledge: Scientific Decisions, and Nature of Scientific Reasoning: Logical Reasoning, Cause/Effect). These five items were chosen as to provide a representative understanding of NBCSTs' conception of the nature of science.

Results from the VOSTS questionnaire are presented for each question based on the number of responses and the NBCST's certification area. For each certification area (biology, chemistry, earth science, physics) there are three NBCSTs. Tables are used in place of graphs to aid in interpretation of the data.

Table 10

*Nature of Scientific Knowledge: Scientific Models*

<b>Your position, basically:</b> (Please read from A to J, and then choose one.)	<b>Understanding</b>	<b>NBCST Responses</b>
<b>Scientific models ARE copies of reality:</b>		
A. because scientists say they are true, so they must be true.	Plausible/ Appropriate	
B. because much scientific evidence has proven them true.	Appropriate	Phys(Jane) Chem(Peter)
C. because they are true to life. Their purpose is to show us reality or teach us something about it.	No Agreement	
D. Scientific models come close to being copies of reality, because they are based on scientific observations and research.	Plausible/ Appropriate	Chem(Anita) Bio(Amy) Phys(Carl)
<b>Scientific models are NOT copies of reality:</b>		
E. because they are simply helpful for learning and explaining, within their limitations.	Naïve	Bio(Scott, Tom) Chem(Allen) ES(Cathy, Donna) Phys (Diane)
F. because they change with time and with the state of our knowledge, like theories do.	Naïve	ES(Sarah)
G. because these models must be ideas or educated guesses, since you can't actually see the real thing.	Naïve	
H. I don't understand.		
I. I don't know enough about this subject to make a choice.		
J. None of these choices fits my basic viewpoint.		

For the item, Nature of Scientific Knowledge: Scientific Models, 42% of participants held *Appropriate* or *Plausible/Appropriate* views. Of these, all but one

discipline were chemistry and physics. Of those classified as Naïve (58%), all but one were biology and earth science. Chemistry and physics participants tended to hold *Appropriate* (n=2) or *Appropriate/Plausible* (n=2) understandings of the item with the exception of (Allen and Diane). All earth science teachers (n=3) held *Naïve* understandings as did most biology teachers (n=2) with the exception of Amy who held a *Plausible/Appropriate* understanding. Table 11 provides a breakdown of responses by discipline.

Table 11

*Percentage and Number of Responses by Discipline: Scientific Models*

	Naïve	Plausible/ Naïve	Plausible	Plausible/ Appropriate	Appropriate
Biology	66% (2)	-	-	33% (1)	-
Chemistry	33% (1)	-	-	33% (1)	33% (1)
Earth Science	100% (3)	-	-	-	-
Physics	33% (1)	-	-	33% (1)	33% (1)
Total	58% (7)	-	-	25% (3)	17% (2)

Table 12

*Nature of Scientific Knowledge: Tentativeness of Scientific Knowledge*

<b>Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future.</b>		
<b>Scientific knowledge changes:</b>		
<b>Your position, basically:</b> (Please read from A to G, and then choose one.)	<b>Understanding</b>	<b>NBCST Responses</b>
A. because new scientists <b>disprove</b> the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or by detecting errors in the original “correct” investigation.	Plausible/ Appropriate	Chem(Peter) ESci(Donna) Phys(Diane)
B. because the old knowledge is <b>reinterpreted</b> in light of new discoveries. Scientific facts can change.	Plausible/ Appropriate	Chem(Allen, Anita) ESci(Cathy, Sarah) Phys(Carl, Jane)
C. Scientific knowledge APPEARS to change because the <b>interpretation</b> or the application of the old facts can change. Correctly done experiments yield unchangeable facts.	Naïve	Bio(Amy)
D. Scientific knowledge APPEARS to change because new knowledge is <b>added on to</b> old knowledge; the old knowledge doesn’t change.	Plausible/ Naïve	Bio(Tom)
E. I don’t understand.		
F. I don’t know enough about this subject to make a choice.		
G. None of these choices fits my basic viewpoint.		Bio(Scott)

For the item, Nature of Scientific Knowledge: Tentativeness of Scientific Knowledge, 83% of participants held *Plausible/Appropriate* views. All chemistry, earth science, and physics participants responded with *Plausible/Appropriate* views. Of biology participants, none were classified as *Plausible/Appropriate* or *Appropriate*. One participant selected “*None of these choices fits my basic viewpoint.*” Table 13 provides a breakdown of responses by discipline. With the exception of biology, the trend is for all discipline to hold *Plausible/Appropriate* views.

Table 13

*Percentage and Number of Responses by Discipline: Tentativeness of Scientific Knowledge*

	Naïve	Plausible/ Naïve	Plausible	Plausible/ Appropriate	Appropriate
Biology <sup>1</sup>	33% (1)	33% (1)	-	-	-
Chemistry	-	-	-	100% (3)	-
Earth Science	-	-	-	100% (3)	-
Physics		-	-	100% (3)	
Total	8% (1)	8% (1)	-	75% (9)	

<sup>1</sup>One participant responded “None of these choices fits my basic viewpoint.”

Table 14

*Nature of Scientific Knowledge: Precision & Uncertainty in Scientific/Technological Knowledge*

**Even when making predictions based on accurate knowledge, scientists and engineers can tell us only what *probably* might happen. They cannot tell what will happen for certain.**

**Predictions are NEVER certain:**

**Your position basically:** (Please read from A to H, and then choose one.)

A. because there is always room for error and unforeseen events which will affect a result. No one can predict the future for certain.

**Understanding**

**NBCST Responses**

Appropriate

Chem(Amy, Peter)  
ESci(Sarah)  
Phys(Carl)

B. because accurate knowledge changes as new discoveries are made, and therefore predictions will always change.

Plausible/  
Appropriate

Bio(Tom)  
Chem(Allen)  
Phys(Diane)

C. because a prediction is not a statement of fact. It is an educated guess.

Appropriate

Bio(Amy)  
ESci(Cathy, Donna)  
Phys(Jane)

D. because scientists <b>never</b> have all the facts. Some data are always missing.	Plausible/ Appropriate	
E. It depends. Predictions are certain, only as long as there is accurate knowledge and enough information.	Plausible/ Naïve	Bio(Scott)
F. I don't understand.		
G. I don't know enough about this subject to make a choice.		
H. None of these choices fits my basic viewpoint.		

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For the item, Nature of Scientific Knowledge: Precision & Uncertainty in Scientific/Technological Knowledge, 92% of participants held *Appropriate* or *Plausible/Appropriate* views. Only one biology participant held a *Plausible/Naïve* view. The overall trend is for participants in all disciplines to hold *Appropriate* or *Plausible/Appropriate* views. Table 15 provides a breakdown of responses by discipline.

Table 15

*Percentage and Number of Responses by Discipline: Precision & Uncertainty in Scientific/Technological Knowledge*

	Naïve	Plausible/ Naïve	Plausible	Plausible/ Appropriate	Appropriate
Biology	-	33% (1)	-	33% (1)	33% (1)
Chemistry	-	-	-	33% (1)	66% (2)
Earth Science	-	-	-	-	100% (3)
Physics	-	-	-	33% (1)	66% (2)
Total	-	8% (1)	-	25% (3)	67% (8)

Table 16

*Social Construction of Scientific Knowledge: Scientific Decisions*


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**When a new scientific theory is proposed, scientists must decide whether to accept it or not. Their decision is based objectively on the facts that support the theory. Their decision is *not* influenced by their subjective feelings or by personal motives.**

---

<b>Your position, basically:</b> (Please read from A to H, and then choose one.)	<b>Understanding</b>	<b>NBCST Responses</b>
A. Scientists' decisions are based <b>solely</b> on the facts, otherwise the theory would not be properly supported and the theory could be inaccurate, useless or even harmful.	Naïve	Phys(Diane)
B. Scientists' decisions are based on <b>more than</b> just the facts. Decisions are based on whether the theory has been successfully tested many times, on how logical the theory is compared with other theories, and on how simply the theory explains all the facts.	Appropriate	Bio(Amy, Scott) Chem(Anita) ESci(Cathy) Phys(Carl, Jane)
C. It depends on the individual scientist. Some scientists will be influenced by personal feelings, while others will live up to their duty to make decisions based only on the facts.	Plausible/ Appropriate	Bio(Tom)
D. Because scientists are only human, their decisions are, to <b>some extent</b> , influenced by inner feelings, by the personal way a scientist views a theory, or by personal gains such as fame, job security or money.	Plausible/ Appropriate	Chem(Allen, Peter) ES(Sarah)
E. Scientists' decisions are based less upon the facts and <b>more upon</b> inner feelings, upon the personal way a scientist views a theory, or upon personal gains such as fame, job security or money.	Naïve	
F. I don't understand.		
G. I don't know enough about this subject to make a choice.		
H. None of these choices fits my basic viewpoint.		ES(Donna)

---

For the item, Social Construction of Scientific Knowledge: Scientific Decisions, 88% of participants held *Appropriate* or *Plausible/Appropriate* views. Only one biology participant held a *Plausible/Naïve* view. The overall trend is for participants in all disciplines to hold *Appropriate* or *Plausible/Appropriate* views. Table 17 provides a breakdown of responses by discipline.

Table 17

*Percentage and Number of Responses by Discipline: Scientific Decisions*

	Naïve	Plausible/ Naïve	Plausible	Plausible/ Appropriate	Appropriate
Biology	-	33% (1)	-	-	66% (2)
Chemistry	-	-	-	66% (2)	33% (1)
<sup>1</sup> Earth Science	-	-	-	33% (1)	33% (1)
Physics	-	-	-	33% (1)	66% (2)
Total	-	8% (1)	-	33% (4)	50% (6)

<sup>1</sup>One participant responded “None of these choices fits my basic viewpoint.”

Table 18

*Nature of Scientific Reasoning: Logical Reasoning, Cause/Effect*


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**If scientists find that people working with asbestos have twice as much chance of getting lung cancer as the average person, this must mean that asbestos causes lung cancer**

---

<b>Your position, basically:</b> (Please read from A to H, and then choose one.)	<b>Understanding</b>	<b>NBCST Responses</b>
A. The facts obviously prove that asbestos causes lung cancer. If asbestos workers have a greater chance of getting lung cancer, then asbestos is the cause.	Naïve	
<b>The facts do NOT necessarily mean that asbestos causes lung cancer:</b>		
B. because <b>more research</b> is needed to find out whether it is asbestos or some other substance that causes the lung cancer.	Naïve	Bio(Amy, Scott, Tom) Chem(Anita) ESci(Cathy)
C. because asbestos might work <b>in combination with</b> other things, or may work indirectly (for example, weakening your resistance to other things which cause you to get lung cancer).	Appropriate	Chem(Allen, Peter) ESci(Donna, Sarah) Phys(Carl, Diane)
D. because if it did, <b>all</b> asbestos workers would have developed lung cancer.	Plausible/ Naïve	Phys(Jane)
E. Asbestos <b>cannot</b> be the cause of lung cancer because many people who don't work with asbestos also get lung cancer.	Naïve	
F. I don't understand.		

G. I don't know enough about this subject to make a choice.

H. None of these choices fits my basic viewpoint.

---

For the item, Nature of Scientific Reasoning: Logical Reasoning, Cause/Effect, 75% of participants held *Appropriate* or *Plausible/Appropriate* views. All biology teachers held *Naïve* views as did one chemistry and one earth science participant. The overall trend is for participants in all disciplines to hold *Appropriate* or *Plausible/Appropriate* views with the exception of biology. Table 19 provides a breakdown of responses by discipline.

Table 19

*Percentage and Number of Responses by Discipline: Logical Reasoning, Cause/Effect*

	Naïve	Plausible/ Naïve	Plausible	Plausible/ Appropriate	Appropriate
Biology	100%(3)	-	-	-	-
Chemistry	33% (1)	-	-	-	66% (2)
Earth Science	33% (1)	-	-	-	66% (2)
Physics	-	33% (1)	-	-	66% (2)
Total	33%(5)	8% (1)	-	-	50% (6)

*Relationship between Science Subject Content Knowledge and Enactment of Inquiry*

Content knowledge has been found to have an influence on teachers' use of inquiry (Alexander, 1992; Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989). This chapter addresses the research question, "*How does science subject area content knowledge influence teachers' enactment of inquiry-based teaching and learning?*" To

answer this question, NBCSTs' scores on content knowledge assessments were correlated with their scores obtained on the Portfolio Inventory Instrument (PII).

A stratified random sample consisting of a total of 47 NBCSTs selected randomly from the 2008 cohort was analyzed. The sample for this section consisted of the same group of participants whose portfolios were analyzed previously to investigate the influence of discipline on NBCSTs' conceptions of inquiry. Participants were selected equally from the four certificate areas. Biology was an exception and only had eleven NBCSTs due to a data entry error.

For the correlation of the PII items with NBCSTs' content knowledge, a total of 28 participants are necessary to achieve a significance of .05, a power of 0.8 with an effect size of 0.5. This was considered adequate to answer the research question. However, since a sample size of 47 was available, the statistical power increased to 0.97 will maintaining a significance of .05 with an effect size of 0.5. Power analysis was conducted with G\*Power 3 power analysis software (Faul, Erdfelder, Lang, & Buchner, 2007).

Using the PII, NBCSTs' description and enactment of inquiry was measured along thirteen separate aspects of inquiry based on their NB portfolio entry, *Active Scientific Inquiry*. A score between one (the least evidence or presence) and 5 (the most) was recorded for each aspect. These scores represent the independent dependent variable in the correlational study since the research question seeks to find how science content knowledge influences NBCSTs' enactment of inquiry. A detailed description of the PII can be found in the Methodology section of this document.

NBCSTs' content knowledge was measured by their scores from their NB Assessment Center exercises. These scores represent the independent variable in the analysis since the research question seeks to determine their influence on how teachers enact inquiry. A total of six Assessment Center exercises are administered as part of the certification process. Each Assessment Center exercise in this study was given a score ranging from 1.0 to 4.0 by assessors trained by NB. Assessors use NB-developed rubrics and standards to assign scores. The process is "*reviewed annually to ensure that your response receives a reliable, accurate, and fair evaluation.*" (NBPTS, 2009e). A detailed description of the selection of reviewers and the scoring process is available in the Methodology section.

Two NB Assessment Center exercises were used in the analysis. These were *Fundamental Concepts* and *Breadth of Knowledge*. Selection of exercises was made on the basis of how relevant the exercise was to the measurement of NBCSTs' science content knowledge.

#### *Assessment Center Exercises*

The *Fundamental Concepts* Assessment Center exercise focuses specifically on discipline specific content. Candidates must "*demonstrate a depth of content knowledge in your specialized field. You are given a visual, mathematical, or graphical representation of a concept, and you give a description of the concept, analyze relationships, and discuss consequences of changes.*" (NBPTS, 2009b, p. 3). As a result each discipline is given a different assessment based on the content of their discipline.

For the purpose of this study it was assumed that the scores are equivalent measures of NBCSTs' discipline specific content knowledge. To test this assumption

means were calculated for each discipline and were found to be similar (Biology, n=11, Mean=2.9; Chemistry, n=13, Mean=3.1; Earth Science, n=10, Mean=3.2; Physics, n=13, Mean=3.1). This supports the assertion that assessments reliably describe NBCSTs' content knowledge across disciplines. The alternative would be to obtain a larger sample for *each* discipline, in this case a sample size of n=28 would be necessary to achieve the desired statistical power and effect size at a .05 level of significance. Such sample sizes are not available for the 2008 cohort.

The *Breadth of Knowledge* Assessment Center exercise measures candidates' knowledge over a range of science disciplines. Candidates must “*describe a major idea in science*” and “*explain a concept in each of the three major sciences not in your specialty and relate the concepts to the major idea.*” Unlike the *Fundamental Concepts* assessment, here candidates are expected to demonstrate that they are able to relate a concept to all certification areas (biology, chemistry, earth science, and physics). The *Breadth of Knowledge* assessment is identical for all certificate areas.

Each Assessment Center exercise score was correlated to each PII item score. For each exercise a total of thirteen correlations were made. Since PII scores are rank data a Spearman Correlation Coefficient was calculated for each. For significant results a scatter plot was generated to allow for visual inspection of the results.

Participant Assessment Center scores were assigned by NB assessors as part of the certification process. Scores for each PII item were coded after multiple readings of the portfolio entry, *Active Scientific Inquiry*. A detailed description, along with coding examples for each PII item, is provided in the section *Influence of Discipline on Enactment of Inquiry* in this chapter.

*Assessment Center Exercise: Fundamental Concepts.*

The analysis examined the relationships among Assessment Center exercise scores from the *Fundamental Concepts* assessment and each item on the PII. The correlations between pairs are reported in Table 20.

Table 20

*Correlation Matrix for Assessment Center Exercise Fundamental Knowledge scores and Portfolio Invention Instrument Item Scores*

	1A	1B	2A	2B	3A	3B	4A	4B	5A	6A	6B	6C	HYPO
Content Scores	-.01	-.12	.29	.20	.14	.30*	.15	.13	.17	-.09	.02	.39*	-.18

$n=47$

\* $p<.05$ , two tails

\*\* $p<.01$ , two tails

A correlation for the data revealed that NBCSTs' content knowledge scores on the *Fundamental Concept* Assessment Center exercise and Portfolio Inventory Instrument 3B were significantly related ( $r=.30$ ,  $n=47$ ,  $p<.05$ , two tails). However, an examination of the scatterplot indicates that the statistical significance has little practical meaning.

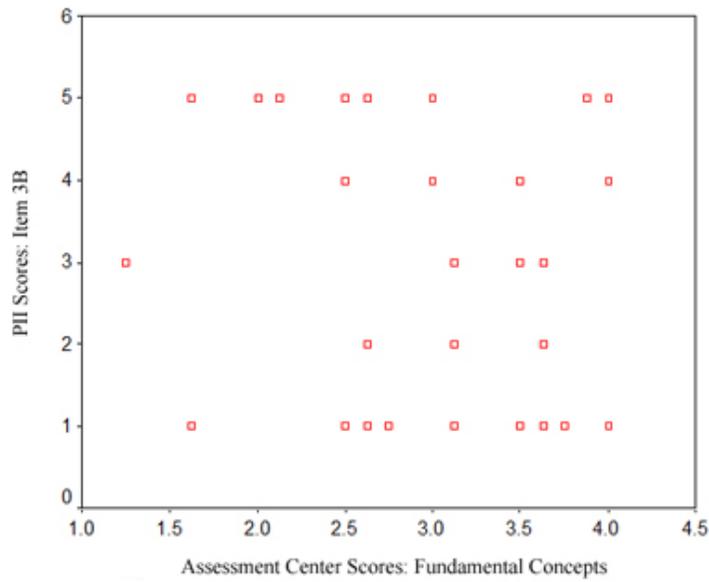


Figure 2. Assessment Center Exercises Scores from Fundamental Concepts assessment and PII Scores for Item 3B.

In addition, correlation revealed that NBCSTs' content knowledge scores on the *Fundamental Concept* Assessment Center exercise and PII item HYPO were significantly related ( $r=.39, n=47, p<.01$ , two tails). However, her again an examination of the scatterplot indicates that the statistical significance has any practical meaning.

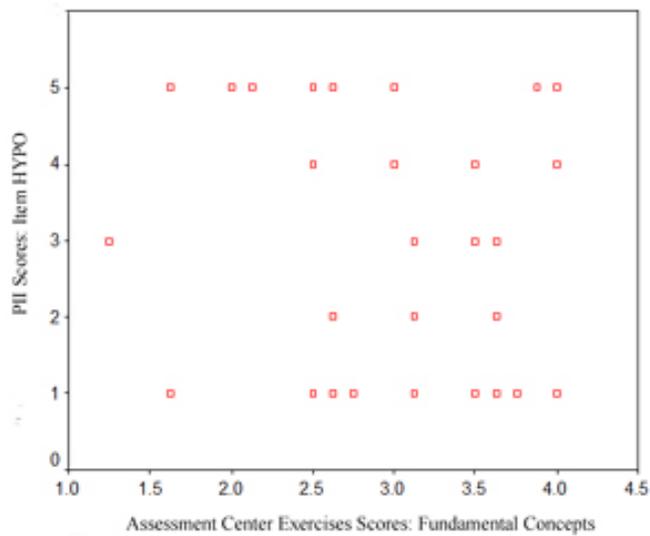


Figure 3. Assessment Center Exercises Scores from Fundamental Concepts assessment and PII Scores for Item HYPO.

*Assessment Center Exercise: Breadth of Knowledge.*

The analysis examined the relationships among Assessment Center exercise scores from the *Fundamental Concepts* assessment and each item on the PII. The correlations between pairs are reported in Table 21.

Table 21

*Correlation Matrix for Assessment Center Exercise Breadth of Knowledge scores and Portfolio Invention Instrument Item Scores*

	1A	1B	2A	2B	3A	3B	4A	4B	5A	6A	6B	6C	HYPO
Content Scores	.12	.06	.09	-.16	-.001	.02	-.07	.18	-.07	.15	.08	.20	-.14

*n*=47

\**p*<.05, two tails

A correlation for the data revealed that no relation existed between content knowledge scores on the *Breadth of Knowledge Assessment Center* exercise and any items on the PII.

### *Summary*

In this chapter, results were presented for the quantitative analysis of several factors that are thought to influence NBCSTs' enactment and conceptions of inquiry. The influence of discipline was investigated using the PII to generate data on NBCSTs' enactment of an inquiry lesson based on their portfolio entry *Active Scientific Inquiry*. The results were then analyzed using a one-way ANOVA to detect any differences between disciplines (biology, chemistry, earth science, and physics). Based on this analysis the following significant results were obtained from the NB high school science teachers who participated in the study:

- Biology teachers are more likely than chemistry and physics teachers to support students' efforts to develop of a research question.  $F(3,44) = 4.31$ ,  $p = .010$ .
- Biology teachers are more likely than chemistry, earth science, and physics teachers to allow students choice of research questions or variables to investigate.  $F(3,44) = 7.70$ ,  $p = < .001$
- Biology teachers are more likely to include the use of a hypothesis in inquiry than chemistry and physics teachers.  $F(3,44) = 8.15$ ,  $p = < .001$
- Physics teachers are more likely to encourage and support use of mathematics in students' investigations than biology, chemistry, and earth science teachers.  $F(3,44) = 6.73$ ,  $p = .001$

- Physics teachers are more likely to have students' work culminate in a model than biology, chemistry, and earth science teachers.  $F(3,44) = 4.39$ ,  $p = .009$

Portfolio text was also analyzed to categorize NBCSTs' goals of inquiry. Results were presented based on NBCSTs' discipline. Portfolios were classified based on four themes that emerged during analysis. These themes are based on teachers' goals and enactment of the inquiry lesson in their NB portfolio entry. They are *Students Conducting Scientific Investigation (SCSI)*, *Science Content Knowledge*, *Modeling*, *Problem Solving*, and a general *Other* category. It was found that:

- Biology teachers tend to view inquiry as *SCSI* (83%).
- Chemistry teachers tend to view inquiry as a means to teach *Chemistry Content Knowledge* (62%) and *SCSI* (31%).
- Earth Science teachers tend to view inquiry as *SCSI* (60%). The remaining participants were distributed across *Earth Science Content Knowledge*, *Problem Solving*, and *Other*.
- Physics tend to view inquiry as *Modeling* (46%), *Physics Content Knowledge* (31%), and *SCSI* (15%).

Trends are explored through participant interviews in Chapter Five.

The Views of Science-Technology-Society questionnaire was used to measure NBCSTs' conception of the nature of science. NBCSTs' responses were presented along with those of experts for comparison. While the sample was not large enough to make statistical comparisons, several trends did emerge.

An overarching finding was that over seventy percent of responses were classified as *Appropriate* or *Plausible* or *Appropriate*. While this is based upon a sample of twelve participants and only five VOSTS items were included in the analysis, it does suggest that NBCSTs hold views of the nature of science similar to experts on the subject.

Disciplinary trends were found in two of the five items. For the item, Nature of Scientific Knowledge: Scientific Models, it appears that chemistry and physics teachers hold views closer to expert judges than biology and earth science teachers. This may be due to the more frequent use of abstract models in these classes. Portfolio analysis was consistent with this finding in that physics teachers were more likely to incorporate modeling in their teaching with inquiry. For the item Nature of Scientific Knowledge: Tentativeness of Scientific Knowledge all disciplines, with the exception of biology, were similar to the expert views. For the remaining three VOSTS items no disciplinary trends emerged and most candidates held views similar to the expert judges.

Finally, NBCSTs' content knowledge, based on assessments given as part of the NB certification, was correlated with their scores on the PII. While several statistically significant results were obtained, upon the visual examination of scatterplots it was decided that these were of no practical significance.

In the next chapter, factors influencing NBCSTs' conceptions and enactment of inquiry will be explored further using qualitative methodologies.

## Chapter Five: Participant Interviews and Cross Case Analysis

### *Introduction*

The statistical analysis of 48 portfolios from the 2007 *Adolescent and Young Adult: Science (AYA Science)* cohort provided a starting point for understanding teachers' conceptions of inquiry and the nature of science, its relation to content knowledge, and how the NB certification process leads to changes in participants' conceptions and enactment of inquiry. However, more depth was needed to provide context and examples of inquiry in teachers' day-to-day practice. To explore this context I interviewed twelve National Board Certified Science Teachers (NBCSTs), who represented the four disciplines of science in this study. They all achieved NB certification in 2008.

All twelve participants received their certification in 2008 in the *AYA Science* certificate area. Within the *AYA Science* certificate area participants specialized in biology, chemistry, earth science, or physics. Invitations were sent via e-mail to a random sample of 2008 NBCSTs until three participants from each of the four certificate areas accepted. I then sent participants the Views of Science-Technology-Society (VOSTS) questionnaires to complete. Upon receipt of the completed questionnaire, I scheduled interviews. Prior to the actual interview, an e-mail with a list of topics was sent to participants to prepare them for the interview. The interview was conducted by phone due to the geographic distribution of participants (see Figure 4). During the analysis and writing stage of this study I sent follow-up e-mails to participants when clarification was needed or further questions emerged.

My original intent was to obtain participants who taught primarily or entirely within one discipline. I made this decision to limit the complexity of participants'

teaching context and provide a clear focus on disciplinary differences. Further, I believed that their conception and enactment of inquiry would be consistent regardless of the subject area within which they taught. Once interviewing began, I found that four of the twelve participants taught in more than one discipline. A fifth taught an additional specialized course on conducting scientific research in addition to her chemistry classes. As interviews and analysis continued it became apparent to me that this complexity offered valuable insights into how teachers thought about and enacted inquiry in different contexts.

In Table 22 I present eight participants who teach primarily biology, chemistry, earth science, or physics. Basic information about their area of NB certification, courses taught at the time this study took place, and years teaching are included in the table. In addition, school setting and participants' educational background are presented. Information on participants teaching in more than one discipline can be found in Table 23. Note that in both tables, course titles, school setting, and educational background are reported as described by participants.

I decided to place multidisciplinary participants in a separate table for both practical and theoretical reasons. From a practical standpoint it is not always clear which discipline they should be grouped with. While they do hold a NB certificate in only one area, this can be misleading. For example, Cathy received her certificate in Earth Science but primarily teaches chemistry. From a theoretical standpoint, the multidisciplinary participants teach in more than one context and are therefore unique.

Table 22

*Participants*

<b>Participant</b>	<b>Certification Area</b>	<b>Teaching (2008-09)</b>	<b>Years Teaching</b>	<b>School Setting</b>	<b>Education</b>
Scott	Biology	Biology	9	Suburban	Bachelor's: Bio Chem minor Master's: Teaching
Amy	Biology	Biology	5	Urban/ Suburban	Bachelor's: Bio
Peter	Chemistry	IB Chemistry	11	Rural	Bachelor's: Bio Master's: Curriculum and Instruction
Anita	Chemistry	Chemistry, Science Research	5	Suburban	Bachelor's: Bio, Master's: Teaching
Donna	Earth Science	Earth Science	14	Rural	Bachelor's: Teaching Earth Science Master's: Science Education
Sarah	Earth Science	Earth Science	8	Rural	Master's: Earth Science.
Diane	Physics	Physics	30	Suburban	Bachelor's: Bio and Education, minors in Chem, Physics Master's: Science Education
Carl	Physics	Active Physics, IB Physics	6	Suburban	Bachelor's: Physics Master's: Teaching

Table 23

*Participant Context: Multiple Disciplines*

<b>Participant</b>	<b>Certification Area</b>	<b>Teaching (2008-09)</b>	<b>Years Teaching</b>	<b>School Setting</b>	<b>Education</b>
Tom	Biology	Biology, Physics	10	Rural	Bachelor's: Bio Master's: Curriculum and Instruction
Allen	Chemistry	AP Biology, Chemistry	11	Suburban	Bachelor's: Bio, minor in Chemistry Master's: Teaching
Cathy	Earth Science	Astronomy, Pre-AP Biology, Chemistry	8	Suburban	Bachelor's: Laboratory Medicine Master's: Science
Jane	Physics	Biology, Physics	8	Urban	Bachelor's: Bio Master's: Bio Education

Figure 4 displays the geographic location of participants. Pilot participants are represented by the check icon. Study participants are represented by the star icon.



Figure 4. Geographic location of participants.

In this chapter I first present description, analysis, and interpretation of participants' conceptions, enactment, and goals for inquiry based on interview and follow-up data. The purpose is to provide insights into the research question, "*How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*"

Next, teachers' views on the nature of science (NOS) are presented to further explore disciplinary differences. Although insufficient data were obtained to address how NOS varies between disciplines, possible reasons for the absence of NOS in participant interviews are explored.

After presenting NOS data, a brief discussion of the relationship between participants' subject matter content knowledge and their use of inquiry is described. Since statistical results did not provide support for a relationship, it was hoped that the qualitative analysis would provide some detail. However, no support was found and after interviewing four participants I decided to focus my efforts on other emerging aspects of this study such as teachers' multiple conceptions of inquiry.

The final section in this chapter explores how teachers' conceptions and enactment of inquiry changed as a result of taking part in the NB certification process. It seeks to answer the research question, "*How did the National Board certification process alter teachers' conceptions of inquiry?*"

#### *NBCSTs' Conceptions, Enactment, and Goals for Inquiry*

In this section I present the conceptions, enactment, and goals for the twelve NBCSTs interviewed in this study. These cases show the diverse contexts and communities in which participants interact and teach. From their general descriptions of inquiry, to more specific classroom enactment and goals, themes emerge in how they think about and enact inquiry. It is from these themes that broader trends across cases are explored.

A major question in this study was how teachers' conceptions, enactment, and goals vary between disciplines. This was explored statistically in Chapter Four and several trends were found. However, the statistical treatment, involving the analysis of 48 NB portfolio entries on inquiry, exists within the context of anonymity and within an environment in which participants are being scored for certification purposes. In order to access a broader set of data and take into account the social nature of teaching, participant

interviews were necessary. The statistical results presented in Chapter Four made it possible to conduct highly focused participant interviews.

For each of the twelve cases, NBCSTs' general conceptions, enactment, and goals for inquiry are presented. For the four participants teaching in more than one discipline, both disciplines are presented and compared. A summary is provided at the end of each case and emergent themes are identified for each participant. These include the themes of *Students Conducting Scientific Investigations*, *Science Content Knowledge*, and *Modeling*. A cross-case analysis is presented afterward to explore broader trends across disciplines.

*Biology: Scott*

*Participant context.*

Scott teaches biology in a suburban school in New York State. He has been teaching for nine years and holds a bachelor's degree in biology (chemistry minor) and a master's in teaching. His classes this year include honors biology made up of ninth graders and a lower ability biology consisting of primarily tenth and eleventh grader students. Scott received his NB certification in biology.

After college Scott worked in an environmental lab conducting soil and water analysis. He also worked for a short time in an industrial chemistry lab running analytical tests and later spent several months running PCR analysis on mouse tissues (DNA analysis). Overall Scott was primarily involved in routine analytical analysis tasks and had a limited role in other aspects such as designing experiments or developing

conclusions from the data collected. As he put it in describing his work with mouse DNA:

*I'd like take little mouse tissue samples, and do like, it was mostly pushing buttons, there wasn't much thinking, add this chemical, dissolve the mouse tail, and I was actually loading a gel and running a electrophoresis, electroDNA analysis on lab mice.*

Due to the routine nature of testing samples his laboratory work had little influence on his teaching. I asked him about the influence of these experiences on his teaching.

*Wayne (Interviewer): Do you feel like that has had an influence on your teaching science?*

*Scott: Probably more in the beginning, you know when I needed to draw examples, draw some examples to help clarify points and help kids understand how science works. I haven't really drawn that much the last couple years. It comes up once in a while but I specifically say "Make sure to tell your story about when you used to do this for living."*

However, I believe that while he does not perceive an overt influence on his teaching and only "comes up once in a while," the experience did orient him to the work in scientific settings and likely plays a role in his conception, goals, and enactment of inquiry.

*General conception of inquiry.*

Scott's primary conception of inquiry is similar to other biology teachers in the study who view inquiry as students conducting scientific investigations. Also similar is the importance he places on student choice as an important aspect of inquiry. Although student choice is important, Scott also believes that for inquiry to be effective it must be structured with clear goals for students. When I asked him what he thinks of when he hears "*inquiry in science teaching*" he responds:

*I think the first word that comes to mind is hesitation. Because it's one of those where whenever you think of an inquiry project you get nervous in saying, "Am I going to have enough time to get that done?" But in some cases some projects are worth it and you can get a lot out of it. I think of balancing the amount of time it takes to get an inquiry project done with the amount of good stuff that will come out of it. That's the first thing that comes to mind for me.*

While Scott believes the use of inquiry is an effective teaching strategy and increases student interest and motivation, his use is bounded by external constraints. Testing and curricular demands compete with inquiry for instructional time. His beliefs about what is possible with inquiry are also constrained by his moving between classrooms several times a day. When asked about his conception of inquiry he responds "*I think the first word that comes to mind is hesitation.*" For Scott, a balance must be established between the benefits of doing inquiry and the impact this will have on meeting the demands of the curriculum and external tests. This tension is discussed three different places in the interview.

When I asked what he would look for in inquiry curriculum, his response highlights a need for inquiry to work within the constraints of his school setting, take place in a manageable timeframe, and at the same time engage his students in conducting a scientific investigation. Here he characterizes scientific investigations as including planning, collecting data, and analyzing the results.

*Wayne (Interviewer): What are the three, say top three, characteristics you'd look for in an inquiry based curriculum that would make it what you want?*

*Scott: Yeah, like doable. First it would have to fit the limitations of our building. It'd have to fit in copier paper box, put out of sight when it's not actually not actually being used. So, you know, things growing in test tubes, things growing in sandwich bags, that kind of stuff. It shouldn't be too long. I'm thinking one week or three for four weeks at the longest. But it should also engage students, they should be seeing something happen and they should also be engaged in the process of tinkering. Where, not only are they watching something happen but they're also wondering if whatever they did is going to cause a change in the end. You know, if they change the concentration of a chemical they should be thinking while the project is going on or while the experiment proceeds, "Is there any difference? Is that difference because of what I did?" Not just like staring at, you know, like staring at a TV screen. Saying "Oh, wow. Look at what's happening. I have no idea why." So, the students, it should be a project that the students should be able to engage in and think about as it progresses and I also think that it should have the, you know, you should be able to plan, data collect, and do data analysis the way that the National Board outlines it.*

My interpretation of Scott's conception of inquiry is that constraints such as time, testing, and the school setting limit his use of inquiry. As a result, while he believes inquiry to be instructionally effective and something he wants to do with his classes, he is struggling to find a balance between constraints and the benefits of inquiry. Based on my conversations with Scott over the course of this study I believe his conception of inquiry is that he sees inquiry to consist of students conducting scientific investigations, similar to the majority of biology portfolios analyzed in this study.

*Enacting inquiry: A biology inquiry lesson*

When I asked Scott to describe an inquiry lesson he talks about his Honors Biology class. He describes students preparing agar gel and placing it in test tubes early in the school year. Then later in the year the students use the gel to investigate factors that influence plant growth. After relating how his students prepared the gel, he states:

*And then whenever I got around to it, maybe a few weeks later, I had them germinate a seed in that gel. It was just an agar gel with a preservative, plant preservative mixture. In the industry, it keeps mold and bacteria from contaminating the gel. So they were to sprout the seed in the gel. I gave them a whole box of different seeds to choose from. It was left over from gardening or whatever, tomatoes, or radishes, turnips, lettuce, there was probably a dozen or more different varieties to choose from. But before they sprouted them I wanted them to melt down their gel and somehow change something, some factor in each of the tubes. So you, know it could have been adding fertilizer, it could have been adding salt, sugar. I tried to narrow it down to one factor, you know, one chemical.*

In the investigation students chose the type of seed they tested and the factor they wanted to change.

*What they had to do was pick a chemical and come up with the different concentrations in each tube. Hopefully they came to realize that one of them should be left alone as a control group.*

Students also were required to select what data they would collect for the investigation.

*One seed placed in a different tube and then a couple of week later they had sprouted and they could collect some data and it was up to them what data they were going to collect. You know, measure the roots, measure the leaves, measure the height of the plant, they were given, we brainstormed as a group and that was part of the portfolio entry, you know, what are we going measure, what's the data that we're going to collect.*

In this lesson students are focused on choosing the type of seed they want to test, selecting a variable to manipulate, deciding what data to collect, and determining if the variable they changed had an effect on the seed growth. His enactment of the lesson supports my assertion that Scott's primary conception is of inquiry involves students conducting scientific investigations.

*Goals of inquiry.*

Scott's goals for inquiry can best be described by the theme *Students Conducting Scientific Investigations*. When I asked about an inquiry lesson for biology he described a lesson about the factors that influence the growth of plants in an agar medium. After

first stating his goals of having students make agar and practice lab safety he cites his inquiry goal as being:

*As far as inquiry goals I just wanted them to come up with a simple experiment, I wanted them to have a single variable, I wanted them to make sure that they could set up an experiment that had a control group, and it had a gradient of the chemicals, not just all or nothing, the control group or nothing, the experimental group with the chemical. I wanted them to have a range of concentration of the chemical in case there was going to be any trends that they would see. I wanted them to choose, go through the process of what data they were going to collect, that was kind of one of the goals also. What are, “I’m not going to tell you what to measure. What are we going to measure? What are we going to count? What are we going to keep track of?” And to realize also one of the major goals is that you’re not going to get to the end when you think you’re at the end. You know, you’re just going to be learning what, if you have to do it all over again what would you do it better.*

Scott’s description of the goals of inquiry further supports his view of inquiry as having students conduct a scientific investigation or as he terms it, to conduct “*a simple experiment.*” The focus on manipulating a variable, having a control group, selecting what data to collect, and the cyclic nature of inquiry highlight how Scott structures his conception of inquiry. Although he discusses the importance of other aspects of inquiry elsewhere in our conversations, my interpretation is that his primary goal for inquiry is for students to have the experience of conducting scientific investigations.

In a follow-up communication, Scott describes his goals for his lower ability biology classes. He has a similar approach to inquiry, although in this case it is a requirement of the curriculum.

*Wayne (Interviewer): Could you tell me a bit about inquiry in your Foundations biology course? What are your goals for those students?*

*Scott: The main goal for these students is to pass the NY state regents exam in biology (known as the Living Environment). There is a significant portion of the curriculum devoted to experimental design. We do lots of practice with designing hypothetical experiments, and usually one or two very simple student designed experiments. Often there is a plant growth experiment where the students choose a simple variable for two groups of plants (water volume, fertilizer, salt). I sometimes have them do a survey project also to try to get the answer to a simple question (i.e. what is your favorite style of music?, do you have a favorite radio station?) to collect data from a large sample size and to get them to carefully craft the survey to get the best quality output. This is at least something they can get into, most experiments don't interest them in the least.*

For his lower ability students the required external assessment is one of the primary drivers of his use of inquiry. In essence conducting scientific investigations, with a focus on design, becomes the content itself. While his description seems in many ways similar to the inquiry he did with his honors biology class, this may be due to the curriculum and I am not sure if he would teach with inquiry in the same manner without this external constraint.

Another constraint is the level of interest his lower ability students have for inquiry. While he states that they are not interested in conducting investigations, he is able to generate an inquiry lesson that stimulates their interest. Nevertheless, I do not believe that he is as enthusiastic about inquiry in the context of his lower ability biology class due to their lack of interest. Further, it is possible that the external testing results in more direct instruction about the components of inquiry rather than actual inquiry, similar to the “*hypothetical experiments*” Scott mentioned in his response.

*Summary.*

Based on my conversations with Scott, and a careful reading of his words, I am confident in categorizing his conception of inquiry as *Students Conducting Scientific Investigations*. My interpretation is supported by his general discussion of inquiry, his enactment of a biology inquiry lesson, and his stated goals.

Discussing inquiry in general, and not related to a specific lesson, Scott cited the challenge of striking a balance between the benefits of inquiry and the amount of time required and the limitations imposed by the school environment. When a balance is achieved, Scott characterizes inquiry as students planning an investigation and collecting and analyzing data.

Further support for classifying Scott’s conception of inquiry as *Students Conducting Scientific Investigations* can be found in his enactment of an inquiry lesson on plant growth. In this inquiry lesson students chose variables they wished to manipulate, planned their investigation, decided on the data they would collect, and conducted the investigation. They then attempted to generate conclusions from their investigation.

Finally, in stating his goals for inquiry in the plant growth lab, Scott cited his primary goal as students designing and conducting a simple experiment. This included selecting a variable to manipulate, having a control and experimental group, making decisions on what data to collect, and coming to the realization that at the end of the investigations they may have generated more questions requiring further research. This is consistent with the category *Students Conducting Scientific Investigations*.

*Biology: Amy*

*Participant context.*

Amy teaches biology in an urban/suburban school in Florida. She has been teaching for six years and holds a bachelor's degree in biology. This year she is teaching honors biology, primarily to ninth graders. Her NB certification is in biology.

Amy received her teacher certification through an alternative certification program. As she states, the program was accelerated and allowed prospective teachers to achieve their certification while teaching high school. Amy explains:

*I guess equivalent that you would take undergraduate but they're kind of accelerated and the excess work is kind of tossed to the side and you're really focused on the twelve practices and building your portfolio, which is at least in Florida is the main goal of all college education classes.*

And

*It was nice because it was cheaper and it was fast and you could do it as long as you taught secondary school, you could do it while you were teaching.*

In describing her coursework she indicated that the program was less intense than a traditional degree in education but maintained the same focus. While it is not possible here to determine how an alternate certification influenced her conception of inquiry, it does represent a different path into teaching.

This interview provides an example of a teacher whose conception of inquiry is different from her enactment. Amy represents one of the few cases where the teacher has a distinct conception of what inquiry “should be” and another that is present in her teaching.

*General conception of inquiry.*

In our initial conversation Amy used the word *discovery* to describe inquiry. Based on our discussion I take *discovery* to mean activating students’ prior knowledge through a demonstration or experience. This helps them ask questions which they can then seek to answer. However, she believes it is then necessary to supplement their learning with factual knowledge. This is shown in her response to my question about how she would describe inquiry. She states:

*I guess it’s letting the students learn through discovery. Um, where they are posed with some sort of, demonstration, or experience that makes them question perhaps their previous knowledge or make them want to learn more, and by doing the activity or the lab work or thinking about the question they kind of come up with, in lack a better word, come up with the answer through I guess discovery learning, and then you supplement what they have discovered with more factual or more of the details of what they have just discovered.*

The need to supplement the inquiry/discovery experience with “*supplement what they have discovered with more factual or more of the details*” could be interpreted to mean that Amy does not believe that inquiry is an effective way for students to learn science content. Her description of inquiry has a structure similar to other biology teachers in the study with students asking questions and taking part in investigations to answer their question. However, she differs in her focus on factual knowledge, something she mentions several places in the interview.

Probing where she was introduced to the term “discovery” I asked her:

*Wayne (Interviewer): When you say discovery learning, is that something that I've heard that term before by a lot of folks, is that you something you studied when you got your science education classes or is it just a term you use?*

*Amy: No, not in college, I think it was a term more so introduced by the alternative certification test that I took, because I don't have a degree in education so to get your certification in Florida they offer, instead of going back to school and getting a masters or bachelors in education you can take alternate certification, which kind of guides you in the education process. That's probably where I discovered it.*

My interpretation is that when she describes discovery learning it originates from her education coursework. However, her use is not well-developed; most likely a result of being removed from our initial discussion and the context of a specific inquiry teaching situation.

From her earlier responses I began to believe that Amy did not hold the belief that inquiry supported student learning is any better than other instructional strategies. In order to explore what she thought about the importance of inquiry, I asked her:

*Wayne (Interviewer): Why do you think inquiry is important to have in our classrooms?*

*Amy: I think that students, if they learn through inquiry based learning it is more impressionable on them and it's more relatable to them, than other the other types of learning that there are, because it asks them to call upon their own previous knowledge and it asks them to think about every day so it allows the student to, I think, to relate a lot of the concepts to their own life and I guess internalize that learning a little bit better.*

For Amy the importance of teaching with inquiry is its relationship to students' previous knowledge and their everyday life. As a result they internalize the concepts "a little bit better." Her choice of wording may indicate that she holds a belief that inquiry doesn't offer significant learning advantages over more traditional teaching strategies such as lecture or worksheets. However, for Amy, it does build connections to students' existing knowledge and experiences outside of the classroom.

At the end of the interview she states her support for inquiry teaching but also cites obstacles that prevent her from doing inquiry frequently.

*Wayne (Interviewer): Do you want to say anything about inquiry in general as we wrap up here?*

*Amy: Oh, I think we went over it. I think that it's a great idea, I think that it makes learning more memorable, but I also think that with the number of standards that we have to cover in any course it would be very difficult to implement it into every activity, every day, or to have an entire curriculum inquiry based.*

Her response could be interpreted to mean that she believes the education community is encouraging inquiry to be the predominant form of teaching, something she does not believe to be possible in her context. Science content, something Amy does not believe is strongly supported with inquiry, is of prime importance as she tries to meet curricular standards. As a result, I believe, Amy has two distinct conceptions of inquiry: what she believes the vision of the science education community to be, and her own personal conception.

*Enacting inquiry: a biology inquiry lesson.*

There is a marked difference in how Amy describes inquiry in general and her enactment of a specific inquiry lesson. In her previous description of inquiry, science content knowledge was reinforced after students answered their research questions. Here it plays a more central role in her example of an inquiry lesson on hypertonic and hypotonic solutions. In the example inquiry lesson provided by Amy, students don't engage in asking questions or designing an investigation. Instead, they observe several different chemical solutions and come to some conclusions about what is happening to the cells in those solutions. The "details" are then presented to the students by the teacher.

*Wayne (Interviewer): Could you talk the, an inquiry lesson plan that you've done, and if it's from your portfolio that's fine?*

*Amy: Ugggggh. Um, well when I teach osmosis and diffusion and stuff along those lines we generally start off with labs which have to deal, like, I know there's a lab, a lab that I do, and I show them, I put it in different solutions, and we blow the egg up, and it shrinks, and they have to figure out the properties and I'll use, you know lettuce or celery or something with dye, and they kind of have to come up with is happening and what's happening to the cells based on what they see, and it kind of leads us into, okay this is a hypertonic or hypotonic solution, and I give them the details but really they come up with the mode of transportation in and out of the cells themselves on their own. I guess that would be the best, that would be one example.*

Her initial response of “Ugggggh” may indicate a discomfort with inquiry. My interpretation is that she believes inquiry is intended to include students designing their own investigations but that there is insufficient time for this to take place in her classroom. Therefore she provides students with directions to conduct the investigation and asks them to make observations. Based on their observations, students then work together to develop explanations for what they observed. Additional details are then provided by the teacher.

In the inquiry lesson on hypertonic and hypotonic solutions students are shown a demonstration and they must figure out what is taking place; in this case, how substances move into and out of cells. From her description it appears that inquiry is used to help students acquire content knowledge. However, inquiry alone is not sufficient and the

teacher must intervene to make sure students have the information. This assertion is supported further when Amy describes the structure students are given when they engage in inquiry.

*Wayne (Interviewer): So when you are doing that what is the structure that the kids have, what is expected of them, from start to finish through that?*

*Amy: Well they are, I have found that it's easier to give the students some sort of direction list instead of asking them to come up with their own directions, which I know is a little bit, some people don't like to do that with inquiry based, they think that that you just give the students, you know, the raw materials they should come up with the plan on their own but sometimes, for lack of time and the pacing in the curriculum I generally give them the directions for how to run the lab, then I ask them to make observations about what they see, and then ask them to compare and contrast the different solutions that they see around the room and the different things that are happening and come up with possible explanations and then we as a class kind of go over what would be good explanations and bad explanations and eventually we narrow it down to the right reason that it is occurring and after that I usually give them a little bit more detailed notes to give them the vocabulary to help them explain what they saw and have come up with, and you know, then we move on.*

Her description is closer to more traditional labs where students are provided a set of procedures and have minimal input into the questions asked or design of the experiment. As she states, “*I generally give them the directions for how to run the lab ...*” In comparison to most other interviews in the study, Amy offers a more limited description of

an inquiry lesson plan. Further, it appears that the primary purpose of the lesson is for students to learn the science content knowledge, which is then supplemented with class notes. Amy differs from most biology teachers in this study with a focus on content knowledge as the central role of inquiry.

*Goals of inquiry.*

In discussing her goals for inquiry, Amy returns to the theme of relating learning to students' previous knowledge and experiences. She also discusses the importance of getting students to enjoy science and be able "to run a good experiment." This is a markedly different from how she enacts inquiry in the classroom example she provides.

*Wayne (Interviewer): When you look at your goals for doing a lesson like that, what would you say your main goals are for the students?*

*Amy: I guess that each student can relate to it, which is probably the most difficult thing in preparing an inquiry based learning, you know lesson or lab, or whatever it may be, is that some students don't have any experiences with produced or whatever materials that you're working with, so that's always a big concern of mine with them.*

When I questioned her further about what she wants students to learn from the experience, she stated:

*Amy: Um, in all honesty? Probably less that they know the exact solutions, but that they can explain things that they see very day, like why wouldn't we put a frog in salt water, in that particular lesson. Overall I would like for them to realize that science isn't necessarily difficult or tedious, nor do you have to have*

*a big vocabulary but you should be able to run a good experiment and know exactly why you got, like you know that your experiment was ran right and there was no other outside variables that could come into it, so that when we get out into the real world they can run simple experiments by themselves and think more scientifically about things.*

Her response is different from the enactment of inquiry in her example lesson. Here she talks about students conducting scientific investigations, students being able to “*explain things that they see very day*” and “*think more scientifically about things*”. In contrast, in her lesson on hypertonic and hypotonic solutions there is no evidence of students conducting experiments or manipulating variables.

*Summary.*

Amy presents a case of an individual holding two differing conceptions of inquiry: one of what she believes inquiry is supposed to look like, and another that she enacts in her classroom. My interpretation of our conversation is that her general conception of inquiry and her goals were constructed from experiences in her teacher education program and the portrayal of inquiry in the education community. Her enactment, however, presents what she believes was possible and appropriate for her students.

I believe Amy holds the conception that inquiry is intended to involve students conducting scientific investigations and as she states, “*letting the students learn through discovery.*” In addition she also believes that content knowledge is an important component. In this sense her conception of inquiry is similar to other biology teacher in this study. Her goals for inquiry also reflect the importance she places on students being

able to conduct scientific investigations or to “*run a good experiment.*” However, this conception may be more based upon what she perceives to be the intent of inquiry in the educational community. Therefore, I place Amy in two categories based on her conception and enactment of inquiry. First, her conception and goals of inquiry are more aligned with the theme *Students Conducting Scientific Investigations* with a lesser focus on content knowledge. Second, her enactment of inquiry would fit into the category of *Content*.

*Biology and Physics: Tom*

*Participant context.*

Tom teaches both biology and physics in a rural school in Wisconsin. He has been teaching for ten years and holds a bachelor’s degree in biology and a master’s in curriculum and instruction. This year his teaching load is split between biology and physics. For physics his students are primarily juniors while his biology students are juniors and seniors. His NB certification is in biology.

Because he teaches in a rural setting Tom teaches a variety of classes which vary considerably from year to year. This year he has to prepare for fewer different classes.

*Wayne (Interviewer): And you said you normally teach biology, physics, and physical science. What’s kind of the, I guess, the ratio there?*

*Tom: It varies from year to year. This year I have, a biology and physics, probably a 50/50 ratio. And it varies, we’re so small and so rural that I end up with different class loads every single year.*

*Wayne (Interviewer): I guess the rural teachers have to teach more subjects.*

*Tom: Everything, right, exactly.*

*Wayne (Interviewer): Okay.*

*Tom: This is one of my better scheduling years; I've only had two preps this year instead of four or five like I normally have.*

Although he does not mention the impact of multiple courses on his use of inquiry, it most likely limits the amount of time he has to plan and prepare for the use of inquiry lessons.

*General conception of inquiry.*

Tom believes teaching with inquiry supports student learning and that students develop a deeper understanding of the science content. Furthermore, he believes that students are more engaged in the learning process. For Tom, inquiry places students in the role of producing or uncovering information with less emphasis on the teacher providing it directly. When I asked him to define inquiry, he responded:

*Tom: I would define it as allowing students to discover scientific facts or information on their own as opposed to giving it to them.*

*Wayne (Interviewer): And why do you think there's a lot emphasis placed on inquiry by the National Board or the National Science Teachers Association?*

*Tom: I think it's real advantageous for student learning. I find at least, that when you tell someone something, it really registers with them, if they can discover it on their own. So they understand how the facts work because they first have established that question and actually recognized that they didn't understand it at the beginning.*

*Wayne (Interviewer): And for you personally why do you think that inquiry is important?*

*Tom: Cause I see the educational significance of it. I see students learn and understand more from it, and I also see it as being a lot more engaging for them.*

*Wayne (Interviewer): Okay. So it's something that they enjoy more?*

*Tom: It's something that they enjoy more and it really also makes the point concrete, whatever that points going to be.*

This general definition of inquiry is broad without offering many specifics. However, in describing specific science lessons he has taught with an inquiry perspective he provides more details. These details offer an opportunity to better understand his conception of inquiry in different disciplinary contexts. Based on his description of an inquiry lesson plan for biology, and another for physics, my interpretation of his use of inquiry suggests that Tom enacts inquiry differently in teaching biology and physics.

*Enacting inquiry: a biology inquiry lesson.*

Based on my conversation with Tom, I interpret his primarily focus in using inquiry in biology to be on students conducting scientific investigations. This is shown with his biology students who are involved in generating a hypothesis, changing a variable, controlling the other variables, collecting data, and coming to a conclusion to confirm or disconfirm the hypothesis.

*Wayne (Interviewer): Is there a biology lesson plan you could talk about just to contrast with the physics?*

*Tom: ... let me think back now, we talked about how exercise increases, or changes body, heart, changes your physical needs, the requirements for you body. So the theory was, the hypothesis was that increased exercise would change your body some how. Is kinda of what I said. They I asked the students to come up with some sort of lab, some sort of test, to try to prove this hypothesis.*

*Wayne (Interviewer): So they were to prove the hypothesis and they had quite a bit of latitude in terms of how they wanted to test that?*

*Tom: Yes, very much so. And the way it worked out, they had recommended that we go to the weight room and we have students, a student on an exercise bike and monitor heart rate, respiration rate, temperature, and uh, there's one more variable, I forget what it was now.*

In his description, students have an active role in selecting the variables they will test and how the experiment is designed. Although they are learning about human physiology the emphasis is on conducting the investigation. Later, recalling an additional variable that students changed, Tom discusses the measurement of how much oxygen was consumed by exercise. In his explanation he discusses how students collected data that did not fit their expectations.

*One of the other variables that they tested for was the amount of oxygen used. So they ended up taking oxygen samples and then of air that was exhaled. It was interesting, those are the numbers that didn't really line up with their hypothesis. They thought that the numbers of oxygen in the exhaled air would go way down, and it didn't go down that much at all. So they started to, certainly try to explain that away, and explain why they that was happened, just happened [?] hypothesis.*

My interpretation is that Tom brings up this example to illustrate the importance of students interpreting data to generate their conclusions, even if it does not fit what they expected to find. This provides further support that Tom conceives of inquiry in biology as students designing and conducting investigations and then generating a conclusion. This is similar to the majority of biology teachers in the quantitative section of this study. However, when teaching with inquiry in physics, he holds a different conception.

*Enacting inquiry: a physics inquiry lesson.*

For physics, Tom's goals involve students gaining an understanding of the content knowledge and developing a mathematical model for predicting the motion of a marble. There is no mention about hypotheses, variables, or data collection. The emphasis is on making calculations based on a given problem and then performing a test to see how accurate their calculations were in predicating an outcome.

*Wayne (Interviewer): Could you describe you an inquiry lesson plan that you've done, in detail.*

*Tom: Sure, I do one in physics that seems to work our pretty well. We have a, I have a student set up a track, like a Hotwheels track, and they set up as a ramp, probably 30 cm tall, and the ramp, this whole track is probably a two feet, three feet long. So it's a ramp that [?] Hotwheels ramp, we use a test, we use a ring stand to hold it up, and it ends up going down to the lab table and they can send a marble off the, we accelerate a marble off of the lab table. So it rolls off and hits a spot on a floor. So can you imagine that setup?*

*Wayne (Interviewer): Yeah, definitively.*

*Tom: Okay, so I show them that set up and I explain that the purpose of doing this is trying figure out exactly where the marble is going to land on the floor. So they calculate that. And this is ahead of learning projectile calculations at all. We haven't done any of that prior to this.*

*Wayne (Interviewer): So you're getting them to kind of figure out how to do it before even ...*

*Tom: Yes. So there's two steps. First of all how are they going to figure out how to do it. What are the calculations involved. And the second part is getting to the math of it. So they go ahead and I give them [?] much like that and tell them to go ahead and figure it out ...*

An essential feature of the projectile motion lab is that students are using calculations to predict where the marble will land prior to being taught the equations involved. While content is an important goal for Tom the emphasis is placed on using math to generate a way to predict projectile motion.

#### *Goals of inquiry in biology.*

The goals Tom has for biology and chemistry are similar to what was found in the quantitative analysis of portfolio entries. Like most other biology teachers in this study, Tom also has a primary goal of having students conduct scientific investigations. He emphasizes the use of hypotheses, developing procedures, controlling variables, collecting data and communicating results.

When I asked what his goal for this inquiry lesson was he emphasized students conducting a scientific investigation.

*Wayne (Interviewer): And what was your goal for doing that with them?*

*Tom: My goal was for them to first of all, take a look at the question, the hypothesis, and take a look at the human body as far as what systems are affected, and then to design an experiment based on that.*

*Wayne (Interviewer): Okay. And when you have them design an experiment, how in-depth do you have them go in terms of talking about variables, and hypotheses ...*

*Tom: Pretty in-depth. We talked about different variables and controls and making sure they had, it was tough for this one because they recognized the fact that you had to have a single person doing the experiment and they also identified the fact that that person would get fatigued after a given amount of time.*

*Wayne (Interviewer): Right. So if you change the person you might have changed ....*

*Tom: Yeah, you change the variable. They felt that if you have the person do the exercise and give them adequate time in between the exercise to catch their breath and get their heart rate back down again that that was sufficient for the experiment.*

For biology, the primary goal of inquiry for Tom falls under the theme of *Students Conducting Scientific Investigations*. Tom described an inquiry lesson where students investigated the effect of exercise on human physiology. When asked about a biology inquiry lesson, he responds:

*... we talked about how exercise increases, or changes body, heart, changes your physical needs, the requirements for your body. So the theory was the hypothesis*

*was that increased exercise would change your body somehow. Is kinda of what I said. Then I asked the students to come up with some sort of lab, some sort of test, to try to prove this hypothesis.*

His description involves a hypothesis for which students were to come up with an investigation. This is echoed in his description of his goals for inquiry.

*My goal was for them to first of all, take a look at the question, the hypothesis, and take a look at the human body as far as what systems are affected, and then to design an experiment based on that.*

Inquiry in biology for Tom is centered on designing and conducting an investigation and then generating a conclusion similar to the majority of biology teachers in the quantitative section of this study. However, when teaching with inquiry in physics, he holds a different conception.

*Goals of inquiry in physics.*

Similarly to other physics teachers in this study, Tom stated goals involve problem solving and developing mathematical models. In this case, students predict the projectile motion of a marble based on their calculations. Content knowledge is less emphasized in the interview but Tom describes it as an important goal. Tom states:

*My goals for them are to have them be able to calculate, first of all, two parts. Number one, to understand the [?] projectile motion. Being, two different forces involved, horizontal and vertical. And the second part is for them to be able to calculate using the formulas that we do eventually learn. And they have actually learned through that process.*

For physics, Tom's goals involve students gaining an understanding of the content knowledge and developing a mathematical model for predicting the motion of a marble. An essential feature of the projectile motion lab is that students are using calculations to predict where the marble will land prior to being taught the equations involved.

*Tom: Okay, so I show them that set up and I explain that the purpose of doing this is trying figure out exactly where the marble is going to land on the floor. So they calculate that. And this is ahead of learning projectile calculations at all. We haven't done any of that prior to this.*

*Wayne (Interviewer): So you're getting them to kind of figure out how to do it before even ...*

*Tom: Yes. So there's two steps. First of all how are they going to figure out how to do it. What are the calculations involved. And the second part is getting to the math of it. So they go ahead and I give them [?] much like that and tell them to go ahead and figure it out ...*

While content is an important goal for Tom the emphasis is placed on using math to generate a way to predict projectile motion.

#### *Comparison of inquiry in biology and physics.*

In addition to having differing conceptions of inquiry for physics and biology, Tom believes that teaching physics with inquiry is easier than biology. His comments suggest that inquiry in biology is more complicated and with less certain outcomes than physics.

*Tom: To go along with that I find it much easier to use in physics.*

Wayne (Interviewer): Really?

Tom: *I don't know why that is, I suppose because there just so many more activities that I'm used to use or able to use in physics. It seems like every day I can throw three or four different labs or activities in and I change those to make them inquiry based. And for biology it seems like a lot of the labs turn to be more difficult and [?] start out with a hundred and seventeen different step process to get through them and it's more difficult to modify those.*

Wayne (Interviewer): *That's kind of interesting ...*

Tom: *There's great examples from both, you can do all kinds of different things with plants and animals. But I just find it a lot easier to use in physics.*

One interpretation is that the structured approach Tom uses with biology allows him to manage the perceived complexity or the “*hundred and seventeen different step process to get through.*” For physics his goal is more centered on problem solving and content knowledge. In his physics inquiry lesson there is only one correct answer and the outcome is known. Therefore, there isn't as great a need for the structured approach he used with his biology inquiry lesson. In contrast, in the biology inquiry lesson there are a number of challenges in designing the investigation and the outcome is less certain. This not only gives students more choices in the design, data collection, and discussion, but also requires more flexibility for the teacher.

*Summary.*

This is an informative interview primarily because Tom teaches both physics and biology. As a result, the interview provides insights into how a single teacher can have

differing conceptions of inquiry based upon their teaching context. While his general conception of inquiry does not offer many specifics, his description and goals of a biology and physics lesson plan follow the disciplinary trends seen in this study.

In his description of a biology lesson, Tom approaches inquiry with a focus on students conducting scientific investigation. His enactment consists of students engaging in generating hypotheses, experimental design, manipulating variables, and coming to a conclusion based on the original hypotheses. For physics, the emphasis is on figuring out how to predict the path of a marble rolling down an inclined plane. Here, students use mathematics to understand the relationship between variables and develop a model to predict projectile motion.

Prior to the interview, I was not aware that Tom taught both biology and physics. In recruiting participants my intent was to only invite NBCSTs who taught within one discipline. This proved to be difficult because of year-to-year changes in course scheduling. However, I found that because Tom teaches in more than one discipline his interview offered insights into the influence of discipline on teachers' conceptions, enactment, and goals for inquiry.

Based on my conversations with Tom, I believe his conception, enactment, and goals for inquiry depend upon the discipline in which he is teaching. For biology, the theme of *Students Conducting Scientific Investigations* is most appropriate. For physics, he is most closely aligned with the theme of *Modeling*. Perhaps most important is that Tom provides a case showing that teachers' conceptions of inquiry are not static and can be considerably different depending upon the context in which they are teaching.

*Chemistry: Anita*

*Participant context.*

Anita teaches chemistry in a suburban school in Florida. She has been teaching for five years and holds a bachelor's degree in biology and a master's in teaching. Her classes this year include honors chemistry, Advanced Placement Chemistry, and a course entitled Science Research. Students in her Science Research class conduct research in preparation for a science fair competition. Anita received her NB certification in chemistry.

Anita is of special interest because she teaches in three different contexts; Honors Chemistry, AP Chemistry, and Science Research. This provides an opportunity to explore her use of inquiry with differing external constraints.

*General conception of inquiry.*

The interview about Anita's conception of inquiry is shorter than most participants in the study. Initially I found it difficult to discern Anita's description of inquiry. When I asked her to describe what she thinks of when she hears the term "inquiry in science" teaching she replies:

*Anita: Pretty much self discovery where the students are actually engaged and trying to figure a problem out.*

*Wayne (Interviewer): And what are they doing when they're figuring the problem out? What structure would go along with that?*

*Anita: Well there's a proposed question and then through some guided suggestions, and letting them brainstorm and then guiding them through the problem to achieve the actual outcome.*

*Wayne (Interviewer): Okay. And what would a goal of that be, from an educational standpoint.*

*Anita: Actually if they're learning it on their own or they're figuring it out they're making more connections where it's more likely to be remembered.*

The brevity of her response could be interpreted to mean that her conception of inquiry is still developing. Anita describes inquiry as a process of “*self discovery*” where students are solving problems with some guidance from the teacher. However, she sees the educational purpose of the discovery process as students “*making more connections where it's more likely to be remembered*”. The goal of students remembering information indicates that she believes supporting chemistry content knowledge is the primary focus of inquiry.

*Enacting inquiry: a chemistry inquiry lesson.*

Her description of an inquiry lesson plan is consistent with her initial description which focused on content knowledge and problem solving. When asked to describe an inquiry lesson plan in detail for her honors chemistry class, Anita talks about a lab where students are studying double replacement chemical reactions.

*Anita: Students were given eight unknowns. And they were given a list of the possible substances they could be. We had finished completing chemical reactions, double replacement, single replacement, [?] reactions, and had done*

*some basic labs with those. They were asked to figure out, to describe a way to identify the unknowns, and then they actually proceeded back to the lab to do so.*

*Wayne (Interviewer): So they were given the unknowns and what they might be and their job was to determine what the unknowns were.*

*Anita: Right.*

*Wayne (Interviewer): And what was your goal for them doing this lesson?*

*Anita: It was for them to actually figure out that the double replacements and to see the different colors of the precipitates that formed.*

Anita's goals for this inquiry lab are limited to developing a procedure to identify unknown chemicals based on the colors and precipitates formed by double replacement reactions. Based on her description of the lesson plan, and her stated goals, my interpretation is that Anita's enactment of inquiry is related to students developing an understanding of double replacement chemical reactions and problem solving. However, because her responses did not offer many specifics, this assertion is more tentative than with other participants. Both structured scientific investigations (manipulating variables, control groups, etc) and developing models of phenomena did not emerge as themes in our conversation. The primary purpose of inquiry for Anita is the development of chemistry content knowledge.

Further support that chemistry content knowledge is a primary goal from Anita can be found in her response where she clarifies the term "*self-discovery*".

*Wayne (Interviewer): When you say self-discovery, could you explain a little bit more? I've heard someone talk about discovery and I just want to see what you mean by it.*

*Anita: Yeah, for example I do a lab where, it's a rates of reactions, and they have to figure out what's affecting the rate of reactions and before that what knows what actually affects the reaction I have, we set up and say "What can we do with this and how does this differ?" and they do a few things and one of them is the different temperature of water. And I give them an Alka-Seltzer tablet and after performing it and playing around with it what they notice is that the hot water tablet dissolves faster. And so by increasing the temperature they're actually seeing the rate of reaction is increasing with me actually going over that concept.*

Her response indicates that by experiencing the chemical phenomena firsthand, students will learn the concept without the need for direct instruction. Here again, the focus is on the content knowledge. In this case the discovery/inquiry experience serves as a substitute for more traditional instruction.

Both her purpose and definition of inquiry are not specific and do not include themes such as students experiencing work like scientists, increasing students' interest in science, or generating models. For Anita, the primary goal of inquiry is for students to be able to better remember the content knowledge involved in the investigation with a secondary goal is to engage students in problem solving. This suggests that inquiry for Anita is primarily a means to help students acquire and recall chemistry content.

*Enacting inquiry: a scientific research course inquiry lesson.*

Anita also teaches a class called Scientific Research. Students in the course conduct their own research that will be entered in a science fair. Her description of inquiry in this course is more specific about the elements and structure of students' investigations.

*Yeah, it's actually based mainly for students participating in our science fair. So they're working on a lot of individual projects or small group projects where they're actually coming up with the problem, designing the experiment, implementing either at school, at research facilities, or at home. And then presenting in the fair. And then after the fair I do a bunch of group projects where they're doing a Rube Goldberg and they have to come up with a way to finish that as well.*

In the Scientific Research course students are assuming the role of scientist and conducting experiments. They are asking the questions, designing the experiment, collecting data, and then presenting their findings at a science fair. Their investigations are supported by a formal structure mandated by the international rules for science fairs.

*Anita: We have to follow the international rules as well. So that when they move on to state or international fairs all the paperwork is set aside correctly.*

*Wayne (Interviewer): And would you term what they're doing as inquiry?*

*Anita: Definitely. Because they're actually coming up with the question and then trying to find a way to a way to prove it or solve it or get more information on that topic.*

*Wayne (Interviewer): So they develop the question and they would design the procedures and you would sign off on that. What would they do after that?*

*Anita: Then they would actually perform the procedures and collect the data and analyze the data and then finally make a final conclusion based on that experiment.*

In her response to whether her students are doing inquiry, she cites asking their own question as evidence. According to Anita, they must “*actually coming up with the question and then trying to find a way to a way to prove it or solve it,*” an idea she discussed earlier in the interview. In describing inquiry in her Scientific Research external constraints define how she engages students in inquiry. The International Science Fair rules must be followed if students are to be able to compete in state, national, and international science fairs. However, approach to inquiry does not transfer to her honors or AP Chemistry courses.

#### *Goals of inquiry for chemistry.*

Based on the evidence presented in this participant profile, for Anita the primary goals of inquiry are to support learning chemistry content knowledge and to engage students in problem solving. However, analysis is difficult due to the limited interview data.

#### *Goals of inquiry for scientific research.*

The International Science Fair rules and regulations provide an external model of inquiry for Anita. What is intriguing is that Anita has a structure for inquiry in her Scientific Research class but does not apply it to her chemistry classes.

She believes her students are engaged in inquiry but her conception is different than that of her honors and AP Chemistry classes. This may be related to the goals for each class. Chemistry contains more content knowledge whereas the Scientific Research is driven by conducting actual research. Still, her conception of inquiry in Chemistry differs considerably from her Scientific Research class. This provides another instance where the conception of inquiry is dependent upon context.

*Goals of inquiry for AP Chemistry.*

Similar to other teachers in the study, Anita finds it difficult to do inquiry with her AP class due to time constraints imposed by the curriculum. In contrast to her Science Research course, the external structure of AP Chemistry constrains her use of inquiry. In AP Chemistry inquiry is described as being “*open activities*” with a goal of building interest in the chemistry content knowledge.

*Wayne (Interviewer): With AP could you talk a little bit about how you might do inquiry in an AP setting?*

*Anita: AP is probably a little harder to do because of all the requirements and required labs. But I do try to do open activities to engage them and get them interested in the chapter topic that we are going to be covering. And that may be by performing the lab and then having them describe what happened and how that applies to what we're going to be learning.*

*Wayne (Interviewer): With AP what are your goals with inquiry? Why do you think it's important for them to do?*

*Anita: Again with the inquiry they're making all those connections. It's going to be a lot easier for them to learn it and remember it if they're the ones actually doing the process instead of me getting up there and saying this is how it is.*

For AP Chemistry the primary goal is for students to remember the content. As she states, “*it is going to be a lot easier for them to learn it and remember it*”. Inquiry offers an effective way to support this learning. An overarching contextual feature of AP courses is the external exam administered at the end of the course. The exam has consequences for both students and teachers. For students, doing well can result in placing out of college courses. For teachers, student scores are reported back to the school. I interpret the goal of students remembering content to be a result of the external AP exam.

#### *Summary.*

Three different contexts for teaching with inquiry are presented here: Honors Chemistry, AP Chemistry, and Science Research. Comparing the use of inquiry within those contexts can enhance our understanding of how external testing and curricular constraints can influence a teacher's use of inquiry.

Like many other participants teaching in more than one discipline, Anita held different conceptions of inquiry depending on the context. For her chemistry class this followed the theme of inquiry as a means to teach science content knowledge. In her Science Research class the focus was on students conducting scientific investigations.

In Anita's Science Research course the curriculum, based on the International Science Fair rules, imposed an approach to inquiry. As a result the class focused on

conducting scientific investigations. In contrast, the AP Chemistry curriculum places an emphasis on chemistry content knowledge which is assessed by an external exam with consequences for both students and teacher. As a result Anita approached inquiry with the purpose of supporting content knowledge.

The two classes, Science Research and AP Chemistry, are at opposite ends of a spectrum. The both placed external constraints on how Anita used inquiry but those constraints resulted in students conducting scientific investigations in one class and focusing on chemistry content in another. Finally, in her Honors Chemistry class, Anita viewed inquiry primarily as chemistry content with a secondary emphasis on problems solving. This is similar to her initial general definition of inquiry. I interpret this to be how she views inquiry in a less constrained context.

*Chemistry: Peter*

*Participant context.*

Peter teaches chemistry in an urban school in North Carolina. He has been teaching for eleven years and holds a bachelor's degree in biology (chemistry minor) and a master's in teaching. His classes this year include International Baccalaureate (IB) Chemistry and Honors Chemistry. Peter received his NB certification in Chemistry.

After college Peter held several jobs involving the chemical analysis of samples. He worked in an environmental chemistry lab, an industrial lab, and for a short time in a lab where he analyzed mouse tissue samples. These jobs involved routine sample analysis and did not involve planning or designing research. Overall the jobs were of a short duration and Peter did not find them particularly demanding.

*I didn't feel terribly challenged. Once I learned how to use the FTIR and not break it. then I found myself doing the same thing every day, ...*

Peter came to teaching through the Teach for America program. As a result he was able to begin teaching immediately without completing a teacher preparation program.

The majority of the interview discusses inquiry in Peter's International Baccalaureate classes. The IB program has specific curricular requirements, rubrics, and assessments. Therefore, a challenge for this participant profile is to separate his conception of inquiry from the vision provided by the IB program.

*General conception of inquiry.*

When asked to describe what he thinks of when he hears the term “*inquiry in science teaching*” Peter immediately begins discussing inquiry in the context of the International Baccalaureate program.

*For me a lot of the inquiry learning, for IB anyway, they have to do a series of planning or design labs, where they have to choose their own experiment give a very broad starting point, like, investigate factors influencing the rate of chemical reactions is one that my juniors are doing. They get to pick whatever they want, they start by picking a dependent, an independent variable, excuse me, and a dependent variable, preferably one that they can graph if at all possible. Something that is continuously changing over a range of values. Like temperature or volume of carbon dioxide collected or something. So they have to plan out the lab, the procedures, the materials, the hypothesis, all that kind of*

*stuff. Then they have to actually carry out the lab and then do analysis, conclusion, and evaluations and all that kind of stuff. That's, when I do inquiry in chemistry it's often in the form of something like that. I try to keep it, it's required for IB so it's convenient, you know, it's not like I have any way around it. [?] But I enjoy it, it's fun.*

When asked about inquiry, Peter thinks first of the context of IB stating “*For me a lot of the inquiry learning, for IB anyway ...*”. This indicates to me that his general conception of inquiry is informed primarily by the IB curriculum.

Based on his description, his conception of inquiry appears to be for students to conduct scientific investigations. However, it is difficult to determine if any differences exist between the IB curriculum and how he personally thinks about inquiry.

*Wayne (Interviewer): Okay. And you would say that the IB has kind of given you a model? Do you like the way they have set inquiry up or would you do it differently if you could?*

*Peter: I think what they do is fine, it makes sense. It's a broad starting point and gives certain things, certain specific that they are looking for, you know they're not expected to start go into dynamite or nuclear fusion or anything. So it's, but, you know, they expect broad starting points like what I said, I gave the students the kinetics lab they're doing now, [?] investigating some factors [...] a chemical reaction, be sure you pick materials which we have in our stockroom, check with me on your procedure before you start writing it, make sure it's okay, like the [?] says, you're going to collect that you're going to collect, and then after you wrote*

*the procedure then we take a look at it to make sure that you're not going to do anything that's going to kill you or another person.*

*So that's basically what the lab says and all the planning labs, the design labs have a procedure, an outline, that goes something like that, very short, one paragraph, and you know, I think that's the point of inquiry, it gives them a platform, some general direction. And then beyond that, just give them, let them know what the rubric is ahead of time, how they're going to be assessed, [?] use planning it, and you want to let them make mistakes so long as they don't hurt themselves.*

His response indicates that he is comfortable with the IB model of inquiry and he does not make any negative comments or suggest areas where he differs. For Peter inquiry gives students “*a broad platform, some general direction*” and then engages them in conducting the investigation. This conception of inquiry closely matches the IB model for inquiry.

*Enacting inquiry: a chemistry inquiry lesson.*

In discussing an inquiry lesson on chemical kinetics Peter explains that he uses inquiry to introduce or follow up on conceptual material. This suggests that one role of inquiry is to support chemistry content knowledge.

*Peter: Sure, really I've already talked about it in a large part. Whenever when I do inquiry, like I said, at least with IB, it's almost always in the form of lab.*

*Whether it's to introduce a concept or to follow up on something that we talked about before. It's like maybe to think a little bit deeper on a concept, more deeply*

*than when I talked about it in class and let them figure it out for themselves. Like for example the kinetics lab that we're doing right now.*

Here Peter indicates that for him, inquiry is about developing an understanding of a concept, something he returns to in discussing his goals for inquiry.

Peter does not go into detail about the structure of the investigations for this inquiry lesson. This may be because the design labs all use the same rubric and he does not feel it is necessary to discuss this information. His response does indicate that students selected the variable they wanted to test, designed a procedure, carried out the experiment, and collected data.

*Like for example with that kinetics lab, the students that I videotaped there were two groups, almost every group in class had a completely different lab, one group had for example had decided to see the effects of surface on the rate of a chemical reaction, no, it was acid concentration on a chemical reaction. They took powdered zinc, and they had solutions of hydrochloric acid ranging from 1 molar up to about 9 molar I think was the top one, and so they were testing the rate of hydrogen production. They were essentially, and their procedure was a little bit flawed but that's okay I let them slide...*

He goes on to describe some of the variables students tested and the variety of different experimental designs students developed. This further supports the idea that students are following the IB rubric described previously by Peter.

*So you know, they were testing for the effect of concentration on the rate of gas production that way. Some very different things going on. Another student tested*

*the effect, of, most of them were doing gases. I'm not sure why they all picked gases.*

For his Chemistry One students much less inquiry takes place. Peter describes a number of reasons this is the case. They include time, materials, safety considerations, and students' ability levels. His beliefs about the students' background knowledge and safety concerns limit his use of inquiry with these students.

*But for me, I do a little bit of inquiry probably in Chem One level, I do a lot more at the IB level because they have a little bit more background and I trust them with the chemicals a little bit more too.*

In addition, students' ability level also contributes to his limited use of inquiry with his Chemistry One students.

*And honestly I like it so much when I do stuff like that with Chem One, and I have done it, like if I have Chem One classes that are sophisticated enough, and that are academically, I guess homogenously sophisticated enough, then I have done it with Chem One classes before and I use the exact same rubric because it makes complete sense.*

For Peter, the IB rubric for inquiry is appropriate for his Chemistry One classes when he does inquiry when students are “*homogenously sophisticated enough.*” When Chemistry One students are of higher academic ability Peter believes the IB vision of inquiry is appropriate. This provides further support that he is comfortable with the IB vision of inquiry.

With IB classes the time to conduct inquiry is built into the curriculum. This is not the case for his Chemistry One students, placing further constraints on his use of inquiry.

*So with IB the framework is there, the timeframe is there to do inquiry learning the way that I think it really needs to be done. It's really at the Chem One level and the physics and biology where everybody needs to connect so we don't have the time for it unfortunately.*

Finally, lack of materials presents another obstacle in Peter's use of inquiry. As a result, IB classes are given priority for chemical use.

*Peter: I wish I could do it more often. Unfortunately we're limited in terms of the amount of chemicals we can buy. We're a pretty poor school district. You try to use household chemistry type stuff when you can, you can do an acid titration, [?] get vinegar or something. So, you know, that's one thing that keeps me from doing it as much as I might like to with my Chem One class. Cause I know I have to use a lot of those chemicals with my IB.*

While Peter holds the same conception of enacting inquiry in both his IB and Chemistry One classes, there is a marked difference in how much inquiry he does in each class. IB Chemistry students regularly engage in inquiry. For Chemistry One students, Peter cites numerous barriers that limit their opportunity to engage in inquiry. My interpretation is that the external curricular requirements of IB, coupled with his beliefs about what is possible with Chemistry One students lead him to overwhelmingly teach with inquiry in his IB classes.

*Goals for inquiry in chemistry.*

Peter's description of an inquiry lesson has students involved in asking questions, designing procedures, collecting data, etc., as dictated by the IB rubric. However, this tells us little of his goals or why he believes inquiry is important for chemistry students. When asked about his goals for inquiry, content knowledge emerges as a theme.

*Wayne (Interviewer): What are your goals, like with the kinetic lab, what do you want to see the students take away from it?*

*Peter: Mainly I want them to an operational understanding of chemical kinetics, that they can apply the stuff that we talked about, or that they've previously learned, that they can apply that in a tangible fashion to something in the real world. I really, I try to place a high value on creativity. Cause I see so many of these labs, doing the same type of lab year after year after year, like I want them to try something different. Not necessarily, it doesn't have to be hard. [?] But try to pick something that is practical, that's real world, try to address a real problem...*

The primary goal for the kinetics inquiry lab is for students to develop “*an understanding of chemical kinetics.*” He wants them to understand the content and to be able to apply it to the real world. However, along with his focus on the content knowledge he wants students to also be creative in their work.

*Wayne (Interviewer): You had said one of the goals was the content, the science knowledge about kinetics, and applying it to the real world, and then creativity is another important thing for you?*

*Peter: Yeah, exactly. I don't want them to just go on the internet and find a procedure, and just try to carry it out. First of all it's plagiarism. I'll have them e-mail their labs to me and then I'll run their labs through a search filter to make sure that they're not plagiarizing. I tell them to pick something that they actually think is personally interesting. I think that when they do that, when they are personally invested in a lab a little bit more, I think [?] more creative things. Any number of times people will start doing a lab and say that's not very interesting and then they'll get an idea off something they did, whether it was something that went wrong, or just a side tangent that they realize while they were doing the lab. I've had students end up spending 20 hours on a lab that which only takes three hours to do.*

My interpretation is that the primary goal for conducting inquiry in his IB classes is for students to gain chemistry content knowledge. However, he wants them to be creative and to be “*personally invested*” in the process. For Peter part of the value of inquiry is that it can generate interest and motivation for chemistry.

Discussing Peter's goals for inquiry for Chemistry One students is challenging since his use of inquiry is limited. When I asked him about his goals for Chemistry One he responded describing constraints that inhibit his use of inquiry.

*Wayne (Interviewer): You talked about your IB students quite a bit and I feel like I have a pretty good idea with them. Could you briefly mention your goal, your goals for using inquiry with your Chem One students? I know you said you weren't able to do it a lot, but what are your goals when you work with those guys?*

*Peter: I do inquiry with Chemistry One students very, very little. I actually do it a lot more with my physics students than my chemistry students. Part of the reason that it's hard to do inquiry with Chem One students is first of all, our curriculum is so thick that unfortunately I don't have time for them to live and learn and make a lot of mistakes. It's much more time consuming than what we really time for, I do have time for in IB, in fact it's part the IB curriculum, that's why it's sort of a mute point.*

*With Chem One students, when I do it, it's usually something fairly simple. Never a full-fledged lab, but more, like maybe some demonstrations and I'll invite a couple of kids, and say, "Come up here. What do you think is gonna happen?" and then let them tinker with something or play with something, they see the results of what they do, and then think what could I do to make this a little bit better. Something that I could do in a short period of time, like fifteen minutes or so. And again the other limiting factor that keeps us from doing a ton of inquiry is materials, particularly in this economy, it's really, it's killed us. We've been able to order very little new stuff.*

The scope of the curriculum, time, and materials all are obstacles for using inquiry in Chemistry One. His goals appear more focused on providing students an opportunity to become familiar with chemistry concepts by viewing demonstrations and making predictions about what might happen. These are relatively brief encounters with inquiry appearing informal and introductory.

*Summary.*

For Peter, inquiry is largely defined by the external IB curriculum. In his conception and enactment of inquiry this was expressed as students conducting scientific investigations. However, in discussing his goals for a lab on chemical kinetics, chemistry content knowledge was the predominant theme. He also emphasized the importance of students engaging in creative thinking. In this sense, Peter exemplifies a case where his enactment of inquiry is driven by external curriculum but his goals may be more representative of his personal conception about the purpose of inquiry.

A comparison of IB and Chemistry One classes does not inform us of disciplinary differences in his use of inquiry. However, it does provide an example of how teaching context can influence the use of inquiry. The IB chemistry framework incorporates a considerable amount of inquiry into the curriculum. Rubrics and assessments place an expectation on teachers to approach inquiry with an emphasis on designing and conducting scientific investigations. As a researcher, I see this as a reason to exercise caution when drawing conclusions about a teacher's conception of inquiry without taking into account the context of their teaching situation.

Inquiry within the structure of the IB curriculum focuses on students conducting scientific investigations. As a result, Peter's IB students frequently engaged in inquiry experiences in this manner. For his Chemistry One students he cited a number of constraints that limited his use of inquiry. While there were not sufficient data or opportunities to discuss a more detailed use of inquiry with Chemistry One students, it appears he holds a similar conception and goals as in his IB classes. If this assumption is

warranted, it would indicate that the manner in which IB approached inquiry may transfer to other settings.

Participants like Peter complicate my overall analysis of disciplinary differences. External factors, such as IB, make it challenging to detect disciplinary differences by effectively requiring teachers to approach inquiry from a certain standpoint. At the same time, there is much to be learned about how an external curriculum can influence a teacher's use of inquiry. As was the case with Peter, while he followed the IB guidelines in his enactment of inquiry, he also saw inquiry as a way to build chemistry content knowledge.

#### *Chemistry and Biology: Allen*

##### *Participant context.*

Allen teaches chemistry and Advanced Placement (AP) Biology in a suburban school in Wisconsin. He has been teaching for eleven years and holds a bachelor's degree in biology (chemistry minor) and a master's in teaching. His classes this year include General Chemistry, Organic Chemistry, and AP Biology. Allen received his NB certification in chemistry.

Allen teaches several different subjects but focuses on general chemistry (his NB certification area) in this interview. However, his education background is predominantly in biology and he believes that his content knowledge is strongest there. Similar to Tom, a biology and physics teacher, Allen perceives it to be more difficult to use inquiry in teaching biology. This perceived difficulty, and the structure the AP

curriculum places on his biology teaching, were deciding factors in Allen's decision to seek National Board certification in chemistry rather than biology.

While this interview does address his approach to inquiry teaching in biology, the majority of the interview is about chemistry. Inquiry is used infrequently in his AP Biology class. The structured and test-centered nature of AP Biology has a strong influence on the amount of time Allen believes he can engage his students in inquiry-based work. Therefore, this interview in particular highlights the challenge of teaching with inquiry in AP courses.

*General conception of inquiry.*

In a follow-up email I asked Allen what he thought of when he heard the phrase “*inquiry in science teaching.*” My sense is that, without the context of a specific lesson his response contained less detail than our later discussions about inquiry in chemistry and biology.

*Wayne (Interviewer): Could you describe to me what you think of when you hear the word inquiry in science teaching?*

*Allen: In my mind inquiry in the context of teaching is the creation of a worthwhile problem in which the students are capable of solving. Inquiry has many names including constructivism and authentic pedagogy. I try to use inquiry based learning from a stand point of avoiding condescension toward my students, if they can determine an answer then I don't need to provide them with that answer, and to that end they take ownership over the thought process as well as the solution.*

His response centers on students working to solve a “*worthwhile problem.*” For Allen, I believe when inquiry works students are capable of solving problems themselves. As a result the teacher does not have to present the information in a more traditional manner. In addition, through their involvement in the problem solving process students place a higher value on their learning.

*Conception of inquiry for general chemistry.*

For General Chemistry his focus is on conducting a scientific investigation. In planning and teaching with inquiry Allen conceptualizes inquiry as consisting of a three-day cycle. The cycle starts with identifying a problem and then developing a procedure to solve the problem. The second stage involves carrying out the procedure and collecting data. Finally the data is analyzed and discussed to arrive at a conclusion about the phenomena. For Allen a well-planned inquiry lesson generates new questions to allow the cycle to start again.

*Wayne (Interviewer): Now I'd like to talk with you how you'd teach an inquiry based lesson of your choice.*

*Allen: Basically I try to operate all of my lessons, especially in the lab based classes, on about a three day schedule, meaning that the first day we tend to create a problem, we'll either, mathematical or conceptual, and the back half of that first day, we operate on a 52 minute periods, I try to lead them to creating, having them recognize a problem that exists, either something that we can longer handle mathematically, or something new that arises, and then we work on a lab protocol, procedure, small groups sometimes, sometimes there's a whole group, to solve that. What data would we have to collect, what is our objective going be,*

*what's it going to like in terms of the units, and usually try to lead them towards a graphing aspect, and then the next day we run the lab, then day three we basically come together and debrief on it, and if I've done my planning correctly, that third day discussion pretty much leads us in to whatever the next problem is going to be.*

Based upon his description, I believe Allen has a very structured and developed model that guides his planning and teaching with inquiry. As a result, the use of the three-day cycle appears to be a major feature in his teaching of general chemistry. An example of the three-day cycle can be seen in the inquiry lesson on determining the molar volume of a gas. Allen begins the lesson with a discussion about solids and gases. In the discussion he leads students to identify a problem with treating solids and gases the same.

*Allen: I did molar volume of gases. What I did was took a look at, set up a problem, I did a limiting reactant problem with them. And up to that point we had been handling all our states of matters as a mass. So whether it was aqueous, whether it was a gas, whether it was a liquid, we just dealt with just as a mass.*

*Wayne (Interviewer): Like grams?*

*Allen: Correct. And basically we solved the problem and then I just simply asked them a question, "I don't quite like this because" and then I lead into the understanding that if we're dealing with a gas it's probably not logical for us to use with a mass, that's not something we can deal with in a lab as a mass.*

For Allen the question evolves from dissatisfaction with the current understanding of a chemical concept or when a new approach is needed to solve a problem. In the

molar volume example, using the concept of mass to describe gases is problematic. Once the question is identified Allen works with students to develop a procedure that will generate data that can be analyzed to solve the identified problem.

*Allen: And then we lead them towards “Alright, now what should we have?” and kind of give them the idea that we need to have something that’s a relationship between the volume and the moles and from that we are able to develop a lab procedure, and we ended up developing a lab procedure that will measure a mass, which we can convert to moles, and then the volume and we ended up using dry ice. There’s enough kids that have an experience with dry ice and can make that connection in just about every class that the idea thing that we need is something that we can easily measure as a solid but easily converts into a gas as well.*

*Wayne (Interviewer): That’s interesting.*

*Allen: Then we collect all of the data, post it on an excel sheet, and I’ve got a class website, so they can each do a trial, and then we use that, we graph it out, and the slope of the line ends up becoming the molar volume. At that point we haven’t corrected for STP which comes along later. [?] pressures and volumes can affect, excuse me, temperatures and pressures can effect this volume so now what should we take a look at.*

The previous example provides evidence that the three-day cycle is an important model supporting Allen’s planning and teaching with inquiry. The model allows him to proceed from the development of a question, designing procedures, collecting and analyzing data, coming to conclusions about the phenomena, and finally generating new

questions. In the inquiry lesson above, students have resolved the issue of how to work with gases but are now faced with new complications. Since they are now working with gases they must take into account how atmospheric pressure and temperature affect their work with gases.

*Conception of inquiry for biology.*

Initially when asked about a biology lesson using inquiry there is a pause and Allen asks if we can return to the question. He states that in his AP Biology class, inquiry and experimentation does not receive as much emphasis.

*Wayne (Interviewer): So, you did the chemistry certification, in chemistry. Is there a biology lesson plan, inquiry lesson you could talk briefly about.*

*Allen: Pause.*

*Wayne (Interviewer): That uses inquiry.*

*Allen: Yeah, my bend is so much, in terms of the biology, my slant and my biases are so much in the molecular biology that I tend to turn most of my biology into chemistry anyways. The inquiry stuff in regards to the biology, I'm thinking specifically in terms of my AP Biology, that class operates so much more on discussion rather than experimental. [Pause] Let me kind of think about one and [?] at the end.*

In his response he equates inquiry and with the “*experimental.*” I take this as an indication that he views inquiry in biology to consist primarily of students conducting scientific investigations. However he does not use inquiry as extensively as it appears in his chemistry classes.

For Allen, using inquiry in biology is constrained by the structured and test-oriented nature of an AP curriculum. The limitations of time, the curriculum, and the AP exam limit the amount of inquiry teaching he believes he can do. Later he states:

*But teaching AP Biology I do not have the flexibility in the general biology class.*

*You know, my year is planned out every day from the exam date back. We have a snow day, it doesn't matter, we skip that material and we gotta keep going.*

Similar to Scott and Tom, Allen perceives the use of inquiry in biology to be more challenging. Although he has only taught biology at the AP level, he believes that general biology is not often taught using inquiry. For Allen, inquiry is described as students designing an experiment where they do not know the outcome of the investigation. In contrast, the term “*student led demonstration*” is used to describe how inquiry is generally conducted in biology classes.

*Biology is a tough one because so much of what you do in biology is not as much as an experiment as a student lead demonstration. At least the way I've seen it done and in my district. The only biology I've ever taught is the AP Biology. So I didn't do the general bio here. But usually what I see is not what I would consider a lab experiment as I tend to see in my chemistry classes where kids don't know the outcome, in which they have to design it, and they know what is going to happen and you go the back of the lab and you look at the different parts of the flower and it's more of a student led demonstration is what I tend to see versus an actual inquiry activity.*

My interpretation is that, for Allen, biology does not present as many opportunities to use inquiry. As a result, fewer opportunities exist to engage students in

conducting scientific experiments. As a consequence, “*student led demonstrations*” take the place of experiments, which Allen believes do not constitute “*an actual inquiry activity*.” This discussion on the use of inquiry in biology strengthens my belief that Allen considers inquiry in biology to consist of students conducting scientific investigations.

Later in the interview we return to discuss an example of inquiry in his AP Biology class. Allen expresses surprise that didn’t recall a two-month genetics investigation his students conducted using fruit flies.

*Wayne (Interviewer): Okay, do you want to back and talk a little bit about the biology, and if nothing comes to mind that’s okay.*

*Allen: Yeah, what I’m doing, even, my AP Biology kids will be shocked that we haven’t figured this out. It took me so long to remember we’ve been working on a project for about there or, since the first part of December. They’re going to hand it in on Friday. It’s the drosophila fruit fly genetics stuff. So that would probably be about as close to inquiry based as I can get. And the reason is that I simply give them two vials of flies, one of them is wild and one of them is mutant, they don’t know which is which. You’ve got about two months, I’ve need to know how these things are inherited. It’s pretty weak in terms of inquiry, but it defiantly allows them to reinforce Mendelian genetics.*

*Wayne (Interviewer): So they breed them and ...*

*Allen: Yeah, they have to take it out to the F2 generation. It’s standard Sturtevant and Morgan type stuff. And then the culminating project on that is that*

*they have to write the report which needs to be a manuscript fit for publication. So I get some sizable tomes coming in and when they're done correctly they're done very well.*

Although his use of inquiry in AP Biology is limited, the class project on breeding fruit flies does place students in the role of designing a scientific investigation, collecting and analyzing data, and communicating their results. My interpretation is that this class project places students in the role of scientists with a final report that is in the form of a “*manuscript fit for publication.*” Although it is only one project, students spend two months conducting the investigation and preparing the final report.

*Goals of inquiry in biology.*

For biology, my interpretation is that Allen has a primary goal of having students conduct scientific investigations. He emphasizes the use of identifying a question, developing procedures, controlling variables, collecting data and communicating results. This can be seen in the two-month investigation by students into fruit fly genetics. Students research the literature at a local university library, design their experiment, collect and analyze data, and create a detailed final report.

*Wayne (Interviewer): What is your main goal, of having them conduct this with the fruit flies?*

*Allen: To a small extent it's the reinforcement of the genetics, to a larger extent it is the actual manuscript writing, the actual searching, for the research aspect of it as well, and then the designing the actual controlled experiment as well as the statistical analysis that's required. There are three part objectives for it.*

*Wayne (Interviewer): Right, so the smaller part would be the content, the bigger part would be ...*

*Allen: The experience I guess.*

*Wayne (Interviewer): Conducting a real study, would you say?*

*Allen: Yeah, a controlled experiment.*

The overall experience of conducting the investigation is seen as a major goal of the project. When asked whether he means a “*real study*” his answer provides support for this assertion. In his answer he takes a “*real study*” to mean a “*a controlled experiment.*” Based on the fruit fly example, my interpretation is that Allen’s thinks of inquiry as conducting a scientific investigation.

*Goals of inquiry in chemistry.*

For chemistry Allen also has a primary goal of having students conduct scientific investigations. In his enactment of an inquiry lesson he emphasizes the use of identifying a question, developing procedures, controlling variables, collecting data and communicating results. Here he provides further evidence that the experiment itself, along with the communication of results and error analysis, is the primary purpose of inquiry in chemistry.

*Wayne (Interviewer): What would your goals be with chemistry, when you are doing inquiry in chemistry what would you see your goals as?*

*Allen: Designing the experiment itself and communications. And then understanding the procedural errors. I want them be able to take a look at a*

*piece of research and think apart that research to see where the errors may be and why it's not a concrete number.*

*Summary.*

For Allen, both chemistry and biology inquiry was centered on students conducting scientific investigations. However, several important differences existed between his use and beliefs about inquiry in biology and in chemistry.

Inquiry teaching occurred less frequently in Allen's AP Biology class. This was largely due to time constraints resulting from AP Biology curriculum and the pressure to prepare students for the AP exam. However, Allen also believed that inquiry was more difficult to do in biology and that there were not as many opportunities for experimentation in biology leading to less frequent use of inquiry. As a result, he stated that most of what he sees being done is not inquiry, but rather "*student led demonstrations.*"

For chemistry, Allen used a three-day cycle in teaching with inquiry. The identification of the inquiry problem was an important part of this cycle. Such a detailed approach to inquiry was not present in his AP Biology class. I believe that this is related to his conception of the structure of biology as a discipline allowing fewer opportunities to engage students in inquiry. Because inquiry was not used as frequently, a detailed cycle was not as relevant to his teaching context.

Time pressures and exam preparation placed additional constraints on his AP Biology class. However, Allen did have his AP Biology students engage in a long-term inquiry project into fruit fly genetics. This suggests to me that when an appropriate

opportunity for inquiry exists Allen approaches it as students conducting scientific investigations.

*Donna: Earth Science*

*Participant context.*

Donna teaches Earth Science in a rural school in Pennsylvania. She has been teaching for fourteen years and holds a bachelor's degree in teaching earth science and a master's in science education. Her classes this year include Honors Earth Science, College Prep Earth Science, and General Earth Science. Her students are primarily ninth graders. Donna received her NB certification in Earth Science.

Donna works in a school that supports inquiry and where teachers collaborate on designing inquiry lessons. All ninth through twelfth grade students are required to do one inquiry lesson each year. The lesson described by Donna in this interview was written by Donna in collaboration with another teacher and is used by all ninth grade earth science teachers.

*Wayne (Interviewer): That's very comprehensive. How did you come up with that lesson?*

*Donna: We, the girl that teaches next to me, she and I both went to the same masters program, they wanted to do the 5E type of thing, you know, where are you on that scale, and they wanted to get the student to totally come up and manipulate and design the whole thing. So we did a weather one that we do at the end of the year and we also did a crystal growing one and we just kind of tried to meet all that criteria for them.*

For Donna, her coursework from her master's degree provided her with a model and structure for teaching with inquiry. In addition, it gave her the opportunity to collaborate with another teacher at her school to develop inquiry lesson plans. This collaborative environment also exists at her school where inquiry is incorporated into the curriculum for all students.

*Wayne (Interviewer): Do you feel like you have the support of the school to do this stuff?*

*Donna: Oh yes. They actually, we actually made it mandatory that they have to do at least on inquiry based lab. So they support you and they want you to do it.*

I consider this to be a noteworthy case because it provides an exemplar of how a teacher education program, collaboration with a colleague, and a supportive school environment influence Donna's conception and enactment of inquiry teaching. It is also of note that her conception of inquiry that has developed in this context is similar to other earth science teachers in this study.

*General conception of inquiry.*

Donna was one of the first interviews conducted in this study. In the interview, Donna was not asked the prompt about what she thinks of when she hears the phrase "inquiry in science teaching." Follow-up emails were sent but at the time of writing I have not yet received a reply. As a result there is inadequate information about her general conception of inquiry.

*Enactment of an earth science inquiry lesson.*

For Donna, inquiry is focused on students conducting scientific investigations. In describing her inquiry lesson plan about crystal growth, students generate a hypothesis, design an experiment, control and manipulate variables, analyze data, and present findings to their peers. This structure can be seen in her description of an earth science inquiry lesson.

*Wayne (Interviewer): Well, I'd like to talk now about how you would teach an inquiry-based lesson of your choice. Could you describe in as much detail as you could what that might be?*

*Donna: Um, usually at the school we teach, all of our ninth grade teachers teach the same inquiry lesson. We make sure 9-12 that every year they have an inquiry lesson that they have to do and write a lab report about. So we do mineral formation with a crystal formation type of thing. Where they grow crystals basically. We start out and we have them do a fishbone type activity where they go to a web site and collect information on what type of variables could affect the growth of salt crystals and from those variables they can find out how they want to manipulate crystal growth and they form their hypothesis from there and we make sure that they quantify them and predict how things will be manipulated. From there they design the experiment, and from the experiment we make sure that they do three trials for validity of the experiment and then we look at the data make sure they control just that variable and then they graph it in Microsoft Excel and see how their manipulated variable, that's the responding variable, and then they have to conclude at the end the type of relationship is affected, if there's any*

*relationship at all, and then what type of analysis, what type of error might have occurred, and then what they would like to do for future studies, then we have them present it in front of the class.*

Her description is detailed and structured with a focus on conducting a planned and carefully designed scientific investigation. Students are using the Internet to research factors that influence crystal growth, making decisions about what they will study, hypothesizing, designing the investigation, collecting and analyzing data, and presenting their findings to their peers and teacher.

Comparing her description to others in the qualitative section of this study, Donna presents one of the more structured approaches to inquiry. This may be due to ninth grade students having less experience conducting investigations. It could also be a result of the lesson being used by a number of different teachers and the collaborative nature of its development. Since the lesson was developed in collaboration with another teacher as part of an education program, I believe a considerable amount of effort went into its development.

When students have completed their investigation, they present their findings to their peers and teacher. The hypothesis is a key element of their presentation.

*Wayne (Interviewer): With the students communicating their results, you said they write up a report and then you talked something about peer review.*

*Donna: They, I always make them stand up, present their results, what their hypothesis is, the procedure they carried out, and then, you know, this is the data, this is what the data is saying, and then I make five students in the class comment*

*on it, like ask a question about it and then, we kinda just go from there. We don't repeat any experiments the way we probably should and retest them.*

My interpretation is that Donna enacts inquiry consistent with the theme of *Students Conducting Scientific Investigations*. This is seen in how students present their findings. The structure of the experiment is the primary focus here with students reporting to the class their hypothesis, the procedure they used, the data they collected, and the conclusions they are able to draw from their data. Further, Donna states “*We don't repeat any experiments the way we probably should and retest them.*” indicating that if time permitted it would be appropriate to conduct more experimental trails. For me this represents additional emphasis being places on the structure of the scientific investigation.

*Goals of inquiry.*

My interpretation is that Donna also has a primary goal of having students conduct scientific investigations. She emphasizes the use of hypotheses, developing procedures, controlling variables, collecting data and communicating results.

*Wayne (Interviewer): What, for you, what is the main goal of doing this type of inquiry lesson plan?*

*Donna: I think for them to be able to pick variables and test those variables and understand that there is a relationship that one's manipulating the other and if you control it you can actually see how that manipulation causes a response. So for them being able to analyze their data.*

In addition to Donna's detailed inquiry lesson plan, her stated goal provides further support that her conception of inquiry is centered on the process of conducting scientific investigations. She states a goal that students can "*pick variables and test those variables*" and "*control*" variables to determine their relationships. This indicates to me that the actual structure of the investigation is of primary importance. Finally, for Donna the part of the certification process that was most important dealt with the process of conducting scientific investigations. She stated:

*Donna: "I think that it was that, it is an important process that all kids should go through, and that even if saying this effect this, cause and effect, cause and effect is a higher level skill and before I used to think "how can they not get cause and effect?" So I think teaching them cause and effect, teaching them that if you manipulate one it will affect other things, and that if you can't control an experiment then the variability is not there and that if you lost that variability you can't prove definitely that one definitely affected the other."*

For Donna, the certification process helped her think about the process of conducting scientific investigations. Throughout the interview, she returns to this theme supporting the assertion that her conception of inquiry is students conducting scientific investigations.

#### *Summary.*

Donna presents an illustrative case of the theme, *Students Conducting Scientific Investigations*. By this, I mean that all of the elements of a structured inquiry lesson focused on the process of conducting a scientific investigation were included in her

enactment. Three additional themes emerged in Donna's interview: the influence of grade level, collaboration with peers, and the support of the science department at her school.

Earth Science classes at Donna's school consisted of ninth grade students. I believe this to be the primary reason for the structured nature of her inquiry lesson. Ninth graders have taken fewer science courses and have not received as much exposure to inquiry as students in tenth grade and above. While they may have done inquiry in elementary and middle school, it is most likely not at the high school level. In addition, in high school, students come from different middle and elementary schools, often varying in their use of inquiry. Structure is necessary to build students' ability to conduct scientific investigations.

Considerable collaboration took place at Donna's school. She wrote the inquiry lesson on crystals with a colleague as part of a masters program they were enrolled in. In addition, all Earth Science teachers used this inquiry lesson with their students. The collaborative nature of her use of inquiry is unique in this study and represents an important contextual factor in her use of inquiry.

Finally, inquiry was encouraged in her science department. Out of the ten science teachers in her department, Donna stated that nine include inquiry in their teaching. Further, all ninth through twelfth graders were required to complete at least one inquiry activity each year. My interpretation was that inquiry is seen as an integral part of how science was taught at her school.

*Earth Science: Sarah*

*Participant context.*

Sarah teaches earth science and astronomy in a rural school in New York State. She has been teaching for eight years and holds a master's degree in Earth Science. Her classes this year include Earth Science and Astronomy. Sarah received her NB certification in earth science. She teaches primarily ninth graders.

Prior to teaching high school Sarah worked as an Earth Scientist for a consulting firm doing primarily environmental work. When asked how her work influenced her teaching she responded:

*Well, I have a lot of, sort of practical applications of earth science that I like to bring into the classroom. Stories, and you know, I know how they really do earth science out there so I want to make it as realistic as possible for them, what you would really have to do, what it is really is out there. This is how you can apply it to the real world.*

Throughout the interview Sarah stressed the importance of inquiry in giving students the opportunity to see “*how they really do earth science out there.*” Although several other participants have previous scientific work experience, most were involved in routine sample analysis and the impact on their teaching with inquiry appeared minimal. Sarah is unique in this respect and her previous scientific research experience influences how she thinks about and implements inquiry. In a follow-up email I asked Sarah the impact her experience on her teaching with inquiry.

*Wayne (Interviewer): Can you give an example of a project or research that you've done as an Earth Scientist that has influenced how you teach with inquiry?*

*Sarah: As an Earth Scientist I worked on many projects and geological investigations of groundwater contamination beneath industrial sites that started with very little or no data available about the site before the project began. We used the scientific method from start to finish and the results were often hard to anticipate or ambiguous. When I was a new geologist right out of school it bothered me at first that there was no "answer key" with which to correct my work, that no one knew the answers and it was intimidating to accept that the purpose of real science: to find (or try to find) answers. This experience influences how I teach inquiry because students in school, even when doing inquiry based projects, still expect the teacher (or the text book) to have the "answer key", and are often uncomfortable in the role of the primary investigator finding their own results. I try to emphasis this process of becoming the "expert" on their own experiment, and to minimize my role as the "grader" or the person who is going to correct their work as either "right or wrong."*

My interpretation is that Sarah has developed a personal sense of how science is done in research settings. This can be seen in her use of inquiry by her desire for her students in "*becoming the 'expert' on their own experiment.*" She also refers to using "*the scientific method*" in her work, something I believe to influence her enactment and goals for inquiry. Based on the more detailed comments in her response to my follow-up question, and throughout our conversations, Sarah works to integrate these ideas into her teaching with inquiry.

*General conception of inquiry.*

When first asked what she thought of when she heard the work inquiry in science teaching, Sarah responded:

*Sarah: To me it means, it's usually an activity that the students will do where they will discover something during the lab, not something that I teaching them but something that they learn by doing it themselves.*

Inquiry, for Sarah, offers students the opportunity to discover ideas or information without having the content presented to them in a more traditional manner. Here the role of the teacher as presenter of knowledge is minimized and students are acquiring the science content knowledge by themselves. Further, an important aspect of the process is that students are engaging in science the way it is done by practicing scientists.

*Wayne (Interviewer): And you do you think this is important, if you do think it's important, to have kids do?*

*Sarah: It's important because that is how real science is done and it is also more fun for them. They are actually just involved in the process of discovering and doing science and they remember better what they learn if they've actually discovered it themselves.*

According to Sarah “*discovering and doing science*” is more enjoyable and is the way scientists work in the real world. Her work as an Earth Scientist prior to becoming a teacher may partially explain the importance she places upon students experiencing “*real science.*” Also of note in her response is the belief that students are able to remember material better when engaging in inquiry. Here again the idea of inquiry as a process of

discovery with the ability to help students learn and remember science content knowledge is emphasized.

*Enacting inquiry: an earth science inquiry lesson.*

When I asked her to describe an inquiry lesson plan, Sarah chose a lesson on soil porosity and permeability. In the lesson students are involved in choosing the factors they will investigate, making predictions, designing their experiment, collecting and analyzing data, and finally presenting their findings to their classmates and in a written report.

*Sarah: So which soil is going to be more porous, which soil will have better permeability, what determines what makes the soil more permeable or more porous.*

*Wayne (Interviewer): And what does that look like for the student? They come in the class, what are they given?*

*Sarah: First they decide which property they want, first we learn the definitions of porosity, permeability, capillarity, and the mathematical manipulation of that, then I have a collection of soils out. I have processed sand, course sand, mixed sand, some clays, gravels of different sizes and different shapes. Then they pick, let's say they're going to get one factor of the soil. For example they may look at grain size because grain size affects porosity. So then they would get fine sand, medium sand, and the gravel. They'd get to pick which soils they're going to look at, they pick [?] they could look at size, they could look at [?], they could look at sheath, they could look at sorting, degree of sorting, every group will pick*

*something different. And then they will have to design their set-up, their apparatus, how they're going to test it. And for the apparatus they use, then they will go ahead and test it.*

In this lesson, inquiry involves students deciding what they want to investigate, making predictions, designing a way to test their predictions, collecting and analyzing data, and then presenting their results to their peers and in a written report. While there isn't any direct description about manipulating variables and control groups in her description of the porosity and permeability lab, my interpretation is that a major objective for Sarah is to have students engage in a scientific investigation much like practicing scientists in the real world.

After student have collected and analyzed their data they report back to their findings to their peers. I asked Sarah why she believed this to be important.

*Wayne (Interviewer): Why is it important for students to share their results with their peers?*

*Sarah: Communicating results to peers and others is important because unless the knowledge is shared and communicated to others it can't be evaluated or used. In a classroom, the students share their results so that everyone can learn from the results and can discuss them and critique them as well, which mirror the process of science in the real world.*

In her response I interpret the importance of sharing data with peers to be related to her previous science research experiences as an Earth Scientist. Similar to the scientific community, presenting results allows others for discussion and information

sharing. For Sarah, this is the primary rationale for students presenting their findings to their peers.

*Goals of inquiry.*

Sarah's goals for inquiry are consistent with her earlier comments on inquiry as students conducting scientific investigations. In her description she emphasizes deciding what variables to investigate, planning the investigation, collecting data, and coming to a conclusion. As stated earlier in the interview, the goal isn't coming up with a correct answer, rather finding one of many ways to approach the investigations.

For Sarah it is also important that students develop a feeling of ownership for their work. For her, ownership takes place when students are involved in the entire cycle of inquiry from start to finish. Ownership is also supported by students having the opportunity to develop their own approach to the investigation without being given a set of directions to follow. When I asked about her goals for the earth science inquiry lesson she responded:

*Sarah: So that particular one I want them to come away with, they started it, they designed it, they finished it. Kind of a sense of ownership that they did the whole thing and that they experienced it from beginning to end and they were responsible for the design of it, because often they're used to having the directions handed to them, and that is out of their comfort zone in many cases to, for there not to be a right answer or for one right way to do, that there're many right ways to do it.*

Based on her emphasis on students taking part in each part of the investigation, I interpret her response to indicate that a primary goal of inquiry is to have students conduct scientific investigations. In addition, she also had a goal of students becoming personally invested in their research as a result of involvement in the inquiry lesson. As she states, “*they started it, they designed it, they finished it.*”

Generalizing her goals for the porosity and permeability lab to other inquiry lessons, Sarah states:

*Wayne (Interviewer): So, your goals for inquiry in general are similar to that?*

*Sarah: Yes, I have them experience a scientific experiment they create, that they're responsible for and that they learn from and it's not, and the results are not, you know, are unanticipated perhaps.*

Her response provides further evidence that she sees the role of inquiry as students conducting scientific investigations where they “*experience a scientific experiment they create.*” However, science content is also important to Sarah and students are learning science content from their experiment.

*Wayne (Interviewer): What would the top three things be that you would look for in an inquiry lesson that you got online or from someone else?*

*Sarah: First I would look to see how feasible it was to do it with the students. I would also look to make sure that it achieved one of the learning goals or one part of our curriculum that I need to cover. But to do a lab that was [?] the curriculum, I wouldn't really have time that [?].*

*Wayne (Interviewer): Right.*

*Sarah: And I would look to see that it would be something that would be interesting, that the students would enjoy and have fun with.*

Feasibility is the first thing mentioned by Sarah but meeting the curricular requirements is also a major concern. Any inquiry lesson that does not fit into the curriculum and meet a required learning goal would not be included due to time constraints. She returns to this theme again later in our conversation.

While science content is an important concern, the main goal of inquiry for Sarah is on students conducting scientific investigations in an authentic manner. However, in a follow-up I attempted to elicit more detail about the role of science content knowledge in students conducting scientific investigations.

*Wayne (Interviewer): Which is more important to you as a teacher; students learning science content or students having the experience of designing and conducting a scientific experiment?*

*Sarah: It is more important to me on a daily basis that my student learn the science content because they have a high stakes state test to pass at the end of my course, and without the content knowledge they do not have the background to perform science inquiry successfully. However, I do think it is an very important part of science education that students learn how to design and conduct a scientific experiment, but most of this process is taught in earlier science courses, so that the goal when they reach my course is to be able to conduct such an experiment in my content area, using their content area knowledge.*

*Summary.*

Inquiry for Sarah involves two primary themes, students conducting scientific investigations and inquiry as an instructional strategy to build science content knowledge. In our initial conversation I came to believe that her primary goal and enactment of inquiry was to have students conduct scientific investigations but with a secondary goal of content knowledge. In a follow-up it became apparent that content knowledge was of similar importance.

Sarah's previous scientific research experience in earth science was a consistent theme in her discussion of inquiry. Out of this experience comes a desire to have student take part in inquiry experiences that mirror scientific practice in the research community. Therefore a driving force in her conception, enactment, and goals was that inquiry should involve students conducting investigations that approximate scientific practice.

Content knowledge was also a major goal "*on a daily basis*" for Sarah. This was largely a result of required tests that her students are required to take. This can also be seen in her use of inquiry throughout our interactions where the theme of content knowledge is present. Further, she believed that the ability to design and conduct a scientific experiment was taught in prior courses and that inquiry in her class was therefore a mix of designing experiments based on the earth science content knowledge.

For Sarah the interplay between these two goals resulted in her students enacting inquiry within a structure that was similar to what practicing scientists would use. This drew from her conception of inquiry as students conducting scientific investigations. A major component of her enactment was driven by the external pressure of acquiring

content knowledge to perform well on external assessments. Together these situate Sarah's conception of inquiry within the context of the earth science classroom.

*Astronomy, Chemistry, and Biology: Cathy*

*Participant context.*

Cathy teaches astronomy, biology, and chemistry in a suburban school in Washington State. She has been teaching for eight years and holds a bachelor's degree in laboratory medicine and a master's in science. Her classes this year include one Introductory Biology course and Honors Chemistry. Cathy received her NB certification in earth science.

Prior to changing careers to become a teacher, Cathy worked in a hospital laboratory. In a follow-up e-mail Cathy clarified her work experience in the medical field.

*Wayne (Interviewer): Do you have any previous experience with inquiry?*

*Cathy: In regard to experience with inquiry, I'm not sure my experience as a lab scientist counts or not. I used to be a hematologist and often collected data to make decisions regarding the storage and selection of various blood typing reagents and chemical markers and stains. While there were options to consider, the process was somewhat guided in how it needed to be performed because of FDA requirements, etc.*

While her experience did not involve designing or conducting research, she was involved in collecting data and managing equipment and chemicals. It is likely that these experiences have influenced how she thinks about and teaches with inquiry.

As a career-changer, Cathy entered teaching through an alternate certification program. When asked about the certification program she clarified:

*No, this was a program, a second program for people who already had a, their undergraduate degrees and just decided to change careers. So it was a one-year program to teach the fundamentals of teaching and prepared you to get your residency.*

Cathy cites limited professional development with the exception of her teacher certification program which placed an emphasis on inquiry:

*Well since I've been a teacher relatively not long, part of my teaching certification, initial program, was on inquiry. So a bit I guess. I've done a lot of reading about it but I haven't actually taken a course called "Inquiry."*

Like many of the teachers in this study, Cathy's teaching takes place against the backdrop of a variety of experiences with scientific research and preservice coursework. In addition, she also provides a useful comparison of how one teacher approaches inquiry in three different disciplines; biology, chemistry, and earth science.

*General conception of inquiry.*

When I asked Cathy about her general conception of inquiry in science teaching her response suggested that she had not previously considered what was meant by inquiry. As she talked through her description of inquiry, the construct of "*thinking*" emerged as a central theme.

*Wayne (Interviewer): Well, let's talk about inquiry a little bit, what you think of when you hear the word inquiry in science teaching?*

*Cathy: What do I think of, okay. I haven't formulated a thought for this. Inquiry to me would mean that given a problem, I guess, or a scenario, an individual would have the opportunity to think about the question in terms of coming up with an approach to gather more information about the topic. So not necessarily that inquiry will always yield a result or an answer, I don't perceive that as being inquiry. I don't think that in order for my students to be successful that they need to come up with the right answer. In my opinion, doing research and the process of thinking about things itself is worthwhile. My goal, I try, and I know you try to, my goal is to make my students think. So to me inquiry is processing the information, the given information about a situation, thinking about ways to gather more information, and then hopefully given the opportunity to pursue some of the information and possibly coming up with a conclusion. Or as least another direction with which to go.*

“Thinking” forms the core of Cathy’s conception of inquiry. Students must develop a plan to collect data or information in order to come to a conclusion or arrive at another way to look at a problem. For Cathy, arriving at a final answer is not as important as participating in the actual research and thinking about the problem or question. A possible interpretation is that her hospital laboratory background led her to develop the belief that the process of gathering and processing information is a primary focus of science. Based on her experience, it is possible that collecting and managing information and engaging in critical thinking is of higher importance than conducting experiments.

To clarify her conception of what thinking means in the context of inquiry I asked her why she thought inquiry was important for her students.

*Wayne (Interviewer): And why would you say that inquiry would be important, if you believe it's important for students to engage in?*

*Cathy: Yeah, I think the process of inquiry and logic, just the logical process that's required for what, you know, educators, now use as the buzzword inquiry is what's the most important. I don't think that finding the little pathway to figure something out is always necessarily inquiry. Yeah, I just think, thinking. It's probably as good a skill, as high a skill as I can hope my students will achieve. I tell them at the beginning of the school year, every year, you know, I hope to teach you some chemistry, biology, whatever, but I'm hoping that you'll be a better student when you leave here and you can apply those skills to other areas as well, other than science.*

In her response inquiry is referred to as a buzzword for a “*logical process*” and “*thinking*”. Again she reiterates the importance of thinking over discovering new knowledge. In her description of inquiry, scientific content knowledge is not as important as learning logic, something that is useful outside of science.

Based on my conversations with Cathy, I understand her use of the word “*thinking*” to mean the careful collection and organization and processing of data. The point isn't as much what students learn in terms of content knowledge but rather that they learn how to collect, manage, and think logically about information.

*Enacting inquiry: a biology inquiry lesson.*

When I ask Cathy for an example of an inquiry lesson plan in biology she chose to talk about a lesson she was in the process of developing. The lesson was to take place during the last three weeks of school and deals with students constructing and studying ecosystems using two-liter plastic bottles, something I have used in the past as a teacher.

She states:

*Okay, I'll run this by you and since this is my first year to teach biology in a while. It's a new curriculum so I don't yet have the particulars, I don't know how this is going to go exactly yet. But I have a plan, I can share the plan with you. Where we're at in the year is we're just now talking about ecosystems and one of the projects that I've used in the past for a different class, a class on ecology itself, was an ecotube....*

Her plan was to have the student create ecotubes, essentially closed systems made from two-liter bottles containing plants, small animals such as fish or crickets. The ecotubes were to allow students to investigate the ecosystems and the factors that how the different elements interact. In her description students are involved in identifying these factors and later are able to choose which ones they want to investigate. She states:

*So I'll introduce the parameters, the temperature, hopefully someone will introduce that, the dissolved nitrates, the dissolved oxygen. Those are things they may or may not suggest. But we'll talk about the factors, and then I'm going to give them the goal of keeping these organisms alive and we'll be monitoring daily or every other day some of the parameters that we can access, such as the temperature....*

In biology her enactment of an inquiry lesson involves students identifying factors that are important in ecosystems, building an ecosystem themselves, and collecting data. In her description students are able to choose the variables and questions they investigate, design and build the ecotubes, collect and graph data, and share their finding with their peers and others.

*I'm hoping that we'll have a lot of different variables and then that all of the students, basically after then I show them how to put them together decide, how many, what do you want to put in the bottom? Do you want rocks, do you soil, do you want any plants in the water? ... So I'm hoping that they're going to draw from their knowledge of what we've discussed ... that they'll make some wise choices about how they construct the bottle and where to place the bottle in the room.*

*They need to write up, they need to write out a summary of how their designing their bottle, they need to diagram it, and then there're also be a graph, well the data table, and then after they collect the data for as long as we have left in the school year, then they'll be doing some graphing, and then finally they'll present their bottles to the class and a brief summary and we'll do some comparing of graphs.*

Overall her enactment of the inquiry lesson is closest to the theme of *Students Conducting Scientific Investigations*. However, it is not as clearly focused on the theme as other participants in this study. The elements of student choice, selecting variables to investigate, designing the investigation, collecting and analyzing data, and presenting to class are all present. However, she does not discuss hypotheses or control groups, or

other aspects of experimental design. Since our conversation did not describe and actual enactment, it is possible that Cathy would add these elements when students actually did the investigation.

In comparison to her general conception of inquiry, she is consistent allowing students' choices and in not focusing on correct answers. Absent is discussion about critical thinking and logic. Further, her goals for inquiry in biology do not focus on the theme of students conducting scientific investigations.

*Goals of inquiry for biology.*

Cathy's goals for the inquiry lesson are less aligned with the theme of *Students Conducting Scientific Investigations* than her description of how she plans to enact the lesson. They also differ considerably from her general conception of inquiry where logic and critical thinking are emphasized. For her, a major goal is for student to develop an understanding of how biological systems work together. She also places a high value on having the students become personally invested in the construction and maintenance of their ecotubes. When I asked her goals for the lesson she replied,

*Cathy: What is my goal? Wow... Let's see, I've got a lot of goals. One of my, one of my goals quiet honestly is, I'm interested in how all these systems and variables work together. So, I guess, two big goals. I want them to see how different variables, or various factors, both biotic and abiotic factors, affect living organisms and a bigger picture is an ecosystem. But I also want them to be interested in how these things work. And I think by giving them the fish, and I know my kids, my kids will be really interested for the most part, they're pretty caring kids, I think they're going to want to keep these little guys alive. And I*

*think if I can give them something to care about then I think they'll become more engaged then if we just do a paper pencil model.*

*Wayne (Interviewer): Right, it's not the same.*

*Cathy: So I want to engage them as well as hopefully give them a bigger picture about the roles of [?] smaller scale and perhaps they're translate that to a larger scale. Hopefully, maybe even some of them will talk about the planet. I don't know how many people will grasp the large concept but we'll discuss that and I think some of them will grasp the larger concept, it just connects to a much larger scale to our world.*

A larger goal is for students to be able to extend what they learn from the ecotubes to the world around them. Because the investigation was to take place at the end of the school year, it is likely that high stakes testing was not a factor in her planning. Without this pressure it may be that she felt more freedom to pursue other goals such as students becoming personally connected to their investigation and connecting their investigation to the world outside the classroom. In addition, because the students were of lower academic ability she may have seen the lab as an opportunity to motivate students and build interest in science.

*Enacting inquiry: an astronomy inquiry lesson.*

In contrast to her biology course, Cathy's description of an astronomy inquiry lesson plan is more focused on science content knowledge. In this inquiry lesson students are moving through a series of lab stations where they are investigating the behavior of light. They make predictions and then observe how different materials either

transmit or absorb light. Astronomy content knowledge is the primary emphasis in her description.

*... we talk about light. What light is, and the electromagnetic spectrum, and we talk about filters, and we talk about detectors and transmitters. So I ask them to make predictions about what objects, obviously we've talked about transmitters, we have a notion, they have a notion about detectors, what detects. I'm trying to get them to understand that a radio, a little handheld radio, that's a detector. That's not a transmitter. And "Ohhhh, okay." and that's a new concept for most of them. And then we talk about filters and whether certain types of energy will pass through a certain type of material. And they make predictions. And so then what I do in this lab is I have my stations around and I have as many stations of light as I can.*

In her description students are observing and collecting data about how light interacts with different materials. They are not actively involved in designing the investigation or selecting and testing variables. The focus is on observing whether light will pass through different materials. Based on her description, my interpretation of her enactment of inquiry is on students developing astronomy content knowledge.

*Goals for inquiry in astronomy.*

Cathy's goals for inquiry are consistent with her enactment. For her, the lab was successful if students gained a better understanding about light, energy, frequency, and wavelength. Content is the focus and there is no mention of experimental design. She describes her goals for the lesson as:

*... and so I think that lesson worked really well for them and they all went away understanding, I think better how light works, a little bit better about how the energy it carries, has to do with frequency and wavelength. And they went on to another unit ... but they had to design a telescope plus a satellite for a specific purpose.*

Her goals for the lab also extend to a future activity where students use their astronomy content knowledge to design a satellite or telescope. Based on their knowledge of light they selected the appropriate type of satellite for a specific purpose. In this lesson the focus is closer to her general conception about inquiry as a way to stimulate critical thinking skills. They do so through the application of astronomy content knowledge. Her description of the lesson includes students designing the satellite followed by a comparison of existing satellites in orbit today.

*So they had to pick a target that they would be looking at and then, in very simple terms, choose a frequency that they believe would accomplish that goal, and then they had to choose similar parameters for their satellite as well, and then we also did some comparison and looked at a lot of satellites that are now in orbit and how they're used and the technology. And I think the kids really liked it, they got a lot out of it.*

In the inquiry lesson about light the focus was primarily on astronomy content knowledge. In the second lesson the emphasis was on students using the content knowledge to accomplish a task, in this case designing satellites. The second lesson is more consistent with her general conception of inquiry as a means to encourage critical thinking and being able to apply learning to the real world.

*Enacting inquiry: a chemistry inquiry lesson.*

The majority of the classes Cathy teaches are honors chemistry. When asked to describe an inquiry lesson for chemistry she chose to talk about a lab where students had to separate a mixture based on the characteristics of the different substances. She states:

*... they were given a task to separate some materials and I did not give them information on how to do it, but I wanted them to come up with the idea of solubility. And through the lesson they discovered, by various means in the end, that they all learned from one another eventually the process of this week-long lab that solubility is really an important characteristics to look at for chemicals. And that can be useful in terms of separating components. So in the end, this big lesson that they were able to come up with was, not only that solubility is important, and solubility can be determined, but they were also able to give me several of the factors that affect solubility and that was just from working with the task and playing with the materials and trying different things. So they were able to give me several different ways, not only that solubility is important, but also to increase solubility.*

In her description an emphasis is placed on the concept of solubility. An important part of the lesson is for students to “*to come up with the idea of solubility.*” Using solubility, along with techniques based on the characteristics of the substances, students are to separate a mixture of different substances. Based on her description, I interpret her enactment of inquiry to be primarily centered on students learning about the chemistry content knowledge. A specific emphasis is placed on the concept of solubility. To probe her focus on chemistry content knowledge I asked her about the relation

between the process of separating the substances and concepts students would acquire through the inquiry experience.

*Wayne (Interviewer): So the actual kind of process was going on but there was also the concepts.*

*Cathy: Right, so they basically taught themselves the concepts by experimenting and learning the best way to do it.*

For Cathy, the act of separating the substances based on their properties allowed students to learn the chemistry concepts on their own. While she uses the term experimenting in her response, I interpret it to mean a less structured exploration of how to separate the substances rather than a controlled experiment. Chemistry content knowledge is the primary goal.

In addition to students learning about chemistry content knowledge, the inquiry lab is also consistent with her general conception of inquiry. As she states earlier, students are not given any instructions about how to separate the mixture. They are to work with the materials and test different ideas in order to determine a way to perform the separation. In this sense, the lab relates to her general conception of inquiry as critical thinking.

*Summary.*

Cathy offers an opportunity to compare her general conception of inquiry to three different enactments. Much like other participants in the study, there were differences between her general conception of inquiry and how she enacted inquiry in different

contexts. For biology, the difference was most pronounced, whereas astronomy and chemistry were more closely related to her general conception of inquiry.

Cathy's enactment of a biology inquiry lesson is similar to trends found with other biology teachers in this study. Here she approached biology as students conducting scientific investigations. However, at the time of our interview Cathy was planning the investigation and had not yet enacted the lesson with students. Therefore our discussion was about what the inquiry lesson would look like. It is likely that there would be differences in her actual enactment.

The timing of the inquiry lesson is also important. The lesson was to take place at the end of the school year, most likely after testing was over. Because of this testing was not a factor in her planning. However, even without the influence of external testing, her approach followed the trend seen with other biology teachers in the study.

In discussing astronomy she initially selected an inquiry lesson that focused on astronomy content knowledge. Later she talked about a lesson that built upon this content and contained elements of her general conception. These included critical thinking and transferring knowledge to the real world. It is possible that controlled scientific investigations are more difficult to accomplish in astronomy where there are limitations on equipment and logistical concerns such as nighttime data collection.

In chemistry, content knowledge was also the primary emphasis. This is consistent with trends found for other chemistry teachers in this study. Like astronomy, there was also a secondary emphasis on critical thinking and problem solving.

At the end of our interview Cathy expressed a concern that an emphasis on inquiry could have a negative influence on students developing science content knowledge, especially for upper secondary students who she believes already have experience with conducting scientific investigations. She believed that this would place students at a disadvantage when they went to college. Cathy's perception was that the science education community was encouraging the use of inquiry as the predominant form of teaching. In doing so, scientific content knowledge was being sacrificed.

*Physics: Carl*

*Participant context.*

Carl teaches physics in a suburban school in Virginia. He has been teaching for six years and holds a bachelor's degree in physics and a master's in teaching. His classes this year include International Baccalaureate Physics and Active Physics. Carl received his NB certification in physics.

International Baccalaureate (IB) Physics consists of seniors and has a well-defined curriculum with requirements including a minimum of forty hours of lab work. He also teaches Active Physics, a class for sophomores who did not pass algebra. For Active Physics he has a less proscribed curriculum but at the same time is working with less motivated and mathematically skilled students. The two groups present an opportunity to view his conception of inquiry in classes with different ability levels.

Carl has taken part in a science teaching fellowship for several years and has received considerable support and professional development through the program. Fellows in the program have a bachelor's or higher degree in science, engineering or

mathematics and teach high school science or mathematics in the U.S. They receive support both financially and professionally for as long as five years. In our conversations Carl said that the fellowship was “*very inquiry focused.*” In addition, Carl has also attended a workshop on modeling and a *Physics by Inquiry* workshop.

In discussing professional development, Carl indicated that he has attended workshops and that teaching with inquiry was emphasized in his fellowship program.

*Carl: I have done the modeling workshop at Arizona State. I have done the Physics by Inquiry workshop at University of Washington. I have the science teaching fellowship, which is very inquiry focused. And then I have attended county professional development days, which have focused on inquiry.*

Carl does not have previous scientific research experience. However, his substantial professional development background, especially his participation in the fellowship program, is influential in how he thinks about and enacts inquiry.

*General conception of inquiry.*

Carl believes that inquiry is an important instructional strategy for teaching science, providing students with the opportunity to experience how science is done in the real world.

*Wayne (Interviewer): Could you describe to me what you think of when you hear the word inquiry in science teaching?*

*Carl: What I think of when I hear inquiry in science teaching? I think of the way science should be taught.*

*Wayne (Interviewer): Okay. Could you expand just a little on that? Why you think ...*

*Carl: I think that it is a way that allows students to experience how real science is done and if we really want our students to really understand science then they need to have an understanding of these inquiry skills that, you know, real scientists use in the real world.*

I interpreted his immediate and definitive answer that inquiry is “*the way science should be taught*” to mean that he sees of inquiry as a central feature of his teaching. An important part of inquiry for Carl includes having students engage in “*real science*” as it is done by practicing scientists. He returns to this theme several times in the interview. Later, when I asked him to give an example of an inquiry lesson, he stated that he considers most of his lessons to be based on inquiry.

*Wayne (Interviewer): Let’s talk about an inquiry based lesson plan of your choice.*

*Carl: Okay. I mean, most of my lessons are inquiry based*

I interpret his response to mean that he uses inquiry frequently and has many examples to draw from. For Carl, inquiry is a central feature of his practice.

Another dominant theme in the interview is the importance he places on students being held accountable for the results of their investigations. For Carl students must not only be able to explain why they designed their experiment a certain way, they must also be able to critique other students’ work. The theme is related to students’ understanding

of “*real science*” where scientists make their research available to the scrutiny of the scientific community.

The theme of accountability is present in Carl discussing how his IB students communicate their results to peers.

*Wayne (Interviewer): ... when they were presenting the whiteboards to each other, what type of communication took place between you and them or you and students, and so on?*

*Carl: So two questions that I have they use, practice in class are “How do you know?” and “Why do you think?” and so I do a lot of scaffolding but at this point in the year they ask really good “Why did you do that?” “How do you know that it was a quadratic relationship?” “How many trials do you do?” sort of.*

*Questions to, to try and uncover the differences between groups that similar experiments but came up with different results. General questions to hold each other accountable on, you know, a lot of times it “Did you subtract your initial mass” or “Did you have a zero mass?” or “Did you put zero on your graph?” “Why did you do that?”*

However, this theme is only present when discussing inquiry for the IB Physics classes. With the lower ability students in Active Physics the focus is on working with students to develop the ability to conduct an experiment. This may be due to his IB students already having learned the basics of designing and conducting investigations, whereas his Active Physics students are still working to acquire these abilities and knowledge. This idea is explored further his goals for using inquiry.

*Enacting inquiry: an Active Physics inquiry lesson.*

When asked to describe an inquiry lesson plan, Carl first chooses a lesson from his Active Physics students. In the lesson, students are investigating the energy stored in a rubber band and how changing the rubber band will change the amount of energy it stores.

*Wayne (Interviewer): Okay. Now is there an inquiry lesson plan that recently you've done that comes to mind?*

*Carl: We just did one in Active Physics where we were looking at getting energy out of a stretched rubber band. And so we brainstormed ideas for "What might we change about a stretched rubber band?" and we came up with some different things. One was putting twists into a rubber band chain, and doubling back the rubber band chain, pulling the rubber band chain further, pulling it back with a different amount of force, and then for our DV almost all the groups build a little paper hornet and they shot it and measures how far it went along the floor. One group shot their hornet into a Lego block and measured how far the Lego block moved. The basic idea of "What do we do to the rubber band?" and "What's our understanding of the effect it has on another object?" because in this class we defined energy as, something has energy if it can do something to something else. That was sort of the definition that class came up which I was, it sounds like the ability to do work. The class came up with this idea on their own and I think it worked out really well.*

My interpretation is that his conception of inquiry for Active Physics centers on students asking questions, planning an investigation, manipulating variables. Later in the

interview while discussing his goals for using inquiry with his Active Physics class, Carl states that he wanted students to be able to “*carry out an experiment to completion and discuss the results.*” Therefore, his goals for inquiry can be categorized as students conducting scientific investigations.

Ability levels of IB and Active Physics could be the primary reason for differences in how Carl thinks about inquiry in these classes. Students in IB Physics have considerably more mathematical and experimental sophistication than students in Active Physics. As a result it is not necessary to spend as much time or place an emphasis on the structure of conducting investigations. With his IB students, Carl is able to rely on students’ ability to do these things without instruction. Content becomes more important, especially with IB testing requirements.

Age may also be another factor. Seniors will have had more science classes than sophomores and more exposure to science and conducting scientific investigations. For seniors it would not be as necessary to emphasize how to conduct a scientific investigation.

*Enacting inquiry: an International Baccalaureate inquiry lesson.*

In his description of an IB Physics lesson plan, students work with a computer simulation to measure the effect of changing different variables on circular motion.

*... was a circular motion investigation. Where we observed a toy superman flying around on a string and we brainstormed observations about this event in an attempt to think about things that we might change about the situation and things we might be able to measure. And so things we came up with, for example were,*

*length of the string, the speed of the object moving in a circle, the tension in the string, the mass of the object, so on and so forth. Then the kids discussed the, you know, the strengths and the weaknesses of trying these different characteristics as an independent variable or the dependent variable, and then to conduct this lab they actually used a simulation program.*

While Carl does not explicitly state that students are engaged in modeling, the simulation software allows them to measure the effect of the variables on circular motion. The idea of modeling is further supported by his description of how students are can make changes to one variable to see how it influences the others.

*Wayne (Interviewer): So they, all the computer program had all those variables built in?*

*Carl: Right. I actually built a screen for them with the basic ones they change. Mass, velocity, radius, force, and they could measure. So it sort of allowed them to change those things and measure the other ones at the same time.*

Towards the end of the interview I asked Carl about sources of curriculum for teaching with inquiry. The generation of models is a central theme in his response.

*Wayne (Interviewer): Where would you go to find inquiry based curriculum for a class?*

*Carl: You know the Physics by Inquiry texts are really good. That's sort of a different model than I think then, the modeling curriculum is all about this paradigm lab or this experiment lab that they do and once you understand this lab then you apply that understanding to different situation. Physics by Inquiry is*

*more of a building process where you ask questions and form a model of how things behave by continuously asking questions, you know, thinking about the questions, or taking measurements to see what happens if different things are tried.*

*Wayne (Interviewer): Which one do you think works better for you?*

*Carl: I think it's a combination of both that I use. Some things, I use the Pasco curriculum for circuits. Which is a sort of guided inquiry where students sort of figure out how a circuit works and then you present them with something that sort of goes against what they think should happen and then they do some experiments to try and explain what's going on and sort forming this model of what's happening inside of the wires. I think it's different. Both methods are good and some are more suited for different topics.*

Carl demonstrates his knowledge of the different inquiry curricula available and the strengths of each. For him, the choice of which to use is guided by the topic being presented. Regardless of the curriculum, modeling is a consistent theme in his description.

*Goals of inquiry: Active Physics.*

For the Active Physics class Carl is not as constrained by the curriculum and testing as he is in IB Physics. Although the process is challenging, he is working to have students conduct a basic investigation and discuss the results.

*Wayne (Interviewer): And then for that lab, that inquiry lab, what were your main goals for those guys there?*

*Carl: Um, we're still sort of struggling with experimental design. This is a tougher population of students. Getting them to carry out an experiment to completion and discuss the results. I feel like I'm still, we've been trying it all year and still not successful with this group of kids.*

My interpretation is that because students are struggling with the basics of designing scientific investigations, Carl is unable to engage students in some of the inquiry activities he does with his IB students, such as mathematical modeling. So while he has different goals for Active Physics students, his overall conception of inquiry is consistent. I believe that if his Active Physics students mastered the basics of experimental design, he would move on to more modeling-based inquiry activities.

*Goals of inquiry: International Baccalaureate physics.*

For IB Physics the theme of accountability is again present. Carl believes that the results of students' investigations should be made available to their peers, who represent the scientific community. He states a major goal that students “*hold each other accountable for the information they presented as a scientific community.*” Further, he emphasizes that students should understand that presenting results to the scientific community is an important aspect of science in the real world.

*Wayne (Interviewer): What were your goals for them in this lesson plan?*

*Carl: Hmmm. What were my goals? Um. Some overarching goals were to hold each other accountable for the information they presented as a scientific community. To analyze data to determine the relationships between variables that weren't linear.*

*Wayne (Interviewer): When you think back to, what did you want the kids to go away with?*

*Carl: Yeah. That's a good question. You know, definitely I want them to understand the relationship between the velocity and radius and mass for an object moving in a circle. That's sort of the content knowledge that they need to understand. And then, in holding each other accountable, you know, I want them to have a better understanding of why is it important that we our data to a group of our peers. What's the benefit? Right. We sort of explicitly talked about why do we go through this process and what good does it do.*

Developing an understanding of physics content knowledge is also a major goal of inquiry for Carl. It is likely that the emphasis on physics content knowledge is related to the IB testing requirements.

#### *Summary.*

For Carl, inquiry is an integral part of how he thinks about and teaches science. It is likely that his long-term participation in the fellowship program and other professional development programs are influential in his conception and enactment of inquiry. Of particular interest is a comparison of Carl's use of inquiry in his Active Physics and his IB classes. These classes offer two contexts for his use of inquiry in teaching physics.

While his enactment and goals for inquiry initially appeared very different for his IB and introductory Active Physics classes, it may be helpful to think of the two classes as at two places on a continuum of his conception of inquiry. In IB Physics, which consisted primarily of seniors, students have mastered the basics of designing and

conducting investigations. As a result, Carl was able to focus more on other aspects of inquiry such as content knowledge and importance of accountability and communication with peers. For Active Physics, where students were less knowledgeable and motivated, the focus was on being able to “*carry out an experiment to completion and discuss the results.*”

*Physics: Diane*

*Participant context.*

Diane teaches physics in a suburban school in Missouri. She has been teaching for thirty years and holds a bachelor’s degree in biology and education, minors in chemistry and physics, and a master’s in science education. Her classes this year include astronomy, senior physics, introduction to physics, and biology. The biology class is taught in summer school. Diane received her NB certification in physics.

While Diane has not recently participated in any professional development on teaching with inquiry, she has been active in the QuarkNet program. QuarkNet is a program supported by the National Science Foundation and the Office of High Energy Physics in the Department of Energy. The program involves teachers in particle physics experiments with practicing scientists.

During our discussion Diane mentioned that having several different classes to prepare for required considerable time. This may constrain her use of inquiry, particularly in courses like biology where she only teaches one class. It is also noteworthy that Diane has taught for thirty years, the longest of participants in this study.

*General conception of inquiry.*

For Diane, inquiry provides a way to introduce students to a mathematical concept prior to more traditional teaching. By participating in an inquiry experience, students are able to see the relationship between variables and develop an understanding of the mathematical equation. To illustrate her ideas she provides an example where students measure the circumference and diameter of a circle to determine pi.

*Wayne (Interviewer): Could you describe to me what you think about when you hear the term inquiry teaching in science?*

*Diane: I think inquiry in science is going to happen as a predecessor, that activity, whatever inquiry activity you think you've designed, is going to happen to be a predecessor to any equation that you may give the students to show them a relationship between variables. So the inquiry that you're setting up, see I'm a physics person, so I'm going straight to an equation. With biology or chemistry it might not be an equation. But for example in the introductory physics courses, we do an inquiry about pi, the constant pi, in order to review and to introduce inquiry. [...] So that would be an example of an inquiry activity because eventually you're going to get to the equation for pi that shows the relationship between circumference and diameter.*

Diane describes herself as “a physics person, so I'm going straight to an equation.” Similar to other physics teachers in the study, for Diane inquiry often results in the development of an equation to describe a phenomenon. For her, the end result of inquiry is the development of an equation and an understanding of the relationships between variables. Her approach to inquiry can be categorized as using inquiry to

develop mathematical models of physical phenomena. It is important to note this class is a non-honors introductory class and that she holds this orientation towards inquiry with all of her physics classes, not only her higher level classes.

In addition to students studying physical phenomena to develop an equation, Diane also believes that inquiry provides a way for students to experience what she calls “*the thrill of discovery.*” For her, inquiry makes the content more meaningful to students. As a result, they are able to internalize the information to a greater degree.

*Wayne (Interviewer): Okay, what is the goal of doing that in an inquiry fashion as opposed to just telling them what pi is or just showing them that?*

*Diane: To make it more meaningful. So that can feel the thrill of discovering it. I think that's there's much more internalization if they have the thrill of discovering it even though it's already been discovered by someone hundreds ago or whatever the case may be.*

*Wayne (Interviewer): Okay.*

*Diane: So I think there greater ownership and more internalization. But it's a lot more time consuming. It's good sometimes.*

Even though Diane believes that students internalize concepts and develop ownership through the use of inquiry, she also feels that the amount of time needed for inquiry is a limitation. She adds that inquiry is “*good sometimes*” which could be interpreted to mean that inquiry is appropriate in certain situations but the amount of time required is a constraining factor.

*Enacting inquiry: a physics inquiry lesson.*

For her Introductory Physics class, a non-honors course consisting of 9<sup>th</sup> through 12<sup>th</sup> graders, Diane describes an inquiry lesson plan about acceleration.

*... And it was an inclined plane lab and we had not yet covered the formula for acceleration even though I think some of the kids had an idea of what it might be, and for a lot of the sophomores, this is still a good lesson for them. Particularly because many of them have gotten their drivers permits, so they're just on the cusp of becoming drivers. So anyway, part of the difficulty of acceleration is that kids don't really understand it as an increase in velocity. And they're also confused about the double time factor in the denominator. The squared factor rather, time times time.*

Similar to her earlier description, inquiry is used to introduce students to a concept, in this case acceleration. Students had not yet learned the mathematical equation for acceleration. The description returns once again to the equation, specifically acceleration as an increase in velocity and the units of time squared.

In addition to introducing students to concepts and equations, inquiry also generates questions. Diane explains:

*What the inquiry provides in an inclined plane lab, is that the way I set it up, they're timing over a two meter track, they just timing the ball rolling down the incline. And I do allow students some individual variation, in terms they're going to get to choose what the angle of their incline is, because they're eventually going to whiteboard their results and compare their slopes and acceleration*

*values and everything else, but, and then they're going to have to backtrack and say "Well, why was this table's acceleration this value? Why didn't we all get the same numbers?" Cause gravity is what's making it roll down. Why isn't it the same number?"*

In her description, students are actively thinking about and physically experiencing the phenomena. This relates to her earlier comments about the value of students taking part in inquiry before learning the equation or phenomena in a more traditional manner. Through the inquiry activity, they can begin to ask questions and develop an understanding of the variables and relationships that make up the mathematical equation.

In this inquiry lesson, Diane emphasized that students “*physically need to experience*” acceleration and how it varies over the inclined plane.

*Diane: So we get into a lot of discussions but I think the inquiry part of this is not so much the equation but the idea that the time to move the same distance keeps getting shorter. And what the students physically need to experience to help them over that hurdle, is that timers who were at the bottom of the track, they have been able to see through repeated trial and error, that their job is harder and that they have a more difficult task than the people at the top of the track.*

Diane’s use of inquiry here could be interpreted as a way to provide students with a physical understanding of acceleration and the relationship between variables preceding the actual introduction of the equation. The inquiry experience helps students internalize and develop ownership of the equation, making traditional instruction more meaningful. This interpretation is supported by her statement about the difficulty students have in

relating mathematics to the actual variables; in this lab, time and the angle of the inclined plane.

*Diane: They don't necessarily see the mathematics, they don't necessarily relate the symbol to a variable.*

For Diane, inquiry allows students to “see” how the variables relate to the actual mathematics. Here, inquiry forms a bridge between abstract mathematical symbols and what students can physically observe in the lab.

*Goals of inquiry for physics.*

After discussing the physics inquiry lesson on inclined planes, I asked Diane about her goals for the lab. Her initial response focused on the specifics of the lab such as velocity, plotting distances versus time, how to determine the instantaneous rate of velocity, and how to draw tangents. But when asked what she wanted students to take away from similar experiences she responds with broader goals.

*Wayne (Interviewer): So what did you want the kids, when you do an activity like that, what do you want them to go away with or be able to do?*

*Diane: The relationships. The derivation for acceleration first of all. And the relationship of, ramp angle to acceleration, why the acceleration has seconds squared, they're going to get some skills in timing. And just, I hate to generalize it to something as simple as this, but common sense. There're going to gain some common sense skills about why it's more difficult at the end of the ramp, and there's some cooperative learning skills that they are learning, and graphing skills, maybe doing dependent and independent skills that they learned in Bio One*

*and Chem One, and derivation of the equation of a line. We're going to get to  $y=mx + b$  eventually. When we plot final velocity on the y, it's going to come up, the  $y=mx + b$  is going to be that  $v_s = v_i + at$  where  $a$  is the slope and  $x$  is the time and  $v_i$  is the y-intercept.*

Her response returns again to the relationships between variables, a consistent theme in her description of inquiry. The physical experience of conducting the inquiry lab also helps students develop “*common sense*” about how variables relate to each other; in this case, why it is easier to measure velocity at the top of the ramp. At the end of the inquiry experience, students arrive at the equation for acceleration by graphing the data they collected. This provides further support for categorizing Diane’s conception of inquiry as mathematical modeling.

*Enacting inquiry: a biology inquiry lesson.*

When asked for an example of her use of inquiry in biology or astronomy, Diane indicated that she couldn’t think of one at that time.

*Diane: No, not off the top of my head because I’m just not as well versed in those. And I’ve been doing physics for so long that when I do have to, you just commented about having, I can imagine having five, well, sorta neither can I. When I do a bio, I’m pretty much taking whatever my colleagues do and saying “Yeah, I can do that.”*

In her response she cites two reasons for her limited use of inquiry in biology. First is her level of familiarity where she is not as “*well versed*” in biology. Second, the pressures of having a large number of courses to prepare for, Senior Physics, Intro

Physics, Astronomy, and Biology (summer), limits time she has to prepare inquiry lesson plans. As a result, she relies on her colleagues. My interpretation is that for biology, Diane teaches with inquiry infrequently. When asked for an example she describes a lesson about osmosis.

*Diane: I can think of one. When we were studying isotonic, hypertonic, and hypotonic solutions, we define those things, and then we do a lab, standard potato lab, you put it in three different salt solutions.*

However, Diane doesn't provide much detail about the lab as she did with physics. In addition, she considers the biology lab to only be only marginally inquiry.

*Diane: And they have to decide which percentage solution is which defined word, and why. So that's on the fringe of inquiry, it's more than telling them the whole thing up front.*

My interpretation is that Diane sees herself primarily as a physics teacher with a strong mathematical orientation. Like other NBCSTs who teach both biology and physics, Diane does not seem as comfortable with inquiry in biology. As stated in the interview, Diane sees herself as a very structured person. It may be that biology, as mentioned by other participants, is not as structured due to the number of potentially confounding variables. In conjunction with other very real constraints, such as multiple courses to prepare for, Diane does not use inquiry teaching frequently with biology. The context of teaching biology in summer school may also influence her use of inquiry.

Another factor may be her reliance on her colleagues teaching biology. If they are not using inquiry in their teaching it is unlikely that Diane will also engage her

biology students in inquiry. In addition, since she identifies most with teaching physics she is somewhat of an outsider in the biology department. As a result, she is unlikely to deviate from the norm for teaching biology at her school.

*Summary.*

While Diane teaches multiple subjects, her primary focus is physics. Within the context of teaching physics, her approach to inquiry is centered on students experiencing and developing an understanding of mathematical equations to describe physical phenomena. Therefore, her teaching with inquiry can be placed under the theme of *Modeling*.

Both her general conception of inquiry and enactment of a physics inquiry lesson were consistent in that they introduce students to variables and mathematical relationships prior to more traditional teaching. In this sense, they were approaching the physical phenomena, here acceleration on an inclined plane, with limited knowledge about the mathematical equation. Through the inquiry activity, which includes generating and analyzing graphs, they learned about the equations.

In her biology class, which she teaches during the summer, Diane had less to say about inquiry. Contextual factors, such as the nature of summer school, and the fact that she only teaches one biology course, appear to constrain her use of inquiry in biology. Due to the limited use of inquiry in biology it was not possible to classify her use of inquiry within that context.

*Physics and Biology: Jane*

*Participant context.*

Jane teaches biology in an urban school in New York State. She has been teaching for eight years and holds a bachelor's degree in biology and a master's in biology education. She is currently working on finishing her master's in physics education. Her classes this year include non-honors biology and lower level biology for students who have not passed the state test. Jane received her NB certification in physics.

Although her educational background is in biology, during the previous three years she taught physics to ninth graders. As a result, her National Board certificate is in physics. Due to changes to the course sequence at Jane's school, ninth graders at her school now take biology instead of physics. Because Jane wanted to continue working with ninth graders she shifted to teaching biology. Therefore at the time of this interview the biology curriculum was still new to her. Several times in the interview she discussed the challenges of the shift and her efforts to incorporate more inquiry into her biology classes. She continues to work on completing her master's degree in physics education.

Prior to teaching, Jane worked for three years in a cancer research laboratory. To better understand how her research experience influenced her teaching, I asked her to describe her work in a follow-up email.

*Wayne (Interviewer): You mentioned that you worked with cancer research for several years. Could you describe your work? How does it influence how you teach?*

*Jane: For three years I worked for [company name]. While there, I was a part of both the research and quality control/assurance departments. Working in a lab made the transfer to education generally easy as I was accustomed to reporting research data to both small and large groups. I was also responsible for portions of the testing, and organization and communication were crucial – much like in education. As for in the classroom, I found that I began to break away from “cookie cutter labs” that simply asked students to follow directions (though, this is definitely key to reading and following SOPs in the lab) and began to design what I now know to be “inquiry” labs where students are developing the questions and procedures themselves (in a very guided manner).*

Jane was an active participant in numerous aspects of the research process and her response indicates to me that her research experience was influential in her teaching with inquiry. Her involvement in research, reporting data, and communicating results to others facilitated her ability to teach inquiry. For Jane, students asking questions and designing experiments are manifestations of this influence. Reporting research data is another aspect. She does stress, however, that student inquiry needs to be structured in her situation. This is most likely due to the age and academic ability level of her students.

Jane also received considerable professional development in teaching with inquiry, including several experiences doing scientific research. She participated for two summers in a research program for teachers at a local university where, along with other teachers, she conducted research under the guidance of scientists. Part of the summer program involved developing inquiry-based curriculum for her classroom.

*General conception of inquiry.*

When asked about what she thought when she heard the phrase “*inquiry in science teaching*” she responded by talking about inquiry in biology.

*Jane: I think that inquiry is mostly, I think of guided inquiry, I know that there's sort of two camps with inquiry, like some teachers introduce their students to all the equipment that's available to science or at least what they have in their school and then kind of let kids explore and discover on their own and I teach ninth graders. And I'm more of a structured person, so I feel like just complete inquiry isn't where I feel comfortable so I'm more a guided, you know, give them an introduction, give them a blurb to read, and then kind of lead them through the questions that they're discovering. So I try to develop, I don't have complete lessons right now, that's something I'm trying to do, hopefully in the next couple of years all my labs will be inquiry and all of my lessons will be more inquiry based than they are now.*

*Wayne (Interviewer): What would, like, a complete inquiry lab consist of?*

*Jane: For biology, I would want my students to have a little background knowledge, maybe something that they've read, or an article, short article, or maybe a topic from a lecture from my class, and be able to develop some of their own questions, not necessarily the labs that maybe you and I did when we were in high school or in middle school where there was a question that was already stated for us and then we followed the procedures, found the materials that we needed. I'd want them to kind of come up with that on their own, so they're coming up with a hypothesis, coming up with a purpose, and um, but along with*

*that I'm kind of guiding them the way to, you know, the right questions, and come up with correct, um, I don't want to say [?] just helping guide what their observations, or telling them do they need repeat it, is something not working, were they completely going in the wrong direction, do they need to talk to their partners and get that kind of back on track.*

In her description, she describes herself structured and feels that “*complete inquiry isn't where I feel comfortable so I'm more a guided.*” Several places in our conversation she stresses her preference for inquiry to be guided. Here sees her role as the teacher to provide structure and guidance that will ensure students are engaged in fruitful work that will lead to meaningful answers. For her, this involves students asking their own questions, constructing hypotheses, developing their own procedures, and collecting data to find an answer to their question. In this sense, her description of inquiry is similar to the portfolios of other biology teachers analyzed in this study.

Several times in the interview, she returned to the role of guided inquiry. One interpretation is that her experience with ninth graders leads her to feel the need to provide more structure to be successful. Since she currently teaches non-honors and remedial biology, it is possible that the ability level of her biology students also requires a more structured setting.

*Enacting inquiry: a physics inquiry lesson.*

When I asked her to describe an inquiry lesson plan in physics, Jane discussed a lesson from her non-honors ninth grade physics class. The lesson she describes involves providing students with a scenario where they are to investigate alternate designs for

Jersey barriers (concrete barriers separating lanes on a highway) that are more environmentally friendly.

*Jane: Sure, the inquiry lesson that I did was [labs?] that could be broken up into two different sections, and that was, we were at the time kind of in the middle motion and forces, and my students were having a more difficult time with friction than I anticipated. And they, again this was probably, I was dealing with non-honors students, and so again, a lot of their misconceptions would be addressed, I tried to make the lesson address their misconceptions. So they could tell me about friction and give me the information I wanted but when I asked them to apply it, it wasn't necessarily coming through. And so what I did was took a bunch of different lessons and we discussed the term "Jersey barriers" I don't know if everybody in the United States uses those, but the concrete, kind of like, almost like, almost like a triangle, very narrow at the top and the go down.*

*Wayne (Interviewer): I know what you're saying.*

*Jane: We were currently in the middle in construction, there was a new middle school being build and so we went out and we observed them and discussed what they would be for and why they would be in the middle of the road or on the side or road and the idea being that they were, the tires would be up against them and that slow somebody if they had gone off the road. And so we were also trying to do a lot in our school to [?] with, becoming a little bit more green and thinking about some of the materials that we were releasing into the environment as garbage and all that. So after we [?] kind of introductory part of the lesson, I gave them different materials, manipulatives, like wooden blocks and sand paper*

*and rubber, and Styrofoam and all types of different materials and they kind of developed a new Jersey barrier that might be a little bit more green than slabs of concrete. So the kind of developed these little cars that they could test their devices with. So that was what they were working on in their groups and then I led them to answer some of the questions that I was hoping to pull from them and that kind of the more guided inquiry as they were going along. They had to research the materials and the costs and, you know, accidents and stuff like that with their cars.*

In this lesson students are working to find a solution to a real world problem by designing model Jersey Barriers and testing their design. They are given a scenario where they have been asked by the mayor to conduct research and make recommendations for more environmentally friendly Jersey barriers. Jane believes this structure is more effective than lecture in helping students learn about the physics concepts of friction, motion, and forces. She also believes that the lesson will not create or reinforce students' misconceptions about motion and forces, a concern she states several times in our conversations.

Jane's description of the inquiry lesson does not have the more formal structure she described in her description for biology previously. However, while it does not involve students generating hypotheses, it does have a structure where students investigate a real-world problem relevant to their community.

In a limited sense, her approach involves some aspects of modeling similar to that found in the portfolios of other physics teachers in the study. Students are designing their model Jersey barriers, conducting an investigation, and collecting data to make

recommendations on how to make effective and more environmentally-friendly barriers. At the same time, the primary focus of the lesson was for students to develop their content knowledge about friction and forces in a manner that applied to a problem relevant to their community. Jane believes that presenting a real-world scenario is the most effective way for students to learn the content and overcome misconceptions.

*Enacting inquiry: a biology inquiry lesson.*

Jane's enactment of a biology inquiry lesson is very different from the description she provides at the beginning of the interview where she has students developing their own questions, purpose, and deciding what observations to make. Here her focus is more on students developing content knowledge. This highlights the difference between what she believes inquiry should be and what is possible in her classroom. For Jane, there is a large difference between the two.

*Wayne (Interviewer): Okay, I think I've got a pretty good idea of what you did there with the inquiry and the physics there. Is there a biology inquiry lesson plan that you taught, that you can just off the top of your head talk about.*

*Jane: [Pause]*

*Wayne (Interviewer): I didn't mean to put you on the spot here.*

*Jane: Oh, no, no. I'm trying to think of the most recent one that I would consider to be inquiry. So I did one where we were working with, it was after we did photosynthesis, so we working with plants. And at the same time I was trying to, the main, the overarching theme was photosynthesis and I was trying to hit all the standards that I needed to and then incorporated, at the same time we had to*

*think about monocots versus dicots, so the different types of plants and I wanted my students to compare monocots and dicots and at the same time understand about light and dark reactions. So what I wanted them to understand about the monocots and dicots was the difference between the vascular bundles, like xylem and phloem, and what their purposes were. One for the water and the other one for the sugars and the fact that plants actually use the sugar that they create. It's not like they're just creating it for us it's like they're seeking the sunlight and making all these things and they can use them. And a misconception I was running into was is that they just, they only take in carbon dioxide and actually only produce oxygen.*

In her description, the major focus is on biology content knowledge. There is no evidence of students asking questions, developing procedures, or collecting data as found in her description of a physics lesson plan. The lesson is intended to support students' understanding of the topic of photosynthesis while meeting the state standards. Related to the emphasis of biology content knowledge, she finishes her description of the lesson by returning to the theme of students' misconceptions. Here she explains one of the goals of the lesson was for students to correct their misconception about the role of carbon dioxide and oxygen in photosynthesis.

*Goals of inquiry for physics.*

Physics inquiry goals for Jane are centered on getting students to further their understanding of physics while avoiding generating misconceptions.

*Jane: My goals for them were for them to be basically, my goals are in misconceptions I guess, and actually own the physical laws that were associated*

*with it. I want to say that we were also to get them, I was also trying to get them to think outside than some of the prefab labs that I had given them earlier in the year. Kind of building on their knowledge that they were building in the classroom, not necessarily reconstructing some of the misconceptions as well. Kinda a combination of those two.*

When asked the amount of choice students had in their investigation, Jane further clarifies the goal of students developing an understanding of the physics content knowledge from the experience.

*The underlying point for the lesson was basically about friction and how friction works and I was also trying incorporate acceleration, and then velocity, and balanced forces, unbalanced forces. I wanted them to think about everything that they learned up to that point so they were calculating, you know, the velocity of their car, they were taking time measurements and taking distance measurements, they were calculating acceleration, they were graphing, so it was kind of a culminating lesson.*

While the goal of the inquiry lesson is related to content knowledge and avoiding misconceptions as in biology, the investigation has considerably more structure than her biology inquiry lesson. Students are making decisions about what factors they will test, designing their investigation, collecting and analyzing data. In addition, Jane later describes how students then present their findings from their investigations to peers and other teachers in the school in a poster session. My interpretation is that the primary goal of the lesson is the physics content knowledge. However, students are also involved in designing an investigation, collecting data, coming to a conclusion, and presenting their

findings to peers. In this sense an unstated, but underlying goal is to have students conduct a scientific investigation.

*Goals of inquiry for biology.*

In a follow-up email I asked Jane about her goals for inquiry. In her response, she cited meeting standards as a primary concern. For Jane, in order to invest time on a lab activity it must result in standards being covered. She states:

*Wayne (Interviewer): Could you discuss what your goals for inquiry are when teaching a biology class?*

*Jane: I look to achieve the following:*

*Covering at least 2-3 **standards** [bold emphasis in her email] in one lab/activity.*

*We have 6 main strands and each strand is broken into at least 8 standards (and those standards are quite general) so to spend time on a lab means it must be worth it vs. time on teaching.*

Her goal of covering “at least 2-3 standards” is consistent with her overall focus on students gaining biology content knowledge as described in her biology inquiry lesson. She also stated a goal of having students take part in authentic lab experiences. She asked,

*Is it relative to a real lab experience? Am I giving them a pencil-paper activity or is this something that can transfer to a real lab experience?*

For Jane, “pencil and paper” activities do not help her students gain scientific knowledge and skills that are relevant to the world outside the classroom. Inquiry labs are valuable because students can use the knowledge in actual lab experiences. I interpret

this emphasis on authentic lab experiences to be influenced by her experiences in cancer research prior to becoming a teacher.

*Summary.*

Jane's recent change from teaching physics to biology to ninth graders is an important consideration in how her conception of inquiry is interpreted. However, I believe it is not the main reason for the differences seen in her enactment and goals for each discipline. Other contextual factors, primarily testing and the structure of the disciplines, lead to differences in how she approaches inquiry in biology and physics.

Discussing inquiry in biology in a more general sense, Jane is similar to other biology teachers in the study who think about and enact inquiry as students conducting scientific investigations. But her implementation was very different, focusing mainly on biology content knowledge. I believe this difference between her general conception and enactment of inquiry exists for several reasons. First, Jane was still in the process of developing inquiry curriculum for her biology class, something she mentioned several times. Second, mandated testing led to an emphasis on biology content knowledge, as evidenced by her frequent references to learning standards when discussing biology. Finally, similar to two other participants who teach biology and another discipline, Jane may have found inquiry to be more challenging in biology than in physics which she is used to teaching.

In contrast, in physics Jane was more familiar with the curriculum and was not constrained by mandated testing. As a result, she was able to engage students in an investigation that involved using physics to develop solutions to a societal problem. Although physics content knowledge was one goal of the activity, it was not the primary

goal and state learning standards are not mentioned in the discussion. In addition, there was a well-articulated structure that culminated in students presenting their results to their peers and others.

Jane offers the opportunity to explore the importance of contextual factors that influence the use of inquiry in biology and physics. In her case, state-mandated testing appeared to play a major role in how she approached inquiry in biology, and lead her to focus on biology content knowledge.

#### *Cross-Case Analysis of Participants' Conception, Enactment, Goals for Inquiry*

In this chapter I presented twelve participants and their general conception of inquiry, a specific inquiry lesson plan of their choice, and their goals for that lesson plan. The purpose is to show individual variation within the context of each participant's practice. Building upon those contexts, in this cross-case analysis I explore themes in a broader context: the similarities and differences both within and between biology, chemistry, earth science, and physics. The analysis provides insights into the research question, *"How does a NBCST's science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?"*

Eight participants, two from each NB certificate area, teaching in only one discipline, are presented in Table 24. They are sorted alphabetically by certificate area. One participant, Anita, taught an additional, specialized course and has been included in table one since her primary discipline is chemistry. In Table 25, four participants teaching more than one discipline are presented. There is one participant for each

certificate area. I made the decision to create a separate table to facilitate analysis since each individual's conception of inquiry can vary between disciplines.

The first column lists the participant and their NB certificate area. In the second column the classes they currently teach are listed. The column "General Conception" provides short text segments taken from data presented previously. It represents their response to the question, "*What do you think of when you hear the word inquiry teaching?*" This provides their general view of inquiry apart from the context of a specific lesson plan or discipline.

My interpretation of participants' enactment of a specific inquiry lesson of their choice is provided under the column "Enactment." This was generated from detailed interview text and is influential in deciding which theme best represents participants' conception of inquiry. Participants' stated goals for the specific lesson plan are presented in the "Goals" column.

The last column, "Theme" is my interpretation of the participants' overall conception of inquiry. It is based upon a careful reading of interview text and follow-up conversations with participants. Participants' general conception, enactment, and goals for inquiry, summarized in Tables 24 and 25, were used to generate themes.

Table 24

*Participants' Conception, Enactment, Goals for Inquiry*

<b>Participant</b> (Cert. Area)	<b>Teaching</b> <b>(2008-09)</b>	<b>General Conception</b>	<b>Enactment</b>	<b>Goals</b>	<b>Theme</b>
Scott (Biology)	Biology	<i>"students ... should be able to plan, data collect, and do data analysis..."</i>	SCSI	SCSI	SCSI
Amy (Biology)	Biology	<i>"students learn through discovery"</i>	Content	SCSI / real world connection	Content
Peter (Chemistry)	IB Chemistry	<i>"for IB anyway, they have to do a series of planning or design labs"</i>	SCSI	Content	SCSI & Content
Anita (Chemistry)	Chemistry	<i>"trying to figure a problem out"</i> <i>"more likely to be remembered"</i>	Content	Content & Problem Solving	Content
	Science Research		SCSI	SCSI	SCSI
Donna (Earth Science)	Earth Science	Insufficient Data	SCSI	SCSI	SCSI
Sarah (Earth Science)	Earth Science	<i>"discover something during the lab" "how real science is done"</i>	SCSI	SCSI & Content	SCSI
Diane (Physics)	Physics	<i>"more internalization if they have the thrill of discovering it"</i>	Modeling	Modeling	Modeling
Carl (Physics)	Active Physics	<i>"how real science is done"</i>	SCSI	SCSI	SCSI
	IB Physics		Modeling	Content & "Accountability"	Modeling

Table 25

*Participants' Conception, Enactment, Goals for Inquiry: Multiple Disciplines*

<b>Participant</b> (Cert. Area)	<b>Teaching</b> (2008-09)	<b>General Conception</b>	<b>Enactment</b>	<b>Goals</b>	<b>Theme</b>
Tom (Biology)	Biology	<i>“discover scientific facts or information” “makes the point concrete”</i>	SCSI	SCSI	SCSI
	Physics		Modeling	Modeling & Content	Modeling
Allen (Chemistry)	AP Biology	<i>“creation of a worthwhile problem in which the students are capable of solving”</i>	SCSI	SCSI	SCSI
	Chemistry		SCSI	SCSI	SCSI
Cathy (Earth Science)	Astronomy	<i>“I just think, thinking.”</i>	Content	Content & Application	Content
	Pre-AP Biology		SCSI	Content & Student Engagement	SCSI
	Chemistry		Content	Insufficient data	Content
Jane (Physics)	Biology	<i>“so they’re coming up with a hypothesis, coming up with a purpose ...”</i>  She does not mention physics.	Content	Content	Content
	Physics		Modeling & Content	Content	Modeling & Content

The analysis and description of each of the twelve participants in this chapter provides rich data about individual teaching situations. In this cross-case analysis, I make connections between cases, provide exemplars for each theme, and lay the groundwork for exploring these themes in the context of biology, chemistry, earth science and physics teaching.

In the next three sections each of the three themes that emerged, *Students Conducting Scientific Investigations*, *Science Content Knowledge*, and *Modeling*, are presented.

*Inquiry as Students Conducting Scientific Investigations.*

For many teachers in this study, inquiry involves students conducting scientific investigations. Investigations typically consist of students asking a question, stating a hypothesis, designing procedures that involve the manipulation of variables (and often specific mention of a control group), coming to a conclusion, and communicating findings to their teacher and peers. Learning science content may also take place; however, it is not the primary purpose.

In this conception of inquiry, students often begin with a question or hypothesis. “*My goal was for them to first of all, take a look at the question, the hypothesis...*” (Tom). Frequently students have a choice of the question or variables they will investigate such as or “*where they have to choose their own experiment give a very broad starting point.*” (Peter) or “*I wanted them to melt down their gel and somehow change something, some factor in each of the tubes.*” (Scott). In the nine instances where participants held the conception of inquiry as *SCSI*, eight gave students a choice of the question or variables they investigated.

As was the case with most participants in this study, students were responsible for designing the investigation. However, the manipulation of variables was a frequent feature in the *SCSI* theme. In addition, having a control group was often included when discussing variables. Scott states:

*As far as inquiry goals I just wanted them to come up with a simple experiment, I wanted them to have a single variable, I wanted them to make sure that they could set up an experiment that had a control group, and it had a gradient of the chemicals, not just all or nothing, the control group or nothing, the experimental group with the chemical.*

Donna, an earth science teacher, provides an exemplar of this conception of inquiry. She describes an investigation into the factors that influence crystal growth.

*We start out ...where they go to a web site and collect information on what type of variables could affect the growth of salt crystals ...how they want to manipulate crystal growth and they form their hypothesis from there and we make sure that they quantify them and predict how things will be manipulated. From there they design the experiment, ...look at the data make sure they control just that variable and then they graph it in ... and see how their manipulated variable... to conclude at the end the type of relationship is affected, ... and then what they would like to do for future studies, then we have them present it in front of the class.*

Although there are commonalities between participants, there are also instances that are distinct. Amy has a general conception of inquiry as discovery learning but her enactment focuses on students acquiring content knowledge. Different still are her goals for inquiry, which stress the importance that “*each student can relate to it*” and “*run simple experiments.*” Therefore, while Amy stated a goal of *SCSI*, her general conception and enactment did not lead me to believe this to be thematically representative of her conception of inquiry.

### *Inquiry as Science Content Knowledge*

Participants within this theme emphasize the acquisition of content knowledge as the primary role of inquiry. While students may develop their own procedures, select variables to investigate, or work with mathematical equations, the predominant theme in their conception of inquiry is the development of subject specific content knowledge.

There are different reasons for a focus on content knowledge. For Amy, inquiry facilitated students' understanding of content by allowing them to observe phenomena and generate ideas about what they observed. Even so, it was still necessary to provide additional content in the form of notes and vocabulary.

*“Eventually we narrow it down to the right reason that it is occurring and after that I usually give them a little bit more detailed notes to give them the vocabulary to help them explain what they saw and have come up with” (Amy)*

Meeting external requirements also played a role in some teachers' emphasis on content knowledge. For Jane, standards were one factor in her conception of inquiry in biology. She states:

*“The overarching theme was photosynthesis and I was trying to hit all the standards that I needed to...” (Jane)*

Standards and curricular constraints can be perceived as so severe that they actually prevent inquiry from taking place at all. While Peter frequently uses inquiry with his IB Chemistry students, he rarely does so with his Chemistry One students.

*“I do inquiry with Chemistry One students very, very little.... Part of the reason that it’s hard to do inquiry with Chem One students is first of all, our curriculum is so thick that unfortunately I don’t have time....”*

Sarah also cites the pressures of standards: *“they have a high stakes state test to pass at the end of my course.”* However, her general conception, enactment, and goals for inquiry focus on *SCSI*, indicating that external requirements do not lead all teachers to focus on content knowledge.

For Peter, who teaches within the structure of the IB program, enactment is guided by the IB curriculum and fits the theme of *Students Conducting Scientific Investigations*. His goals, however, support this theme but also emphasize content knowledge. He states, *“Mainly I want them have an operational understanding of chemical kinetics ....”* As a result I made the decision to place him within two themes, *SCSI* and *Content*.

Peter, Carl, and Sarah all held the theme of *Content* as part of their enactment or goals for inquiry, although it was not the predominant theme. Part of this was based upon the expectation that students had been exposed to the process of conducting scientific investigations in previous classes. This may mean that for some teachers there is a hierarchical structure of conceptions about inquiry.

### *Inquiry as Modeling*

The theme *Modeling* consisted entirely of physics teachers and most often involved the generation of mathematical equations to describe a physical phenomena. In general, students were presented with a problem or system. They then designed a

procedure and decided what data to collect. Based on the data, they conducted an analysis, often involving graphing, to generate a mathematical model in the form of an equation to describe the phenomena and predict its behavior.

When asked her general thoughts about inquiry, Diane immediately talked about the relationships between variables and the centrality of the mathematical equation. She stated:

*“ ... is going to happen to be a predecessor to any equation that you may give the students to show them a relationship between variables. So the inquiry that you’re setting up, see I’m a physics person, so I’m going straight to an equation....” (Diane)*

Her response is typical of participants who hold the conception of inquiry as modeling. The primary focus was to use a mathematical equation to describe the relationships between variables. In Tom’s physics inquiry lesson, students constructed a mathematical model for projectile motion without having studied the actual equations. They then used their model to predict the path of the projectile.

*Okay, so I show them that set up and I explain that the purpose of doing this is trying figure out exactly where the marble is going to land on the floor. So they calculate that. And this is ahead of learning projectile calculations at all. We haven’t done any of that prior to this. (Tom)*

Carl also held the primary conception of inquiry as modeling. In his inquiry lesson on circular motion, students worked with a computer simulation that gave them the ability to manipulate variables and observe the effects. Carl also taught an introductory

physics course for sophomores who did not pass algebra. Here his emphasis was on students conducting scientific investigations.

*Um, we're still sort of struggling with experimental design. This is a tougher population of students. Getting them to carry out an experiment to completion and discuss the results.*

I believe that for Carl, the ability to conduct a scientific investigation was a necessary precursor to modeling. Students must first be able to conduct an experiment before moving on to generating models. In this sense, inquiry can be seen as a continuum, similar to Peter and Sarah.

For her physics class, Jane also held the conception of inquiry as modeling. Like Carl she taught an introductory physics course. In her class, students collected and graphed data to develop an improved, environmentally friendly barrier to separate highway traffic lanes. While there was a mathematical component, the lesson was more about learning the physics concepts and applying them to the highway barriers. Students were not involved with the generation of equations in this lesson.

### *Summary*

The major purpose of this cross-case analysis was to answer the research question, “*How does a NBCST’s science discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*” Table 27 presents the frequency with which themes occur in the disciplines of biology, chemistry, earth science, and physics.

Whereas the quantitative findings relied solely on the reading of an anonymous portfolio entry for a single class, participant interviews provided a wider range of contexts. NB portfolio entries offered insights about teachers' conceptions of inquiry, but in a limited context. Participant interviews allowed for a variety of abilities, types of classes, and comparisons of how participants teaching more than one discipline. With an expanded context comes greater opportunity for variation, which aided in theory building.

The findings in Table 26 indicate the majority of biology teachers held the conception of inquiry as *Students Conducting Scientific Investigations*. A smaller number viewed inquiry in biology as content. Chemistry teachers tended more towards a conception of inquiry as content, although by a smaller margin. Similar to biology, earth science teachers tended to hold the conception of inquiry as *SCSI*. However, *Content* was emphasized by one earth science participant. Finally, physics teachers overwhelmingly view inquiry as *Modeling*. However, one physics teacher did have equally held conceptions of inquiry as *SCSI* and *Modeling*.

Table 26

*Frequency of Goals of Inquiry for Disciplines*<sup>1</sup>

	<b>SCSI</b>	<b>Content</b>	<b>Modeling</b>	<b>Other</b>
Biology	4	2	-	-
Chemistry	1.5 <sup>2</sup>	2.5	-	-
Earth Science	2	1	-	-
Physics	0.5	-	3.5	-

<sup>1</sup> Participants teaching in more than one discipline were counted multiple times.

<sup>2</sup> Participants in two categories were counted as one half for each category.

Themes emerging from the analysis of interview data are similar to the quantitative categorization of teachers' goals and enactment of inquiry. In Chapter Four: Quantitative Results, several major categories for teachers' goals and enactment of inquiry were identified from the analysis of 48 National Board portfolio entries, *Active Scientific Inquiry*. Table 27 is a summary of teachers' goals and enactment of inquiry from the quantitative analysis.

Table 27

*Primary Goals of Inquiry*

Discipline	Scientific Method	Content	Modeling	Problem Solving	Other
Biology	10 (83%)	1 (8%)	--	--	1 (8%)
Chemistry	4 (31%)	8 (62%)	--	--	1 (8%)
Earth Science	6 (60%)	1 (10%)	--	1 (10%)	2 (20%)
Physics	2 (15%)	4 (31%)	6 (46%)	1 (8%)	--

The quantitative results presented a similar trend, although more pronounced for Biology and Chemistry. For physics a greater diversity of goals were found from the quantitative analysis. Because of the similar trends, the quantitative data provided triangulation for the findings in the qualitative cross case analysis.

Teaching with inquiry takes place within the context of different grades and ability levels, school cultures, high stakes testing environments, mandatory curriculum requirements, and within disciplines. All of these elements can have an impact upon teachers' conception, enactment, and goals for teaching with inquiry.

The intent of this section was to provide insights into how teachers think about and use inquiry within the disciplines of biology, chemistry, earth science, and physics. My interpretation of the contextually rich qualitative data in this section supports the assertion that differences do exist in teachers' conceptions of inquiry in different disciplines.

### *Inquiry and Nature of Science*

Inquiry and the nature of science (NOS) are closely related and considerable evidence exists that inquiry provides an effective context for learning and reflecting upon NOS (Lederman, 2007). The National Board (NB) also recognizes the relationship between inquiry and NOS. In the NB *AYA Science Standards* (NBPTS, 2007) NOS can be found under the heading *Nature of Science and Science as Inquiry*. The *Standards for AYA Science* were developed based on consensus documents in the science education community (NRC, 1996; AAAS, 1993; NSTA, 1993). As stated in the *Standards* (NBPTS, 2007):

*Having a clear understanding of the nature of science is essential for the teaching of adolescents and young adults.*

Due to the connection between inquiry and NOS, I decided to investigate teachers' conceptions and classroom enactment of NOS as part of this study. A primary goal of my research is to identify and explore how teachers' conception, enactment and goals or inquiry differ across the disciplines of biology, chemistry, earth science, and physics. Lederman (2007, p.871) also identified disciplinary differences as a critical direction for future research. He asks:

*Are the nature of science and scientific inquiry universal, or are conceptions influenced by the particular scientific discipline?*

This chapter, along with the data from the Views of Science-Technology-Society questionnaire presented in Chapter Four, seeks to explore the differences in participants' conception and enactment of NOS across disciplines within the context of inquiry.

#### *NOS and K-12 Science Education*

Although there are certain areas where disagreements over the nature of science exist, Lederman (2007) argues that these disagreements are not relevant to the K-12 classroom. According to Lederman these, areas relevant to K-12 are scientific knowledge as:

- Tentative
- Empirically based
- Subjective
- Involving human inference, imagination, and creativity.
- Being socially and culturally embedded

He also includes:

- The distinction between observations and inferences.
- The relationship between theories and laws.

These elements of NOS are appropriate for the teaching context of the participants in this study and are representative of those found in the NB *Standards* document.

Therefore, I decided to analyze interviews for the presence of each element.

The analysis produced very few references to NOS. To explore why this may be I chose three participants who might offer theoretical insights into the lack of NOS in their discussion of inquiry. The first case, Carl, is the only candidate who directly addressed aspects of NOS in our conversations. In addition to addressing elements of NOS, his enactment varied for students of different ability levels. Donna, the second case, did not discuss NOS in her enactment of an inquiry lesson but did believe that the certification process helped her develop a better understanding of the tentative nature of scientific knowledge. Finally, in her Science Research class, Anita's students conducted a year-long inquiry project with a goal of entering a science fair. She presents a case where her use of NOS is defined by external requirements. Together the cases provide an opportunity to seek explanations and build theory about why NOS is absent from participants' discussions about inquiry.

*Carl: Incorporating NOS into Teaching*

Carl teaches physics in a suburban school in Virginia. He has been teaching for six years and holds a bachelor's degree in physics and a master's in teaching. His classes this year include International Baccalaureate (IB) Physics and Active Physics. Carl received his NB certification in physics.

Of the twelve teachers interviewed, Carl discussed more aspects of the nature of science than any other participant, addressing both the empirical nature of knowledge and the socially embedded NOS. In addition, his physics classes were at two ends of the academic spectrum offering an opportunity to view NOS within classes of different ability levels. Students in IB Physics were motivated and high performing. In addition, they were older, most being seniors. In contrast, Active Physics students were

sophomores who did not pass algebra. Carl was chosen as one of the cases because elements of NOS were present in his teaching and because he offered an opportunity to see how NOS was used with different ability levels.

For Carl, the use of inquiry is central to science teaching. Probing further, he clarifies his thinking by connecting inquiry to the practice of scientists working outside of the classroom.

*Wayne (Interviewer): Could you describe to me what you think of when you hear the word inquiry in science teaching?*

*Carl: What I think of when I hear inquiry in science teaching? I think of the way science should be taught.*

*Wayne (Interviewer): Okay. Could you expand just a little on that? Why you think ...*

*Carl: I think that it is a way that allows students to experience how real science is done and if we really want our students to really understand science then they need to have an understanding of these inquiry skills that, you know, real scientists use in the real world.*

My interpretation is that he believes that inquiry is important because it reflects how research is done by “*real scientists use in the real world.*” As a result, aspects of the nature of science are present in his teaching. In our conversation, the empirical nature of evidence and the socially embedded nature of science are present.

*Empirically based nature of science.*

After students collect and analyze data, Carl has them use whiteboards to share findings. More than just presenting their findings, his students had to explain and defend how they collected data and the rationale for their decisions.

*Wayne (Interviewer): When they were presenting the whiteboards to each other, what type of communication took place ...*

*Carl: So two questions that I have they use, practice in class are “How do you know?” and “Why do you think?” and so I do a lot of scaffolding but at this point in the year they ask really good “Why did you do that?” “How do you know that it was a quadratic relationship?” “How many trials do you do?” sort of.*

*Questions to, to try and uncover the differences between groups that similar experiments but came up with different results. General questions to hold each other accountable on, you know, a lot of times it “Did you subtract you initial mass” or “Did you have a zero mass” or “Did you put zero on your graph?” “Why did you do that?”*

Much like real scientists, students must be able to defend their observations and show that they are accurate portrayals of the natural phenomena they are investigating. Comparing findings and trying to explain differences between groups demonstrates how Carl places the inquiry lesson in the context of a scientific community.

Observations are scrutinized by students’ peers and teacher. My interpretation is that, for Carl, students holding each other accountable for their findings means that their observations and treatment of the data are accurate, honest, and that students understand

how they got them. In this manner, I believe his intent is to engage students in a process similar to how “*real scientists*” present and discuss their findings in the scientific community.

*Social and embedded nature of science.*

After he described a lesson on circular motion for his IB students, I asked Carl about his goals for the lesson. He responded:

*Wayne (Interviewer): What were your goals for them in this lesson plan?*

*Carl: Hmmm. What were my goals? Um. Some overarching goals were to hold each other accountable for the information they presented as a scientific community. To analyze data to determine the relationships between variables that weren't linear.*

*Wayne (Interviewer): When you think back to, without what you actually wrote, what did you want the kids to go away with?*

*And then, in holding each other accountable, you know, I want them to have a better understanding of why is it important that we our data to a group of our peers. What's the benefit? Right. We sort of explicitly talked about why do we go through this process and what good does it do.*

Communicating and discussing results are an integral part of inquiry for Carl. I believe he sees sharing data with peers as part of the process of inquiry, similar to practicing scientists in a research community. Here again, he discusses students being accountable and ties this to the benefits of presenting data to peers. Unlike other participants, Carl stresses the explicit nature of this discussion.

*Comparison to Views of Science-Technology-Society (VOSTS) results.*

In Chapter Four: Quantitative Results, participants' responses to five VOSTS items were classified based on the consensus of a panel of experts. For all five items analyzed, Carl's responses were classified as either *Plausible Appropriate* (2) or *Appropriate* (3). Of the twelve participants completing the VOSTS, his responses were closest to the expert consensus used to measure participants understanding of NOS in this study. My interpretation is that Carl has developed views about the nature of science as measured by the VOSTS instrument and as evidenced by interview data.

*Interpretation.*

Of the teachers in this study, my conversations with Carl contained the most talk about NOS. In addition, of all participants, his VOSTS responses were the closest to the expert consensus view. Because of his explicit mention of NOS in our conversations and the similarity of his VOSTS responses to experts, Carl is unique among participants.

While Carl included NOS in our conversation, this only applied to his IB Physics students. I believe this is because students his IB students already had the basic abilities needed to conduct scientific investigations. They were able to design and conduct experiments based on previous academic experiences, and as a result, had more time and opportunities to build on this knowledge. Active Physics students were still working, struggling in many cases, to be able to design "*simple experiments*" as Carl puts it. Emphasizing the basics took priority and left little time for NOS. I believe it is likely that Carl would incorporate more NOS if his Active Physics students had more experience with conducting scientific investigations.

In his teaching with inquiry, Carl made several aspects of NOS explicit. This direct connection between inquiry and NOS is notable because it shows that he considered it an important part of teaching with inquiry. He stated:

*We sort of explicitly talked about why do we go through this process and what good does it do.*

For me, his use of the term “*explicitly*” signals intent and forethought about including this aspect of the nature of science in his teaching. I believe his explicit use of NOS is related to his desire to have his students learn about science like “*real scientists use in the real world*” and to experience presenting their findings as part of a “*scientific community*.”

*Donna: Learning about NOS through the NB Certification Process*

Donna teaches Earth Science in a rural school in Pennsylvania. She has been teaching for fourteen years and holds a bachelor’s degree in teaching earth science and a master’s in science education. Her classes this year include Honors Earth Science, College Prep Earth Science, and General Earth Science. Her students are primarily ninth graders. Donna received her NB certification in Earth Science.

Donna works in a school that supports inquiry and where teachers collaborate on designing inquiry lessons. All 9-12<sup>th</sup> grade students are required to do one inquiry lesson each year. The lesson described by Donna in this interview was written by Donna in collaboration with a fellow teacher and is used by all 9<sup>th</sup> grade earth science teachers at her school.

Donna is similar to most participants in that she did not include any aspects of NOS in her interview. This does not mean that NOS is absent from her science classroom; rather, she does not include NOS in her description of an inquiry lesson plan or her goals for inquiry. What makes Donna unique in this study is that she cites her understanding of science as the only aspect of inquiry that changed as a result of the certification process.

In addition to changing how she thought about the process of conducting scientific investigations, Donna also experienced changes in the way she teaches and the ways students learn about the nature of science.

*Wayne (Interviewer): So now in general in inquiry, as you do inquiry, do you do anything different as a result of ...*

*Donna: Yeah, I think that going through the whole process it kind of made me develop my understanding of science a lot more. Does that make sense to you?*

*Wayne (Interviewer): Yeah.*

*Donna: It's like the whole process of what they're supposed to be doing and what we should be teaching and not just kind of hitting and running I guess. So I teach it probably more in depth now than when I used to.*

She goes on to further to describe how, before, her students thought of science as a collection of facts. As a result of the certification process her teaching now emphasizes that evidence is needed to support factual knowledge, is tentative, and could change in the future.

*So like, I think before students understood like, look at science as, these are the facts. And now they understand that this is the evidence that leads us to this idea but that idea could change, as our technology gets better.*

For Donna, constructing the portfolio entry, *Active Scientific Inquiry*, contributed to her understanding of the process of conducting scientific investigations. When asked what she did differently as a result of the certification process she responded:

*I didn't, the way I design the hypothesis would still be the same. I had to offer up a little bit more on reliability and validity of data to go through that. Before it was like, sorry, once and done, we kind of hit, you need to do this many trials, but we didn't do as many trials we should've and we probably didn't control as much as we should have and I really had to focus on that principle.*

Her response primarily has to do with the process of conducting scientific investigations. Here she mentions the need to have students do more trials and emphasizes controlling variables that could confound the results. My interpretation is that Donna does not distinguish between aspects of NOS and inquiry. Later in the interview we discuss what had the most influence on her thinking about inquiry.

*Wayne (Interviewer): What was for you, in terms of the evolution of your thinking about inquiry, what was the most important part of that whole process that we went through?*

*Donna: I think that it was that, it is an important process that all kids should go through, and that even if saying this effect this, cause and effect, cause and effect is a higher level skill and before I use to think "how can they not get cause and*

*effect?” So I think teaching them cause and effect, teaching them that if you manipulate one it will affect other things, and that if you can’t control an experiment then the variability is not there and that if you lost that variability you can’t prove definitely that one definitely affected the other.*

Again, the more process-oriented notions of inquiry are emphasized. NOS is not a part of her description. This is not surprising given the emphasis on inquiry of the NB portfolio instructions. However, it does indicate to me that, although she is aware of some aspects of NOS, she does not conceive of them as separate from inquiry. I believe that as a result, there is no explicit mention of NOS in her description or goals of her inquiry lesson discussed in this study.

*Views of Science-Technology-Society instrument data.*

For the five items analyzed in the Views of Science-Technology-Society instrument, Donna’s responses were classified at *Appropriate* (3), *Naïve* (1), and “*None of these choices fits my basic viewpoint.*” Her responses could be interpreted to mean that her conception of the nature of science is still developing. However, because one of the items did not have an item that matched her viewpoint, it is not possible to categorize her overall view. In addition, drawing conclusions from such a small set of data is not warranted.

*Anita: Implicit NOS*

Anita teaches chemistry in a suburban school in Florida. She has been teaching for five years and holds a bachelor’s degree in biology and a master’s in teaching. Her classes this year include Honors Chemistry, Advanced Placement Chemistry, and a

course entitled Science Research. Students in her Science Research conduct research in preparation for a science fair competition. Anita received her NB certification in chemistry.

In her Science Research course, Anita's students are involved in a year-long research experience where they develop a research question, design and carry out an investigation, analyze data, generate conclusions, and finally compete in a science fair. Unlike her Advanced Placement Chemistry and general chemistry courses, there are no testing mandates or content requirements constraining her use of inquiry. Therefore, Science Research provides a context where it is possible to see how she incorporates NOS in a class specifically about conducting scientific investigations.

While time and curricular constraints are minimized for Anita, students must follow the International Science Fair rules for student research projects. This external influence and its impact on her use of NOS in her Science Research course also make this case informative.

*Wayne (Interviewer): Could you tell me a little bit about the Science Research course that you teach? That sounds really interesting.*

*Anita: Yeah, it's actually based mainly for students participating in our science fair. So they're working on a lot of individual projects or small group projects where they're actually coming up with the problem, designing the experiment, implementing either at school, at research facilities, or at home. And then presenting in the fair. And then after the fair I do a bunch of group projects where they're doing a Rube Goldberg and they have to come up with a way to finish that as well.*

In her description of the course she does not mention NOS. My interpretation is that for Anita, NOS is not an explicit component of inquiry. Students' efforts are focused on the process of conducting a scientific investigation with the goal of competing in a science fair. To clarify I asked Anita if she believed that students were doing inquiry in the course.

*Wayne (Interviewer): And would you term what they're doing as inquiry?*

*Anita: Definitely. Because they're actually coming up with the question and then trying to find a way to a way to prove it or solve it or get more information on that topic.*

She believes that students are doing inquiry when they are asking questions and engaged in problem solving. Moreover, the purpose of inquiry is for them to acquire content knowledge about the topic being investigated.

#### *Views of Science-Technology- Society Instrument Data*

For all five items analyzed in the Views of Science-Technology-Society instrument, Anita's responses were classified at *Appropriate (2)*, *Plausible Appropriate (2)*, and *Naïve (1)*. Her response pattern is similar to most participants in the study with four out of five responses matching the consensus views of experts.

#### *Interpretation.*

Like most other participants, Anita did not mention NOS in her description of inquiry for chemistry students. Based on my interviews and analysis of the twelve participant interviews I do not find this surprising. However, for her Science Research class, there was also no mention of NOS. My expectation was that the research-centered,

less constrained context would result in a greater emphasis on NOS and on how science is done by practicing scientists.

My interpretation is that the International Science Fair rules have a considerable influence upon her conception of NOS and how it relates to inquiry. A major goal of the Science Research course is for students to conduct research that will be entered into a science fair. Students who do well then go onto the state, national, and international science fairs. Therefore Anita's class follows the International Science Fair rules to ensure they are eligible.

A reading of the International Science Fair rules (Society for Science & the Public, 2009) found no explicit mention of NOS. Since Anita is basing her students' research on these rules I believe this is one major reason that NOS is not present in her description. My interpretation is that in both the International Science Fair rules and Anita's class, the assumption is that, by doing inquiry, students are implicitly learning about NOS. This implicit approach to teaching NOS is well documented in the research literature (Holliday, 2004; Lederman, 2007; Schwartz, Lederman, & Crawford, 2004). Anita, as evidenced by her VOSTS responses, has an understanding of NOS but does not explicitly mention it in our discussion about her Science Research course.

### *Summary*

The absence of NOS in almost all participants, with the notable exception of Carl, may be a result of several factors. First, while NOS is part of the NB *Standards* document, there is little mention in the instructions and guiding questions for the portfolio entry, *Active Scientific Inquiry*. As a result, even though the interview was not specifically about their NB portfolio, the NB process likely influenced participants'

conception of NOS and inquiry. Second, it may be that participants believed that NOS was implicit in teaching with inquiry. In other words, by teaching with inquiry students would also learn about NOS without the need for direct instruction. Such a belief is well-documented in the research literature (Holliday, 2004; Lederman, 2007; Schwartz, Lederman, & Crawford, 2004). Therefore, NOS was seldom included in participants' discussion of inquiry.

There are several limitations in my study of participants' enactment of NOS. Methodologically, the interview protocol used for this study did not include direct questions about NOS. This was intentional. Since a major part of the study was to observe teachers' general conception, enactment, and goals of inquiry, and to look for differences across disciplines, questions were of an open nature and participants were encouraged to provide as much detail as possible. For example, the interview protocol included such questions as, "*What do you think of when you hear the term inquiry teaching?*" and "*Could you describe an inquiry lesson plan of your choice in as much detail as possible?*" My purpose was to get at their conception of inquiry without leading them towards a particular aspect of inquiry. Within this context few participants discussed NOS.

Another limitation was the context in which inquiry was discussed. Due to time constraints it was not possible to explore NOS in the context of other inquiry lessons or general teaching. While it is tempting to go back and gather additional data, it is beyond the scope and context of this study. As practicing teachers, time is a practical constraint placed upon both participants and myself. Due to the limited time available and the

demands of the school context, I did not want to place a further burden on my already accommodating participants.

Finally, another consideration is how further data collection and analysis would aid in answering the guiding question of how differences in teachers' conceptions of inquiry vary across disciplines. In order to study participants' use of NOS, within the context of inquiry or otherwise, instances where they incorporate the use of NOS in their teaching would have to be identified. It is not clear that this would be feasible or yield any new data. For these reasons I decided to conduct my analysis and interpretation based on the existing data set.

The VOSTS data provides some insight into the question of teachers' understanding of NOS across disciplines. However, their enactment must be the subject of future research. Quantitative data suggests that differences in views of the nature of science may exist across disciplines, although data presented in this section does not offer insights into those differences. This is primarily due to the dearth of discussion about NOS in participant interviews. As a result, Lederman's question about whether NOS is universal or differs across disciplines will have to be the subject of future research.

Apart from NOS and disciplinary differences, several other questions also arise. Based on VOSTS data and participant interviews I believe that participants in this study have developed views of NOS but do not explicitly address them in their use of inquiry. Rather, I speculate that they hold a belief that students will implicitly learn about NOS by taking part in inquiry experiences. Research has previously identified this implicit approach to NOS (Holliday, 2004; Lederman, 2007; Schwartz, Lederman, & Crawford, 2004). Data presented in this section supports that notion.

## *Influence of Science Content Knowledge on Inquiry Teaching*

Research has identified a link between teachers' science content knowledge and their use of inquiry (Alexander, 1992; Brickhouse, 1990; Smith, et al., 2007; Smith & Neale, 1989). However, most of this research has been centered on the frequency with which teachers use inquiry. In this study an attempt was made to determine how science content knowledge is related to teachers' conception, enactment, and goals of inquiry. This section, along with the correlational analysis in Chapter Four, seeks to answer the research question, "*How does science subject area content knowledge influence teachers' enactment of inquiry-based teaching and learning?*"

As described in Chapter Four, 48 NB *Active Scientific Inquiry* portfolio entries were analyzed for thirteen different elements of inquiry. NBCSTs' scores on science content knowledge assessments were correlated with their scores obtained for each element using the *Portfolio Inventory Instrument (PII)*. Results did not show any practical relation between science content knowledge and teachers' enactment and goals for inquiry.

Participant interviews were conducted with three teachers in the pilot study to explore the relationship between science content knowledge and use of inquiry. After the initial three pilot interviews it was not clear if participant interviews would yield information. However, the decision was made to include the prompts on science content knowledge in the interview protocol for the larger study. After an additional four interviews it was clear that this approach was unproductive. As a result it was decided to focus on other emerging themes such as the disciplinary differences in NBCSTs' use of inquiry.

One explanation for the lack of sufficient data may be that the participant interview protocol was not sensitive enough to detect the influence of content knowledge on use of inquiry. In order to develop a fuller understanding it would be optimal to assess their content knowledge in a variety of ways and observe how it is used in their teaching with inquiry. This would require classroom observations and is beyond the scope and resources of the current study. However, the topic may be appropriate for future research.

As seen in other areas of this study, in studying teachers' content knowledge and use of inquiry, it will be important to take into account the many other contextual and cultural influences on how teachers think about and enact inquiry. Science content knowledge likely does have an influence on how teachers use inquiry; however, a robust, sensitive methodology with multiple sources of data will be necessary to produce meaningful results.

*Changes in Teachers' Conceptions and Enactment of Inquiry as a Result of the NB  
Certification Process*

Teaching with inquiry has been identified as one of the areas most likely to change during the National Board certification process for science teachers seeking the AYA Science certificate (Lustick & Sykes, 2006; Park & Oliver, 2008). In this study, twelve participants were interviewed in order to answer the research question, "*How did the National Board certification process alter teachers' conceptions of inquiry?*"

Based on interview data, I placed participants into three categories: those who experienced considerable change, those who experienced minor change, and participants who apparently experienced no change as a result of the certification process. These

categories were generated by reading all interview and follow-up data and identifying any text concerning participant change. Transcript text was placed in a separate document and emerging themes were identified in an analytical inductive manner. During this process it quickly became apparent to me that the primary organizing feature was whether or not any change had taken place. As analysis continued I found this categorization to be productive with related themes emerging within categories.

The *Considerable Change* category represents participants who experienced a substantial change in how they think about inquiry. For most, this also led to changes in their use of inquiry in the classroom. For example, it was necessary for Tom to research and develop a conception of inquiry that would work within the context of his teaching prior to creating the portfolio entry on inquiry. According to Tom, “*To the point right now where I’ll think while I’m designing a lesson, how can I turn this into an inquiry based lesson instead of the traditional style.*”

The *Minor Change* category represents participants who experienced little change in how they think about and teach using inquiry. An example is Peter who teaches International Baccalaureate (IB) Chemistry and an introductory chemistry class. He states, “*As a function of doing this I do find myself doing a little bit more in terms of inquiry activities with non-IB classes, but still not a ton of it there.*” The change towards doing more inquiry with his introductory chemistry is not large but I interpret it to mean that he now realizes the potential for using more inquiry and is trying to do more.

Participants in the *No Change* category did not believe, and I did not interpret, that any change had taken place as a result of the certification process. Allen, a chemistry and biology teacher, states, “*I don’t think it is. I went into the National Boards with the*

*only caveat being that I wouldn't have to change what I was doing.*" Allen, similar to other participants in this category, was satisfied and confident with his use of inquiry going prior to the certification process.

Of the twelve participants interviewed in this study, four experienced considerable change in their conception of inquiry (Donna, Jane, Scott, and Tom). Three reported minor change taking place (Anita, Amy, and Peter) and five participants stated that they experienced no change (Allen, Cathy, Diane, Peter, and Sarah). Data for each participant are presented in this section to highlight changes in teachers' conception and enactment of inquiry and to offer insights into the nature of these changes. Participants are grouped based on the amount of change they experienced, detailed in Table 28.

Table 28

*Changes in Conception and Enactment of Inquiry After Certification Process*

<b>Participant</b>	<b>Certificate Area</b>	<b>Currently Teaching (2008-09)</b>	<b>Years Teaching</b>	<b>Nature of Change</b>
Scott	Biology	Biology	9	Considerable
Tom	Biology	Biology, Physics	10	Considerable
Donna	Earth Science	Earth Science	14	Considerable
Jane	Physics	Physics, Biology	8	Considerable
Amy	Biology	Biology	6	Minor
Anita	Chemistry	Chemistry, Science Research	5	Minor
Peter	Chemistry	Chemistry	11	Minor
Allen	Chemistry	Chemistry, AP Biology	11	None
Sarah	Earth Science	Earth Science	8	None
Cathy	Earth Science	Earth Science, Honors Chemistry, Astronomy, Pre-AP Biology	8	None
Diane	Physics	Physics	30	None
Carl	Physics	Physics	6	None

In the next three sections I elaborate on each category, describing, analyzing, and interpreting each participant's words, their teaching context, and how they experienced change as a result of the NB certification process.

*Participants who Experienced Considerable Change*

*Scott.*

For Scott, the National Board certification process provided a way to think about inquiry. In response to my question about how his teaching with inquiry is different, he emphasizes three components of successful inquiry lessons: planning, data collection, and analysis. These components are required in the three video segments that are part of the National Board portfolio entry on teaching with inquiry.

*Wayne (Interviewer): Okay. That sounds excellent. Let's kind of shift gears and talk a little bit about inquiry and the National Board certification process. Based on the earlier lesson plans that we discussed can you describe how your teaching is different, teaching with inquiry is different after completing the National Board certification process, if it's different at all?*

*Scott: It is different in the sense of putting together that portfolio entry. I had to think through a good inquiry lesson, a good inquiry project. Not just something that you come up off the top. It had to be thought out, it had to be sequenced. ... You know, planning out how to do something like that well. Thinking through the steps the way that they have the three video segments, where there was the planning stage, the data collection stage, and then the analysis stage, and then to make sure that all three of those things actually work. And somebody from the outside can see that they work. ... So spending enough time and making sure that all of those steps were done well and done, have the students engaged, there wasn't a follow the recipe kind of thing all the way through. You know, there was a lot of student engagement, they made decisions, there enough of me making sure that all three, the before, during, and after are done well and done thoroughly and the students understand each aspect. That's really what I got out or that most,*

*is that you can't, for a project to be successful you can't come up short on any of those three.*

I speculate that the certification process gave Scott a model for thinking about what makes an effective inquiry lesson. He now believes inquiry must be comprehensive and inclusive. By this I mean that all of the steps he uses to describe inquiry, planning, data collection, and analysis, must be present for an inquiry lesson to be effective. His conception of inquiry as planning, data collection, and analysis is a direct result of his preparation of the National Board portfolio entry, *Active Scientific Inquiry*.

Like most participants in the study, the primary motivation for Scott was financial; however, he found the process encouraged him to think about his teaching more often.

*It wasn't easy. It was a brutal year. And now, the nice thing is that I think about it all the time. I think about how I could be improving. I think about what I could be doing this year and that kind of thing.*

*Tom.*

Tom found constructing the portfolio entry, *Active Scientific Inquiry*, to be one of the most valuable components of the National Board certification process. For Tom, the process resulted in major changes in how he thinks about and enacts inquiry.

*Wayne (Interviewer): Let's talk a little bit about your ideas of inquiry were influenced by the, going through the National Board certification process. Could you describe how with your teaching with inquiry is different now that you have completed the certification? If it did.*

*Tom: Yeah, prior to certification, I did some of this maybe, but not a lot. Even when I read through the whole description lesson, I had to go online and look it up and actually define to it myself and what it was and how it functioned. Because I had a minimal understanding of it, and just through the process of National Board, this is the one area where I really strengthened my own teaching and began to understand all the evidence in support of inquiry lessons. To the point right now where I'll think while I'm designing a lesson, how can I turn this into an inquiry based lesson instead of the traditional style.*

In order to complete the National Board entry, *Active Scientific Inquiry*, Tom needed to first develop a better understanding of what it means to teach with inquiry. As a result, he now sees inquiry as a major part of his teaching repertoire and as he plans new lessons asks himself, “*how can I turn this into an inquiry based lesson instead of the traditional style.*” I believe that his efforts to research and define inquiry for himself and construct the NB portfolio entry on inquiry provided a personally relevant professional development experience. The changes he experienced took place because he was able to place the concept of inquiry in his own teaching context.

Describing what part of the process led to this change Tom identifies the actual process of researching inquiry. For him this process was more meaningful and effective than other forms of professional development.

*Wayne (Interviewer): ... And what was it about that process that made you change...*

*Tom: I think [?] but I felt that the process that I used to change was really an inquiry process. Where I didn't really understand what inquiry was so I had to*

*inquiry about the process itself. And if somebody had just, if I had gone to a seminar to get told about it, I don't know that I would have actually taken it as far. The fact that I did the research and did the inquiry to learn about the process and through that understand its merits, I think really made it cemented into my mind.*

Tom represents the most pronounced change in his conception of inquiry teaching of the twelve participants interviewed. He went from having a limited conception of inquiry to making it a consistent component of his lesson planning. This represents a considerable change in both his conception and enactment. My interpretation is that prior to constructing his portfolio Tom did not have a developed conception of inquiry and how it related to his teaching situation. As a result an opportunity for substantial change existed. His willingness to recognize this and use the opportunity to develop his conception about inquiry is an essential component of change.

*Donna.*

For Donna, constructing the portfolio entry, *Active Scientific Inquiry*, contributed to her understanding of the process of conducting scientific investigations. When asked what she did differently as a result of the certification process she responded:

*I didn't, the way I design the hypothesis would still be the same. I had to offer up a little bit more on reliability and validity of data to go through that. Before it was like, sorry, once and done, we kind of hit, you need to do this many trials, but we didn't do as many trials we should've and we probably didn't control as much as we should have and I really had to focus on that principle.*

The certification process led her to place a greater emphasis on the design of inquiry investigations. Examples include conducting sufficient trials to obtain reliable data and controlling variables during the experiment. In addition to changing how she thought about the process of conducting scientific investigations, Donna also experienced changes in the way she teaches and the ways students learn about the nature of science.

*Wayne (Interviewer): So now in general in inquiry, as you do inquiry, do you do anything different as a result of ...*

*Donna: Yeah, I think that going through the whole process it kind of made me develop my understanding of science a lot more. Does that make sense to you?*

*Wayne (Interviewer): Yeah.*

*Donna: It's like the whole process of what they're supposed to be doing and what we should be teaching and not just kind of hitting and running I guess. So I teach it probably more in depth now than when I used to.*

She goes on to further describe how, before, her students thought of science as a collection of facts. As a result of the certification process her teaching emphasizes that evidence led to the ideas; that knowledge is tentative and could change in the future.

*So like, I think before students understood like, look at science as, these are the facts. And now they understand that this is the evidence that leads us to this idea but that idea could change, as our technology gets better.*

For Donna the part of the certification process that was most important dealt with the process of conducting scientific investigations. She stated:

*I think that it was that, it is an important process that all kids should go through, and that even if saying this effect this, cause and effect, cause and effect is a higher level skill and before I used to think “how can they not get cause and effect?” So I think teaching them cause and effect, teaching them that if you manipulate one it will affect other things, and that if you can’t control an experiment then the variability is not there and that if you lost that variability you can’t prove definitely that one definitely affected the other.*

For Donna the certification process helped her think about the importance of designing scientific investigations and manipulating variables to determine how they interact. In addition she changed the way she presents scientific knowledge, shifting from a factual presentation of information to a more evidence-based, tentative view.

*Jane.*

Jane’s experience with the National Board supported her belief that inquiry is effective when students develop ownership and work on an investigation that relates to a societal problem.

*I guess a little bit more specific, the inquiry that I did for National Board, it really just made me understand that the students have to own the information. Like they have to understand why they’re collecting the data. If they just go up and count cells in the microscope, if they’re trying to answer a question that’s going to solve something for the greater good, they kind of get a little more into it, a little more invested.*

Developing ownership is related to students being able to “*solve something for the greater good.*” This is present in her description of a physics inquiry lesson where students are given a scenario to design environmentally friendly highway barriers. The NB process gave her an opportunity to look at her own teaching and recognize the importance of having students take ownership in their scientific investigations. She goes on in a less specific manner describing the change in the context of how she teaches with inquiry. At the conclusion of the interview Jane stated:

*Wayne (Interviewer): Is there anything else you'd like to add about the whole National Board process that we hadn't really talked about?*

*Jane: No, I thought it was, I thought it was definitely, like I said, I thought that I was doing inquiry lessons sometimes and I wasn't and I thought and I think that's so unique about the whole National Board experience it that it really forces you to look at what you do and it's not just a, this is what I do and score me on it, I mean I had to grapple with a lot of things that I thought that I did well and reassess myself. And that was tough to do at that point in my career just because I had established myself as what I thought to be as a good teacher. And then, there's always room for improvement but sometimes I needed to improve in places that I didn't necessarily think I need to. So it was a very good process. I'm glad that inquiry was a part of it because it definitely improved more of my lessons that way.*

The process was often difficult for Jane as she reflected on her own teaching and identified areas where she needed to change. Part of that change was redefining how she thought about inquiry.

### *Participants Experiencing Minor Change*

*Anita.*

Anita states that she did not experience any change in her use of inquiry. However, the NB certification process did provide her with the opportunity to expand her use of inquiry. This included allowing students to be more independent, ask questions, and write up procedures for labs. As a result she is in the process of modifying some of her labs to be more inquiry-based.

*It hasn't changed, I've always let the kids do a lot of hands-on, I'm trying, it's harder with chemistry to get full inquiry because of all the hazards involved. But I'm trying to rework some of my labs so that they're actually able to do it on their own, and ask questions, and write the procedures with that. National Board doing the double replacement lab really let me find a way that I could do it and still make it safe for them to actually perform.*

Based on our conversation my interpretation is that, while the certification process did not change specific aspects of her conception of inquiry, it did change what she believes is possible in her classroom. She now believes that she can support students in asking questions and designing procedures, and as she put it, “do it on their own.” In this sense the change is more about what she believes is possible in the context of her teaching situation rather than her conception of inquiry.

Although the process encouraged Anita to modify her labs to be more student-driven, she also states that the process had a negative effect on her teaching during the time she was working on her portfolio. The time required to engage students in an

inquiry experience for her portfolio entry meant that she was not able to cover all the required course content.

*Again what I found troubling with the National Boards was that they had a set requirement and while I was trying to meet that requirement as well as teaching it actually deterred from some of my classes. I didn't get to cover enough material in certain aspects, doing the discovery lab, I spent a whole week on that and kids really enjoyed spending a lot of time in the lab actually figuring out stuff and how it applied.*

Anita felt that the time she spent on inquiry to meet the NB portfolio requirements prevented her from covering the course curriculum. However, the process did give her an opportunity to think about her teaching and a chance to try new teaching strategies.

*Amy.*

The National Board certification experience did little to change either the amount or the way Amy uses inquiry in her classroom. In the interview I asked her how the certification process changed her thinking and use of inquiry. She replied:

*I think I do a little bit more inquiry, because I know that it is more meaningful learning. And since I've done this now for so many years I'm more familiar with the curriculum I think I know where I can allow the students to have that time to make it more meaningful, but I honestly haven't changed it tremendously. There have been some changes but very few. Very few. I generally, the type of students I deal with, just because they are honors students, or the class is honors, I don't think that they're necessarily honors students, and that's one of the problems at*

*our school, like, but I'm sure all schools have problems like that, so I have to make it as real world as possible and I think that inquiry helps the students do that. It makes it a little more concrete for them. And I definitely saw that in the National Board process, like in the reflecting part of it.*

Although Amy saw little change in her conception or use of inquiry, the certification process did support her thinking on the need for inquiry to relate to the real world. This connection to the real world is important to her because it results in their learning being “*a little more concrete.*” Based on her response, my interpretation is that her beliefs about her students’ abilities lead her to this emphasis. Reflecting on her portfolio entry strengthened this belief. Finally, having achieved NB certification, Amy states:

*Yeah, I guess now that I have it, especially not being education, and this is the last thing I ever thought I'd going to do was to teach school in all honesty, I never thought that they would hire me, I never thought I would enjoy it, and so it's been a pleasant surprise but I've always, kind of been, um, worried that I didn't have the skills perhaps? So I think it validated that not having that education and you're still a good teacher. For me it did. Because I feel like not everybody can get it and it doesn't matter if you're education major or not, like, it's either you're a good teacher or you're not.*

Although her rationale for seeking certification was financial, like most participants, having successfully completed the process Amy found that made her feel more credible as a teacher. For her certification provided tangible evidence of her teaching abilities and formal recognition that she was an accomplished teacher. Having

entered teaching through an alternative certification program, Amy felt some concern about the impact a nontraditional education background had on her teaching. The NB process served to allay those concerns. While this does not directly relate to her use of inquiry it demonstrates the importance of the certification process to Amy.

*Peter.*

Peter teaches International Baccalaureate Chemistry and Chemistry One, an introduction chemistry course. Required labs in the IB Chemistry curriculum provide a structure and time for inquiry. As a result, Peter does “four or five” labs a semester with his IB students. Peter indicated that he did not change his conception or enactment of inquiry. As he explains:

*That’s what, almost exclusively what inquiry learning would look in the IB class. They have to do so many of these design labs, I end up doing so many design labs with them, so I don’t really go out of my way to incorporate a ton of extra design into lesson planning. I end up doing four or five design labs a semester with them.*

The IB program provides external requirements which result in Peter frequently using inquiry in his IB classes. These requirements effectively provide Peter with a model for inquiry which he cannot appreciably change due to the nature of the IB program and assessments which his students must take at the end of the course.

While there was no change in the way he used inquiry in his IB classes the certification process made him think more about how often he uses inquiry with his

Chem One students. When asked about changes as a result of the certification process, Peter replies:

*Actually, it is different, honestly, to be completely honest, it's not completely different cause I was already doing the inquiry anyway with IB. As a function of doing this I do find myself doing a little bit more in terms of inquiry activities with non-IB classes, but still not a ton of it there. ... But that's a lab that Chem One students could do, once they've got stoichiometry down, and they know some basic lab procedures, like filtration, collecting a gas over water, a Chem One class could do that. And once in a while I will do [?] something basic like that with a Chem One class. But honestly not very often. Not as often as I wished I had time for.*

The certification process did make him more aware of the option of doing more inquiry with his Chem One students. Even so, this awareness did not translate into practice.

#### *Participants Experiencing No Change*

Five participants reported no change in their use of inquiry as a result of the NB certification process. Of those five, Allen, Cathy, Diane, Peter, and Sarah, almost all were satisfied with their current conception and enactment of inquiry. The NB certification process did not alter their conception or enactment of inquiry and some cases supported their conception and use of inquiry.

*Diane.*

Diane believes that her structured approach and familiarity with research on learning precluded change from taking place. In other words, because she believed she already had an extensive background in teaching and pedagogy, the certification process offered little opportunity for new learning. I asked her to discuss the certification process:

*Wayne (Interviewer): Okay. We'll let's talk a little bit about inquiry and the National Board. Based on our earlier discussion here, could you describe how your teaching is different after teaching the National Board process, if it is different?*

*Diane: I don't think it is. I have always been super-organized and very up to date on research. I've had professional development classes on research in brain neurology and learning and memory.*

*Wayne (Interviewer): Okay. So you don't feel that your use of inquiry or anything else has significantly changed as a result of the process?*

*Diane: I don't think so. I've always been very structured in terms of what lessons I do as inquiry, what lessons I use, there also some laboratories that I use as authentic assessments.*

My interpretation is that Diane is comfortable and confident in her use of inquiry. By this I mean that she believes her teaching with inquiry meets the needs of her students and the expectations of the NB. She supports this assertion with having read research on education and through the structured nature of her lessons. It is also likely that her thirty

years of teaching experience is also influential. As a result there are few opportunities for change.

*Sarah.*

Unlike the majority of participants, whose primary rationale for undertaking seeking National Board certification was financial, Sarah was interested in certification as professional development.

*I was looking for professional development experience that would be worthwhile. I've done a lot of other things and felt like I was a plateau where there wasn't much else offered in terms of professional development that I could really learn something from and I thought that this was a logical next step in my professional development. And I knew it would be challenging and I wanted to see if I could do.*

While her there were other changes in her teaching, no change took place in her use of inquiry. This is primarily because Sarah believes that she is already doing inquiry as a result of both an inquiry-centered science department at her school and her teacher preparation program. In her science department there is a focus on inquiry which provides both encouragement and a rationale to use inquiry. The emphasis placed on inquiry in her teacher preparation program created enthusiasm for the use of inquiry, although she found implementation in the classroom to be more challenging than she expected.

*They haven't changed that much because we, specifically in my department we've always be very inquiry focused and [?]. For me teaching is a second career, so*

*I'm kind of late coming to it, so I'm more recently out of school than a lot my colleagues, so that was very heavily emphasized in my teacher program, so I came in all geared up to do inquiry, and then realized that it's not so easy. You know, huge class sizes, you have these great ideas and then the logistics of doing it is much harder. It was nice to see how much, you know sometimes you get discouraged and you feel like I can't do it. But it was nice to see that it was so supported in the National Board and that sort of helped to keep me motivated that, yes, this is how we're supposed to be doing science.*

Although she experienced little or no change, the process did validate her use of inquiry and provide motivation for her teaching. My interpretation is that Sarah had substantial exposure to inquiry in her teacher preparation program and teaches within a science department that supports inquiry. As a result, and like other participants who experienced little or no change, Sarah already had a developed conception of inquiry, although she found it challenging to implement. Therefore, the process did not result in change. It did however support her conception that inquiry is an important and is a valuable way to teach science.

*Allen.*

In his interview Allen described a detailed three-day cycle he uses to plan and implement inquiry. The cycle involves identifying a problem and developing a procedure to solve the problem. After carrying out the procedure and collecting data, students conduct an analysis to formulate a conclusion. This generates new questions and the cycle begins again. He states:

*Wayne (Interviewer): Based on what we've been talking about can you describe how your teaching with inquiry is different after completing the certification?*

*Allen: I don't think it is. I went into the National Boards with the only caveat being that I wouldn't have to change what I was doing. ... But I didn't want to, especially with all the videotaping, and everything else, I didn't want to change what I was doing and try to fit it into something that I wasn't.*

Based on our conversations I believe Allen was satisfied with his approach and saw no reason to change the way he teaches with inquiry. He has spent a great deal of effort to develop a three-day cycle for teaching with inquiry and the cycle provided a working model that shapes his use of inquiry. He saw no reason to do anything differently because he was confident and satisfied with his way of teaching with inquiry.

*Carl.*

Carl teaches IB Physics and *Active Physics*. He indicated that there is no change in either course. Like the majority of other candidates who did not experience any change, Carl is satisfied with his conception and use of inquiry. He states that he entered the certification process already possessing a strong conception of inquiry.

*I don't think I would say it's much different. I think that prior to completing entry two I had a fairly good understanding of the power of inquiry and why to do it.*

My interpretation is that Carl, like Allen, has a model for thinking about and enacting inquiry. In his case, the International Baccalaureate program provides detailed requirements for designing investigations. In addition, his participation in professional development activities, such as a fellowship in an inquiry-centered teaching organization

and participation in workshops on modeling and using inquiry in physics, have helped him to further build upon his conception and enactment of inquiry. Therefore, with his established conception and enactment of inquiry, there is no reason to change how he thinks about or use inquiry.

*Cathy.*

For Cathy, no change took place in her conception or enactment of inquiry but the process of videotaping her classes did help her expand her understanding of her students. This, however, was more centered on interactions with students, in particular students whose first language is not English. She states:

*Yes, I think it did change. I think it changed in regard to, not so much as how I saw inquiry before and after the process, but it changed my opinion in how I've used others processing of information. For example, one of my revelations, and I don't know why this didn't occur to me sooner, but some of my students who speak English as a second language, they were having trouble with some of the concepts, just with communication, and as I was watching the video that was taken during the process of National Board, I was watching it and I was seeing, maybe for the first time, ...*

*Wayne (Interviewer): Anything else you can think of where changes may have taken place? If not that's fine.*

*Cathy: I can't think of anything at the moment.*

Cathy does not, however, discuss why the certification process, in particular the portfolio entry on inquiry, did not lead to any changes in her conception or use of inquiry.

## *Summary*

Together the twelve participants offer different views of how the NB certification process influences high school science teachers' thinking about and enactment of inquiry. The categories *Considerable Change*, *Minor Change*, and *No Change* provide a productive framework to try and make sense of their experiences.

Four participants experienced considerable change. Scott and Tom reported the biggest changes in their conception and enactment of inquiry. For both, the process led them to generate new mental models of inquiry. Tom stated that he “*really didn't understand what inquiry was*” and needed to research the meaning of inquiry to develop his own understanding. This research, along with the certification process, means inquiry became an integral part of his lesson planning. Scott adopted the NB model of inquiry with a focus on three stages of an investigation: planning, data collection, and analysis. For Scott each stage was necessary for successful inquiry and guides his use of inquiry.

Donna and Jane also experienced considerable changes to their conception and use of inquiry, although not as pronounced as Scott and Tom. Change for Donna resulted in an expanded understanding of designing experiments. She also increased her awareness of the evidence-based, tentative nature of scientific knowledge. For Jane, the certification process strengthened her conception that students need to develop ownership of their investigations and one way to do this was to relate these investigations to societal problems.

Of the participants who experienced considerable change, two conditions existed. First, there was a willingness to change. This is seen in Tom's researching inquiry, Scott's adopting the NB model, and Donna's revelation about the nature of experiments

and scientific knowledge. The second condition was that there must be room for change to take place. In other words, there needed to be an aspect of their teaching where there was potential for learning and change. Participants are not likely to change their conception or enactment of inquiry if they are already using inquiry, have a model to support their use, or have a developed conception.

Three participants underwent minor changes in their conception and use of inquiry. The changes tended to support or strengthen existing beliefs and practices and did little to alter their conception. For Anita the certification process provided an opportunity to try new things. As a result, she became more confident in her use of inquiry with her chemistry students. With Amy, the process supported her thinking about inquiry as a way to relate science to her biology students' previous experiences and life outside of the classroom. Peter did not change his conception of inquiry but was encouraged to do more inquiry with his introductory chemistry students, although the increase was minimal. For each, the experience resulted in minor changes, primarily in their use of inquiry, while their conceptions remained mostly unchanged.

The final group, those who did not experience any change, consisted of five participants. For these participants, the NB certification process offered little opportunity or reason to change. They already had developed conceptions of inquiry, reported using inquiry frequently, and were confident in their use of inquiry. For these participants, the certification process served more as a way to recognize their teaching.

Both Carl and Allen described consistent, comprehensive models of inquiry they used to support their thinking and enactment. For Carl, the International Baccalaureate program provided an external model as did extensive professional development

experiences. Allen used a self-developed planning technique to plan inquiry. For both, these well-developed models resulted in the NB certification process offering few new strategies or experiences. Carl and Allen, like others who experienced no change, were both confident in their frequent use of inquiry.

Diane and Sarah were also confident but did not specifically discuss models of inquiry. In addition to her thirty years of experience, Diane was already familiar with inquiry, supported by her interest in educational research. The NB experience did not offer new information or opportunities for change. Sarah cited the support of her science department and inquiry-focused preparation programs providing her support and a foundation for teaching with inquiry. As a result, no change took place, although the process did validate her use of inquiry. For both, their confidence in their use of inquiry meant that the certification process did not provide them with a new learning experience. Cathy also did not experience any change in her use or conception of inquiry although it is unclear why.

Based on teachers' descriptions of changes in their conception and use of inquiry, I believe that several conditions existed that supported their changes. First was a willingness to change. In the case of Tom he was willing to invest the effort to develop a fuller conception of inquiry. Second, room must exist for change to take place. For participants experiencing considerable change there was an area of their practice that was absent or not developed. Participants who did not experience change did not have this space to change. Finally, although a willingness and room to change are important, there needs to be an opportunity for teachers to carefully plan an inquiry lesson, teach and

analyze their teaching, and reflect upon their practice. For many in this study, the NB process provided that opportunity.

## Chapter Six: Discussion

### *Introduction and Theoretical Framework*

At the beginning of this thesis I defined inquiry based on the widely respected document, the National Science Education Standards (NRC, 1996). This, and other influential documents (AAAS, 1993, NSTA, 1995) have shaped public discussion on what inquiry should look like and achieve, including the NB AYA Science Standards. My rationale for doing so was to provide a baseline with which to compare and describe inquiry across disciplines. After studying over sixty National Board Certified Science Teachers (NBCSTs), I now believe that, in comparison to the NSES vision of inquiry, there are a number of different conceptions that result from the contexts in which teachers work.

While each teaching situation consists of many contextual and cultural influences, my research suggests that the subject matter discipline; in this study, biology, chemistry, earth science, and physics; plays a major role in how teachers think about and enact inquiry. The challenge in this discussion is to describe the trends present in my data and to explain why disciplinary differences exist in teachers' use of inquiry.

Situated cognition provided a theoretical framework to organize and make sense of the findings in this study. Located within a sociocultural research paradigm, situated cognition posits that learning takes place within a social context and culture and that the two are intimately related (Brown, Collins, & Duguid, 1989). According to Lave and Wenger (1991), learning is dependent upon context, is socially negotiated, and takes place through enculturation into communities of practice. As was seen in this study,

context and communities of practice lead to differences in how inquiry is taught across the science disciplines. Rather than focusing on the internal mental image of participants in this study, the situative perspective emphasizes systems of interactions rather than individual behavioral or cognitive processes (Greeno, 1997).

This section is subdivided into three sections based on the situative perspective. In Chapter Four and Five, evidence was presented suggesting that disciplinary trends exist between biology, chemistry, earth science, and physics teachers' use of inquiry. Based on the framework of situated cognition this chapter explores those trends. The first section, *Activity*, focuses on teachers' enactment and goals for an inquiry lesson. In the second section, *Context*, I look at how a teacher's environment can influence their use of inquiry. *Discourse Communities*, the last section, addresses teachers' participation in several learning communities that may lead to differences across disciplines. In conclusion, I present a possible model describing the interactions between activity, context, and discourse communities.

#### *Activity of Teaching with Inquiry*

Although much of the development of situated cognition has taken place with students, a growing body of research has applied it to teachers (Putnam & Borko, 2000). Researchers have found situated cognition a useful tool for understanding teacher learning in terms of the context surrounding teaching and the discourse communities in which teachers participate. As described by Brown, Collins, and Duguid (1989, p.32),

*... knowledge is situated, being in part a product of the activity, concept, and culture in which it is developed and used.*

Activity, as applied to this study, is comprised of the act of teaching. In portfolio analysis and participant interviews, this consisted of NBCSTs' description of their enactment and goals of an inquiry lesson plan. In this section, findings from this study are presented to describe the activity of teaching with inquiry.

The NB portfolio entry, *Active Scientific Inquiry*, documents an inquiry lesson and served as the basis for analysis in the quantitative portion of this study. Interviews in which participants discuss their conception, enactment, and goals for inquiry, made up the qualitative aspects of this study. In addition, interview participants also completed the Views of Science-Technology-Society (VOSTS) Questionnaire (Aikenhead & Ryan, 1992) to provide data on their understanding of the nature of science. Together, these multiple data sources inform us how the activity of teaching with inquiry takes place in the disciplines of biology, chemistry, earth science, and physics.

#### *Quantitative Results: Portfolio Analysis and VOSTS*

The quantitative analysis of 48 NB portfolio entries, *Active Scientific Inquiry*, provided evidence suggesting disciplinary differences exist in teachers' enactment of and goals for inquiry. First, in comparing biology, chemistry, earth science, and physics teachers' enactment of specific elements of inquiry, significant differences were found. Second, categorizing teachers' enactment and goals of inquiry revealed thematic trends in participants' use of inquiry. Finally, data from the VOSTS questionnaire suggests that disciplinary trends may exist in teachers' views on the Nature of Science (NOS).

*Analysis of variance (ANOVA.)*

Using the Portfolio Inventory Instrument (PII) developed for this study, portfolio entries for 48 NBCSTs were analyzed. Each portfolio was given a rank score on each PII item. A one-way ANOVA was then conducted for each item to detect if differences existed between biology, chemistry, earth science, and physics teachers. Prior to data collection it was determined that, for the ANOVA, a sample size of 48 participants (twelve in each of the four disciplines) would be necessary to achieve a significance of .05, a power of 0.8 with an effect size of 0.5. The Tukey post hoc test was conducted for significant results to determine which groups differed.

Based on the analysis detailed in Chapter Four, the following significant results were obtained.

- Biology teachers are more likely than chemistry and physics teachers to support students' efforts to develop a research question.  $F(3,44) = 4.31$ ,  $p = .010$ .
- Biology teachers are more likely than chemistry, earth science, and physics teachers to allow students their choice of research questions or variables to investigate.  $F(3,44) = 7.70$ ,  $p < .001$
- Biology teachers are more likely to include the use of a hypothesis in inquiry than chemistry and physics teachers.  $F(3,44) = 8.15$ ,  $p < .001$
- Physics teachers are more likely to encourage and support use of mathematics in students' investigations than biology, chemistry, and earth science teachers.  $F(3,44) = 6.73$ ,  $p = .001$

- Physics teachers are more likely to have students' work culminate in a model than biology, chemistry, and earth science teachers.  $F(3,44) = 4.39$ ,  $p = .009$

No significant differences were detected for the following items on the PII: students engage in designing their scientific investigations; students conduct scientific investigations; teacher encourages and supports the use of technology in students' investigations; students review current scientific understanding, evidence, and logic to determine the best explanations or models; students are encouraged to consider alternative explanations for their conclusions or theories; students communicate about their investigation in writing; students defend their investigation and respond appropriately to criticism from peers or teachers; and students present their presentation publicly.

*Goals and enactment.*

Portfolios were classified based on four themes that emerged during analysis. These themes are based on teachers' goals and enactment of the inquiry lesson in their NB portfolio entry. They are *Students Conducting Scientific Investigation (SCSI)*, *Science Content Knowledge*, *Modeling*, *Problem Solving*, and a general *Other* category. It was found that:

- Biology teachers tend to view inquiry as *SCSI* (83%).
- Chemistry teachers tend to view inquiry as a means to teach *Chemistry Content Knowledge* (62%) and *SCSI* (31%).

- Earth Science teachers tend to view inquiry as *SCSI* (60%). The remaining participants were distributed across *Earth Science Content Knowledge, Problem Solving*, and *Other*.
- Physics tend to view inquiry as *Modeling* (46%), *Physics Content Knowledge* (31%), and *SCSI* (15%).

A detailed treatment, including examples of how participants were categorized, is presented in Chapter Four. Trends are explored through participant interviews in Chapter Five.

*ANOVA and goals/enactment: comparison of findings.*

Both the comparison of groups using the ANOVA statistical test and the categorization of participants' enactment and goals for inquiry produce similar trends. Further, these trends are also present in the qualitative analysis of participant interviews with twelve NBCSTs described later. Biology and physics provide the strongest examples of this.

An analysis of variance found biology teachers to be more likely to have students choose their own questions and provide support to students as they develop those questions. In addition, the hypothesis was a frequent feature in their enactment of inquiry. This trend was also found in the frequency in which the theme *Students Conducting Scientific Investigations* arose in their goals and enactment of inquiry. Over 80% of biology teachers were categorized as *SCSI*.

Participants categorized within the theme *SCSI* primarily approach inquiry with the purpose of teaching students to conduct scientific investigations. While they may

have secondary goals such as teaching science content knowledge or engaging students in activities mirroring the work of practicing scientists, the focus is on how to conduct scientific investigations. Therefore, the ANOVA results, showing a focus on students asking research questions and formulating hypotheses, support the idea of a structured approach consistent with conducting scientific investigations.

Physics teachers were found to encourage the use of mathematics and have students' work culminate in a model, most often mathematical in nature. This statistically significant result is consistent with the categorization of most physics NBCSTs (46%) as having their enactment and goals of inquiry as *Modeling*. However, the themes of *Physics Content Knowledge* (31%) and *SCSI* (15%) were also present.

*Nature of science (NOS).*

The Views of Science-Technology-Society questionnaire (Aikenhead & Ryan, 1992) was used to measure NBCSTs' conceptions of the nature of science. NBCSTs' responses were presented along with those of experts to provide a comparison and a means to rank participant responses. While the sample was not large enough to make statistical comparisons, several trends did emerge.

An overarching finding was that over seventy percent of responses were classified as *Appropriate* or *Plausible/Appropriate*. While this is based upon a sample of twelve participants and only five VOSTS items were included in the analysis, it does suggest that NBCSTs hold views of the nature of science similar to experts on the subject.

Disciplinary trends were found in two of the five items. For the item, Nature of Scientific Knowledge: Scientific Models, it appears that chemistry and physics teachers

hold views closer to expert judges than biology and earth science teachers. This may be due to the more frequent use of abstract models in these classes. Portfolio analysis was consistent with this finding in that physics teachers were more likely to incorporate modeling in their teaching with inquiry. For the item, Nature of Scientific Knowledge: Tentativeness of Scientific Knowledge, all disciplines, with the exception of biology, were similar to the expert views. For the remaining three VOSTS items no disciplinary trends emerged and most candidates held views similar to the expert judges.

These disciplinary differences are an appropriate subject for future research. Rather than a more universal view of NOS, the current study suggests that differences exist between disciplines in teachers' views. Lederman (2007) identified this as a critical question in the NOS research community.

The analysis of portfolios, both for specific aspects of inquiry and overarching themes, suggests that disciplinary trends exist between biology, chemistry, earth science, and physics teachers. However, while this describes the activity of teaching with inquiry, a different methodological approach is necessary to access the contextual influences that shape teachers' enactment and goals of inquiry.

#### *Qualitative Findings: Participant Interviews*

The relationship between discipline and use of inquiry is situated within the context and culture of teachers' practice. Quantitative results indicate that disciplinary differences likely exist between different disciplines. A strength of the quantitative methodology is the ability to detect differences and the probability with which they exist within a population based on a sample. However, to explore why these differences exist,

and to obtain further evidence on how they exist in teachers' day-to-day practice, a more contextualized methodology was required. In order to do so, I conducted participant interviews with twelve NBCSTs from the 2008 cohort group.

A cross-case analysis of twelve participant interviews and follow-up communications resulted in findings similar to the quantitative analysis of portfolios. In general,

- Biology teachers are twice as likely to approach inquiry as *SCSI*. However, the theme *Biology Content Knowledge* was found to be more common than in the quantitative analysis.
- Chemistry teachers are more likely to approach inquiry with a focus on *Chemistry Content Knowledge*. *SCSI* was also a frequent theme.
- Earth Science teachers are twice as likely to approach inquiry as *SCSI* than as *Earth Science Content Knowledge*.
- Physics teachers almost exclusively approached inquiry as *Modeling*.

The qualitative analysis of participant interviews suggests that disciplinary differences exist between NBCSTs' uses of inquiry. In addition, several other trends also emerged during the qualitative analysis.

First, the analysis of participants who teach in more than one discipline indicates that teachers can hold multiple conceptions of inquiry. Further, these conceptions often follow disciplinary trends seen in the quantitative and qualitative analysis. For example, in describing a biology inquiry lesson, Tom approaches inquiry as *SCSI*. In his physics class, inquiry is centered on students investigating projectile motion and modeling mathematical equations.

It was found that biology teachers were more likely to conduct longer-term inquiry projects than chemistry and physics. For the five teachers interviewed who taught biology, four of the inquiry lessons described were longer-term investigations.

Student age, previous coursework and ability also played a role in teachers' use of inquiry along disciplinary lines. Further, these contextual factors also had an impact upon testing, curriculum, and teachers' approach to inquiry.

External testing and curriculum was found to influence how teachers approached inquiry. Comparisons of Advanced Placement, International Baccalaureate, and a specialized science research course found these external factors to influence how teachers approached inquiry. In each case, the approach was related to the structure of the curriculum and testing.

Previous scientific inquiry experiences were found to be influential in how teachers approached inquiry. The differences did not appear to change the overall disciplinary trends, but rather influenced secondary goals within the trend. For example, placing an emphasis on how scientists work or on organizing and managing information.

Finally, the communities in which teachers practice and interact were found to shape their use of inquiry. Both the school environment and professional development activities are thought to mediate how teachers think about and enact inquiry.

### *Summary*

The activity of teaching with inquiry is surrounded by the context and communities in which teachers participate. Both quantitative and qualitative findings detected potential differences in teachers' conceptions, enactment, and goals for inquiry.

These findings provide a descriptive account of *how* the differences exist across disciplines from multiple data sources. This alone is of value to the research and education community and has important implications. However, to understand *why* these differences might exist requires a close look at the context and culture in which teachers work and use inquiry.

### *Context and Teaching with Inquiry*

Having previously described *how* teachers' use of inquiry varies across the disciplines they teach, I now look at *why* these trends might exist based on the context of teaching. Context is defined here as the social and physical factors that are present in the teaching setting (Borko, 2004). These contextual factors can support or inhibit the way teachers approach and enact inquiry.

In my discussion, I selectively focus on contexts emerging from my data relating to disciplinary differences in teachers' use of inquiry. Not discussed here are commonly cited constraints such as time and access to materials. While these do influence teachers' use of inquiry, in this study they do not appear to be specific to individual disciplines. In general, I found these constraints to be evenly distributed across disciplines.

In addition to themes emerging in my data, I also draw from the research literature, where appropriate, to expand upon why disciplinary differences may exist. Three major contextual factors are explored. They are the structure of the disciplines, students, and curriculum and testing.

### *Structure of Disciplines*

Differences between the organization and science content of a discipline may result in differences in how teachers use inquiry. This was particularly evident in this study for teachers who taught biology and another subject. In this study, all five of these teachers found it more difficult to conduct inquiry lessons in biology. This was the case even though four of the five held undergraduate degrees in biology.

To illustrate how the structure of a discipline can result in disciplinary differences, I focus on biology. Here I present two teachers, a biology/physics teacher and a biology/chemistry teacher. Both indicated in our interviews that they found inquiry more challenging to do in biology.

An example of how the structure of a discipline can influence a teacher's use of inquiry can be seen in Tom's interview. Tom, who teaches biology and physics, finds it more difficult to do inquiry in his biology classes. He states,

*Tom: To go along with that I find it much easier to use in physics.*

*Wayne (Interviewer): Really?*

*Tom: I don't know why that is, I suppose because there just so many more activities that I'm used to use or able to use in physics. It seems like every day I can throw three or four different labs or activities in and I change those to make them inquiry based. And for biology it seems like a lot of the labs turn to be more difficult and [?] start out with a hundred and seventeen different step process to get through them and it's more difficult to modify those.*

*Wayne (Interviewer): That's kind of interesting ...*

*Tom: There's great examples from both, you can do all kinds of different things with plants and animals. But I just find it a lot easier to use in physics.*

For Tom, using inquiry with biology is more challenging and complicated than in physics. The number of steps involved and general complexity of inquiry in biology require more planning and the outcome is often more uncertain. My interpretation is that the structure of biology leads Tom to have students focus on designing and conducting a controlled investigation. In doing so they are better able to manage the complexity of experimentation in biology. In contrast, physics offers more opportunities for inquiry and requires less emphasis on controlling the many variables found in biological investigations.

Allen, who teaches Advanced Placement Biology and general chemistry, also believes the use of inquiry in biology is challenging. For his chemistry class, inquiry is an integral part of instruction and he has developed a detailed inquiry-cycle to guide his teaching. Although the influence of the AP curriculum on his teaching must be taken into account, his broader view is that inquiry in biology is more difficult than in chemistry. He states,

*Biology is a tough one because so much of what you do in biology is not as much as an experiment as a student lead demonstration. At least the way I've seen it done and in my district. The only biology I've ever taught is the AP Biology. So I didn't do the general bio here. But usually what I see is not what I would consider a lab experiment as I tend to see in my chemistry classes where kids don't know the outcome, in which they have to design it, and they know what is going to happen and you go the back of the lab and you look at the different parts*

*of the flower and it's more of a student led demonstration is what I tend to see versus an actual inquiry activity.*

According to Allen, there aren't as many opportunities to do inquiry in biology. As a result, much of the inquiry that is done is not what he considers to be inquiry. His response, however, may be more of a statement about how much inquiry is done in biology classes in his district. My interpretation is that he believes the difficulty in using inquiry in biology is related to the way knowledge is structured in the discipline. For Allen, topics are not as readily adaptable to experimentation in the biology classroom. At the same time, Allen does engage his AP Biology students in a long-term inquiry project on fruit fly genetics indicating that he does find inquiry feasible and important enough to do within the busy AP curriculum.

Both Tom and Allen believe inquiry in biology is more challenging. I speculate this may lead biology teachers to structure inquiry with an emphasis on the design and implementation of scientific investigations. By this, I mean there is an emphasis on students choosing a variable to investigate, designing an investigation that focuses on that variable while controlling others, collecting and analyzing data, and reporting their findings. In doing so they are able to manage the complexity of the investigations.

A final observation about inquiry in biology is the duration of the inquiry activities. For the five teachers interviewed who taught biology, four of the inquiry lessons they described were longer-term investigations. In other disciplines, investigations were often shorter, usually taking place over a few days. I interpret this to indicate that biology teachers find more time necessary to conduct inquiry due to the more complex systems being investigated and nature of biological systems.

In the quantitative analysis of portfolios, it was found that the biology teachers were more likely to allow students to ask their own questions and select their own variables to investigate. A similar trend was also seen in participant interviews. So, while biology teachers may find it more difficult to plan and implement inquiry, they also are more likely to give students more choice in what is investigated. I believe this may be due to the more complex nature of investigations in biology that make it feasible to offer more choices to students.

*Age and previous science coursework.*

The context presented by students' age and previous science coursework appears to influence teachers' use of inquiry. Older students tend to have taken more courses and have more knowledge and experience with inquiry and science in general. Because science courses often follow a set sequence, students tend to be grouped by age within disciplines, although this is not always the case. The general pattern is for students to take biology and earth science in either ninth or tenth grade and then chemistry and physics in eleventh and twelfth grade.

As a result of how courses are sequenced, teachers with students in ninth and tenth grades may find it necessary to provide instruction on how to conduct scientific investigations. Upon arriving in chemistry and physics classes, most students already have established a basic understanding of how to conduct scientific investigations. Like most factors in this study, the influence of previous science coursework is part of the complex and dynamic context in which teaching with inquiry takes place.

Amy, a ninth grade biology teacher, believes that middle school science classes do little to prepare students for thinking about and doing scientific activities. As a result, it takes more time and effort to use inquiry with them. She states:

*Sometimes it's very hard to get them to do that, because they don't have enough background to ask the right question.*

Later she says:

*... when they get to my class it's a real shocker for them. 'No, you have to do that science and think scientifically' and they are not at all used to that. So it takes a long time.*

Although her conception of inquiry involves students conducting scientific investigations, her enactment of inquiry is centered on students learning biology content knowledge. It may be that the lack of previous inquiry experiences leads her to focus on biology content knowledge through more traditionally structured lab experiences. However, students' previous science coursework does influence her conception and enactment of inquiry.

Sarah, a ninth grade earth science teacher, offers a more complex example. She expects students to already have experience with conducting scientific investigations.

She states:

*However, I do think it is a very important part of science education that students learn how to design and conduct a scientific experiment, but most of this process is taught in earlier science courses, so that the goal when they reach my course is*

*to be able to conduct such an experiment in my content area, using their content area knowledge.*

Her enactment, though, is largely focused on students conducting scientific investigations with an emphasis on students understanding how practicing scientists work. So while she expects the skills to be developed in previous middle school coursework, her approach to inquiry is very structured with an emphasis on what she terms in her interview as “*the scientific method.*” High stakes testing adds further complexity and earth science content knowledge is also an important theme in her description of inquiry.

Finally, Peter, who teaches general chemistry and International Baccalaureate Chemistry, finds that students’ previous science classes shape his use of inquiry. He believes that students in his general chemistry class are not prepared for the type of inquiry used in IB classes. This contributes to his infrequent use of inquiry with his General Chemistry students. While it does not demonstrate a disciplinary difference, it does again highlight how previous science coursework can be influential, in this case on the amount of inquiry conducted.

*Academic ability.*

Related to age and previous science experiences, academic ability is also an important contextual factor. Students of lower academic abilities often take longer to acquire the necessary skills for conducting scientific investigations. The result is that teachers must focus on these basics. This can be seen by comparing how Carl approaches inquiry in with his IB students and Active Physics students.

For his IB students, his goals for the inquiry lesson discussed were largely centered on developing mathematical models for circular motion and engaging his students in discourse similar to practicing scientists. With his Active Physics students, a lower ability class, he finds it necessary to focus on the basics.

*Um, we're still sort of struggling with experimental design. This is a tougher population of students. Getting them to carry out an experiment to completion and discuss the results. I feel like I'm still, we've been trying it all year and still not successful with this group of kids.*

The ability to design and conduct scientific investigations can be thought of as a prerequisite to modeling and scientific discourse. In this sense, students must first be able to design and conduct experiments before they can construct mathematical models. His Active Physics students are still struggling to “carry out an experiment” although I believe that once these skills were obtained he would then be able to engage students in other aspects of inquiry. It is important to note that his IB students are seniors while his Active Physics students are mostly sophomores who did not pass algebra. Thus, along with ability, age may also play a role.

Peter teaches IB chemistry and general chemistry, a prerequisite for IB Chemistry.

*And honestly I like it so much when I do stuff like that with Chem One, and I have done it, like if I have Chem One classes that are sophisticated enough, and that are academically, I guess homogenously sophisticated enough, then I have done it with Chem One classes before and I use the exact same rubric because it makes complete sense.*

According to Peter, when his students have the ability, he approaches inquiry in the same manner as he does for his IB students. However, this is only the case if students have reached a certain academic ability level. Since his use of inquiry in Chemistry One is limited, it is not possible to determine what how he would approach inquiry for lower ability students. However, his case provides further support for the assertion that ability level can influence how inquiry is used.

While both Carl and Peter teach within only one discipline, academic ability influences how they teach with inquiry. Carl focuses on teaching lower ability students how to conduct scientific investigations, a skill they struggle with. Peter only uses the IB approach for inquiry in general chemistry classes when the students are of a high enough academic ability. Both cases suggest that with students of lower academic ability the tendency is to focus more on how to conduct scientific investigations or to limit the amount of inquiry done.

Due to the graduation requirements and course sequencing, students' academic abilities can influence how inquiry is approached across the disciplines. This is most visible in biology, which is often a required course for all students. As a result, there are often greater numbers of lower academic ability students. This may be one of the reasons biology teachers tend to approach inquiry with a focus on students conducting scientific investigations.

#### *Nature of student.*

A third factor that may influence teachers' use of inquiry is which students enroll in biology, chemistry, earth science, and physics courses. Here again, age and ability are also influential. Students are usually not required to take courses in all four disciplines.

Most often they must complete one or two classes and pass an external exam in one course, usually biology. Earth science is often the course students take when a second science credit is required. As a result, chemistry and physics classes tend to be made of students that are not representative of the student body.

Because of the self-selective nature resulting from graduation requirements and course sequencing, chemistry and physics courses often consist of more motivated and academically prepared students. There are numerous exceptions, such as the Physics First movement, but overall this appears to be the trend. Therefore, depending on the discipline, teachers are likely to have classes with different academic and affective characteristics.

Although there is little or no discussion in participant interviews, I speculate that, in general, students taking chemistry and physics are more experienced with designing and conducting scientific investigations. As a result, for many chemistry and physics teachers, it is possible to place less of an emphasis on the actual design and planning of scientific investigations and more on other aspects of inquiry such as modeling and scientific content knowledge.

### *Testing and Curriculum*

Both testing and curriculum influence teachers' conception, enactment, and goals of inquiry. By testing, I am referring to external tests with consequences for students, teachers, and schools. Consequences for students may include being able to graduate from high school or being placed in remedial courses. For teachers and schools, professional and legislative consequences exist. Curriculum is intended to mean lessons and activities developed by someone other than the teacher. I present examples from

participant interviews to illustrate how the presence or absence of these external influences shape the way teachers use inquiry.

Advanced Placement and International Baccalaureate courses provide an example of how an external curriculum, coupled with a high stakes exam, can produce two different approaches to inquiry. For Peter, the IB curriculum and exam place a considerable emphasis on students planning and conducting investigations. Not only is inquiry emphasized, time is made in available in the IB curriculum. Peter states,

*So with IB the framework is there, the timeframe is there to do inquiry learning the way that I think it really needs to be done.*

Inquiry labs are also required by the IB curriculum.

*That's, when I do inquiry in chemistry it's often in the form of something like that. I try to keep it, it's required for IB so it's convenient, you know, it's not like I have any way around it.*

As a result, for Peter, inquiry is done frequently and is aligned with the theme of *Students Conducting Scientific Investigations* although the theme *Chemistry Content Knowledge* is also present. A similar situation is found with Carl in his IB Physics course.

What is important about these two cases is that they inform us how testing and curriculum can influence how a teacher approaches inquiry. The two cases presented here do not illustrate disciplinary differences themselves, but they do suggest implications for how testing and curriculum can influence the use of inquiry in a discipline such as biology, which is frequently the subject of high stakes external exams.

In contrast, Anita teaches AP Chemistry where the curriculum and external exam leads to students engaging in inquiry less often. She states:

*AP is probably a little harder to do because of all the requirements and required labs. But I do try to do open activities to engage them and get them interested in the chapter topic that we are going to be covering.*

Further, on occasions where students do inquiry the focus is more on building scientific content knowledge. For Amy, the external curriculum and exam have a strong influence on the frequency and intent with which she uses inquiry. Unlike Peter and Carl, who both emphasized a very structured approach to students conducting inquiry, Anita used a more open structure with a focus on chemistry content knowledge.

Allen, an AP Biology teacher, echoed a similar sentiment on the influence of the curriculum and testing. He states:

*But teaching AP Biology I do not have the flexibility in the general biology class. You know, my year is planned out every day from the exam date back. We have a snow day, it doesn't matter, we skip that material and we gotta keep going.*

However he does have his students take part in a long-term investigation into fruit fly genetics with the goal of students conducting a long term scientific investigation. So while the structure of AP courses is influential, it does not exclude the use of inquiry consistent with the trends seen across disciplines.

A final example of the influence of external curriculum can be seen by comparing Anita's approach to inquiry in her AP Chemistry and Science Research courses. In the Science Research course students follow the International Science Fair rules to design

and conduct an investigation of their choosing. Here, the rules lead students to engage in inquiry with a strong focus on students conducting scientific investigations. In her AP Chemistry the focus is on content knowledge as is the case with her Honors Chemistry classes. The contrast highlights the role an external curriculum can play in how a teacher approaches inquiry.

After establishing the powerful influence external curriculum and exams have on teachers' use of inquiry, I now turn to exploring how testing and curriculum results in disciplinary differences in how teachers use inquiry. Scott teaches a biology course for mostly tenth and eleventh graders. He describes the influence of the state exams on his teaching with inquiry.

*The main goal for these students is to pass the NY state regents exam in biology (known as the Living Environment). There is a significant portion of the curriculum devoted to experimental design. We do lots of practice with designing hypothetical experiments, and usually one or two very simple student designed experiments. Often there is a plant growth experiment where the students choose a simple variable for two groups of plants (water volume, fertilizer, salt).*

Because of the emphasis placed on designing experiments in the curriculum and exam, Scott has little choice but to teach inquiry as students conducting scientific investigations. This suggests that a similar external pressure exists for many biology teachers and may offer some explanation as to why the majority of biology teachers approach inquiry with the purpose of teaching students how to conduct scientific investigations.

## *Summary*

Viewing these three contextual factors, disciplinary structure, students, and testing and curriculum, through the theoretical lens of situated cognition, a complex and dynamic system emerges. Each teachers' context, based on their background and the setting they teach, will be different. The situative perspective provides a framework to deal with this complexity and make sure that all possible contextual influences are explored in the data.

In this section, the goal was to discuss findings about the context of teaching with inquiry in biology, chemistry, earth science, and physics. A broader, perhaps less direct influence is the communities in which teachers currently participate.

### *Discourse Communities*

Contextual factors play an important role in explaining why disciplinary differences exist between biology, chemistry, earth science, and physics. However, teachers' ideas about inquiry develop from their experiences as students, through previous scientific research experiences, as pre-service teachers, through professional development, and through interactions in their school and the NB community. Interactions in each of these settings shape how teachers think about and ultimately enact inquiry in their classrooms.

In their seminal paper on situated cognition, Brown, Collins, and Duguid (1989) link activities, culture, and discourse communities to describe how meaning is constructed and negotiated. They state:

*The activities of a domain are framed by its culture. Their meaning and purpose are socially constructed through negotiations among present and past members.*

For NBCSTs, social construction and negotiation take place within discourse communities. I posit that these have a less direct influence on teachers' use of inquiry and may act primarily by influencing the context of teaching. As a result, there is less direct interview data to draw from for this discussion. In a sense, this makes my work as a researcher more interpretive and reliant on the research literature and theory. At the same time, discourse communities are a useful construct within my theoretical framework and offer considerable explanatory power for describing participants' conceptions, enactment, and goals of inquiry.

In my discussion, I chose to focus upon the discourse communities that I believe to be influential in explaining why disciplinary differences exist. In addition, I also draw from the research literature to expand upon why disciplinary differences exist. Three major discourse communities are explored in this section: past and present discourse communities, the science education community, and the school community.

*Past Discourse Communities: K-16 Education, Pre-Service Experiences, and Previous Scientific Research*

Prior to becoming practicing teachers, participants were part of several influential discourse communities. These are thought to have a discipline-based influence on teaching with inquiry. The communities discussed in this section are participation in science education communities as students, previous scientific research communities, and pre-service education communities.

*Participation in science education discourse communities as students.*

A driving force behind the evolution of the situative perspective was the inauthentic nature of many tasks students engage in at school (Brown, Collins, & Duguid, 1989). Ironically, the classroom is a very well situated environment to learn about teaching as it is practiced in schools today. Teachers often find it difficult to teach science and math differently than they were taught as students (Loucks-Horsley et al., 2003). In this study about teaching, schools can be viewed of as an apprenticeship where students learn how to participate in the discourse communities of teaching and learning. While this may be more peripheral and limited than a teacher education program, it takes place over a much longer time span. Therefore, I speculate that it influences how they eventually teach science. Further, I posit that any disciplinary differences are also influential in how NBCSTs think about and teach science.

The primary question I have is whether classroom experiences, K-16, are an *important* influence. In other words, are they a major factor in shaping how teachers view their discipline and teach with inquiry? Or are inquiry experiences rare enough in K-16 education to make a difference? Further, does studying within a discipline, even with more traditional lecture and labs, influence how a teacher ultimately teaches with inquiry? These questions are not easily answered within the scope of this study and data set. However, the research literature provides support that past learning experiences do influence how teachers teach which suggests this would also be the case for teaching with inquiry.

During interviews, participants were not directly asked about how their K-16 or undergraduate degree influenced how they think about and enact inquiry. Due to the

emergent nature of the findings in this study, at the time it was not apparent that this information was important. It is also not clear that such questioning would yield useful results without considerable discussion, which is limited by the scope of this study. However, to begin to understand how past teaching experiences might influence teachers' use of inquiry I compared participants' major undergraduate degree with their enactment and goals for inquiry.

Of the twelve interview participants, eight held bachelor's degrees in biology. These eight were made up of two biology teachers, two chemistry teachers, one physics teacher, and three who taught biology and an additional subject. Cross-referencing each teacher's degree with his or her approach to inquiry did not present any trends in how they approached inquiry.

I believe that school experiences are influential; however, they are nested along with all the other contextual factors and discourse communities within which teachers practice. It is therefore difficult to ascertain their influence. However, within the situative perspective, they represent an important discourse community to consider.

*Previous scientific research experiences.*

Previous experiences with scientific inquiry have been found to influence how pre-service teachers eventually use inquiry in the classroom (Bencze & Bowen, 2001, Friedrichsen & Dana, 2005; van Zee, Lay, & Roberts, 2000). In a multi-case study of pre-service teachers, Windschitl (2003, 2004) found that previous research experience was the most important factor in pre-service teachers' eventual use of inquiry in the classroom. For NBCSTs, previous participation in research communities also appears to influence their use of use of inquiry, depending on the type of experience.

Scientific research takes place within communities of practice. Scientists rarely work in isolation and the enterprise is considered to be social in nature. Viewed from a situative perspective, teachers' participation in these communities, however peripheral, constitutes learning about the practice of scientific research. The degree and type of participation in turn influences their use of inquiry in the classroom. Five of the twelve participants in this study had previous scientific research or laboratory experiences. These cases illustrate how previous scientific inquiry experiences influenced their classroom use of inquiry.

Sarah, an earth science teacher, is an example of how previous scientific research experience can influence a teacher's use of inquiry. Throughout our conversations, Sarah frequently returns to the importance of students taking part in activities that are similar to the work of practicing scientists. This can be seen in her conception, enactment, and goals for inquiry. For example,

*I know how they really do earth science out there so I want to make it as realistic as possible for them, what you would really have to do, what it is really is out there. This is how you can apply it to the real world.*

Based on interview and follow-up communications, Sarah's experiences as a practicing earth scientist had a strong influence on how she thought about and enacted inquiry. Further, these experiences also influenced how she approaches inquiry with her students. In discussing how her students present their results, I asked her why it was important for them to share their results with peers. She responded:

*In a classroom, the students share their results so that everyone can learn from the results and can discuss them and critique them as well, which mirror the process of science in the real world.*

For Sarah, previous research experience provided her with a model for how research is conducted in the field of earth science. In turn, she approaches inquiry in a similar manner with her students. As a result, a major theme in her conception, enactment, and goals is that inquiry should involve students conducting investigations that approximate authentic scientific practice.

In contrast, Peter described his lab experiences as having minimal influence on how he teaches with inquiry. He describes his work as primarily repetitive sample analysis with little emphasis on playing an active role in the design or analysis.

*I didn't feel terribly challenged. Once I learned how to use the FTIR and not break it. Then I found myself doing the same thing every day....*

In the case of Scott, he described a similar experience conducting routine chemical sample analysis. He also did not believe that the experience had much influence on his teaching with inquiry. It appears that working in a laboratory setting and conducting routine sample analysis is not sufficient to affect actual classroom use of inquiry.

Cathy and Jane offer a final example of how previous scientific experience can have an impact on teachers' use of inquiry. Cathy, who primarily teaches chemistry, worked in a hospital laboratory conducting analyses before changing careers. In her discussion of inquiry, she emphasized critical thinking and managing information, skills

that appear to be important in her work in the hospital laboratory. She does not place an emphasis on conducting scientific investigations in her use of inquiry, something that was not part of her previous laboratory experience.

Jane, who recently began teaching biology after teaching physics for several years, provides another example. Prior to becoming a teacher, she worked in the field of cancer research. Further, she worked at a university two summers with other teachers, conducting research under the guidance of scientists.

In her interview, she described inquiry in a very structured manner with students asking a question, formulating a hypothesis, and so on. Her enactment with biology was much more constrained, with a focus on content knowledge and little scientific investigation. This may be due to her recent shift to teaching biology. Her enactment of a physics inquiry lesson involved a real world scenario with a focus on modeling and physics content knowledge.

The main purpose of this section is to explore how NBCSTs' participation in a scientific research discourse community influenced their use of inquiry with an emphasis on how this could result in differences across disciplines. There are two competing hypotheses that may offer explanations.

First, it may be that teachers who have previous scientific research experience in the discipline they teach are more likely to adopt an approach to inquiry similar to their research experiences. Sarah may be an example of this as well as Cathy. With Jane, it is more difficult to determine, with her multiple experiences and recent shift to teaching biology.

An alternate explanation is that teachers who engage in scientific research will tend to teach in a way that corresponds to conducting scientific investigation. Again, Sarah provides an example where *Students Conducting Scientific Investigations* is a major theme. In the case of Cathy, her work experience led her to approach inquiry to include an emphasis on critical thinking and managing information. Jane's conception of biology also follows the theme of students conducting scientific investigations; however, this does not show up in her enactment. With her, physics lesson modeling and science content knowledge are the central themes.

Within the context of this study it is not possible to determine which, if either, explanation is a more accurate account of what is taking place. However, what is apparent is type of research experience does influence teachers' conceptions, enactment, and goals for inquiry. Any influence across disciplinary lines will require further research and, in the end, may not be a question with much practical importance. What is important is that teachers' participation in scientific research discourse communities can influence their use of inquiry.

Given that almost half of the participants in this study had previous scientific research experiences, such experience may be common among NBCSTs. Future research with this group may provide insights into how previous scientific experience influences practicing teachers' use of inquiry and teaching in general. Specifically, the question of how the type of research experience relates to how teachers teach with inquiry is of special interest.

*Preservice and induction experiences.*

Participants in this study became teachers through a variety of entry points. These include traditional preservice programs and alternative programs such as Teach for America and master's programs for career changers. However, because of the multiple contexts and interrelationships, no disciplinary trends emerged in the data. Further, it may be that since most secondary science education programs do not separate instruction by disciplines, there is no opportunity for differences to develop. It is possible that a larger data set with a specific focus on the role of preservice and induction experiences would find some differences, although other contextual factors to appear to be more influential.

*Present Discourse Communities*

Teachers participate and interact in several discourse communities. The communities discussed in this section are the science education community, the school community, and the National Board community. In addition, they also participate in communities of practice during professional development experiences.

*The science education community: past and present.*

The larger science education community also influences teachers' use of inquiry. Curriculum, textbooks, standards, and other documents are generated through discussion and negotiation, often working towards a consensus view of what should be taught and the best way to do so. These in turn influence how teachers structure their teaching. In this section, both the historical and present discourse communities on science teaching as it relates to inquiry are discussed. First, the discipline of biology is presented as one

example of the development of inquiry in a science education discipline. Second, the influence of current science education reform documents on teaching are considered.

In contrast to chemistry and physics, biology did not become an established high school subject until the 1920's. Even until the 1950's uncertainty existed about the content and methods that should make up high school biology courses (Deboer, 1991). For many years the discipline of biology fought to be considered a "hard science" along with chemistry and physics (Goodson, 1993). With an emphasis on the collection and classification of living organisms, biology was considered to be less rigorous than the experimental, quantitative approach of chemistry and physics. A major force behind the push to become a "hard science" was to attain the prestige and resources held by chemistry and physics courses. As Goodson (p. 53) notes:

*"Status through a vision of biology as a 'hard science' was increasingly pursued in the 1960s through an emphasis on laboratory investigations and mathematical techniques."*

It was not until mid-1960 that biology was accepted as a hard science, largely due to developments in the field of molecular biology. While Goodson's work took place within the British school system, it is assumed to be applicable to biology in the United States. The fight to be seen as a legitimate scientific "hard" discipline shaped the biology curriculum, shifting it from a descriptive field towards one in which experimentation was a dominant theme.

Findings in the current study suggest this historical influence is still felt today. Biology teachers were more likely to think of and enact inquiry with a focus on students conducting scientific investigations. In the quantitative analysis, 83% fell under this

theme, with similar, although less pronounced, trends in participant interviews. In addition, biology teachers were significantly more likely to include a hypothesis in their descriptions of inquiry, further suggesting a theme of experimentation. One explanation is that the historical emphasis on scientific investigations, in the form of experimentation, has shaped how inquiry is used in biology.

Finally, curriculum and testing may be one way this historical influence is perpetuated. Teachers like Scott have commented on the need to prepare for tests on the design of investigations.

*There is a significant portion of the curriculum devoted to experimental design.*

*We do lots of practice with designing hypothetical experiments, and usually one or two very simple student designed experiments.*

Given that biology is often the secondary science discipline in which high stakes exams are administered, it is likely that curriculum and testing encourage a similar emphasis.

Regarding the influence of the current science education community, science education reform efforts have also influenced how teachers think about and enact inquiry. One common perception held by participants in this study was that inquiry is supposed to be of an “open” nature. Five out of the twelve participants expressed discomfort with this idea, some strongly. For example:

*“I think that there’s a lot of inquiry going on out there that is not structured correctly. It’s just too much of a free for all.” (Diane)*

*“It was definitely more guided and not so much inquiry, and I probably would have done better in my score if it had been more inquiry....”* (Jane)

In each case, there is a concern about inquiry taking place without structure or goals. For Diane, much of the inquiry taking place is unstructured to the extent of being a *“free for all.”* Describing her approach to inquiry, Jane states that what she is doing does not really qualify for real inquiry because of the structured nature. For her, she perceives that inquiry must be less structured to qualify as inquiry. For Diane and Jane, along with other participants, there is a perception that inquiry is intended to be less structured and more open in nature.

The goal of this section was to demonstrate how the history of the science education community influences how biology is taught today. While not the only influence, it appears to be of importance, especially in relation to biology instruction. Not discussed are historical influences on chemistry, earth science, and physics, although it is hypothesized that influences do exist.

#### *The School as a Discourse Community*

The activity of classroom teaching takes place within the culture of schools (Brown, Collins, & Duguid, 1989). Teachers’ interactions in this culture shape how they think about and enact their teaching. In this study, evidence emerged that school culture may have been influential in several participants’ conception and enactment of inquiry. Although a strong link between disciplinary differences in teachers’ use of inquiry and the school as a discourse community was not established in this study, sufficient data exists to speculate possible influences.

In an example of the potential influence of the school culture on teaching with inquiry, McGinnis, Parker, and Graeber (2004) investigated the influence of school culture on teachers' use of reform-based teaching in a study of five preservice science teachers. Their findings suggest that teachers who are prepared to enact inquiry-based instruction are both aware of and potentially constrained by their perceptions of local cultural norms, including how the participants in the local culture viewed how science should be portrayed and taught. Likewise, school culture and the discourse communities in which NBCSTs participate are thought to influence how they teach with inquiry.

For Sarah, her department provided support and encouragement for the use of inquiry. In discussing why she believed the NB certification process did not change her conception and enactment of inquiry, she states:

*“They haven’t changed that much because we, specifically in my department we’ve always be very inquiry focused....”*

In this case, the department functioned as an active discourse community in which inquiry was an established practice. Therefore, Sarah’s conception and enactment of inquiry were stable and did not change as a result of the NB certification process.

In a similar situation, Donna works in a school where inquiry is a well-established part of the curriculum with all students having to do one inquiry lesson each year. The inquiry lesson described by Donna in our interview was developed in collaboration with another teacher at her school while they were working on their master’s degree. The lesson is used by all ninth grade earth science teachers. Both the support for inquiry from her science department and the collaborative nature of how inquiry lessons were developed indicate that Donna was part of an active discourse community.

Finally, for Cathy, the school culture actually made it more difficult for her to teach with inquiry in her Astronomy course. She states her use of inquiry is:

*“only limited by my access to technology at my school (very limiting!) and my administration’s ability to view astronomy as science (rather than a hobby, or worse, an extension to studying horoscopes).”*

She later states how she used National Science Education Standards to justify her use of technology and inquiry to administrators. Her case highlights another possible influence of school culture on how disciplines are afforded varying levels of prestige in a school. While this does not show up explicitly in other participant interviews in this study, it does suggest that different disciplines and courses hold different levels of legitimacy within some school cultures. This may result in limited access to resources such as technology and materials. It may also mean that teachers of these courses must spend more time justifying their use of inquiry.

School culture and the role of discourse communities were not specifically addressed in the participant interview protocol. However, in the three cases presented here, and in the literature (McGinnis, Parker, & Graeber, 2004), it emerges as a potential influence on inquiry. In two of the cases, the school culture and community had a positive influence on teachers’ use of inquiry. In the case of Cathy, it was shown to have a negative influence.

Establishing a link to disciplinary differences is more challenging with the present data set. Further, no guidance was found within the research literature. It can be speculated that for collaborative school cultures with active discourse communities there is a normalizing effect. Here, as was the case for Sarah and Donna, the enactment and

goals may shift towards the consensus of the group. Further, it is anticipated that this would likely follow disciplinary trends seen in this study.

Finally, there may be instances where the school culture affords a greater legitimacy to certain disciplines at the expense of others. In these cases, teachers' use of inquiry may be constrained or require justification, as was the case with Cathy. Here, there may be more reliance on standards documents to demonstrate the legitimacy of the use of inquiry.

#### *The NB Discourse Community and NBCST Change*

One final discourse community specific to this study is the broader community surrounding National Board certification. Based on the findings in this study, and recent research (Lustick & Sykes, 2006; Park & Oliver, 2008), the NB certification process for *AYA Science* appears to result in changes in the conceptions and enactment of inquiry for many candidates. Part of that change can be attributed to candidates' participation in the NB discourse community.

Each candidate seeking certification interacts with a variety of members of the NBCST and NB community. NB candidates, NBCSTs acting as mentors, informal and formal support groups, NB staff and assessors, colleagues, and others all can play a role in how candidates experience the certification process. While some candidates may approach certification in relative isolation, they still play an active role in the process and must interact with many elements of the NB community. Coupled with the support documents from the NB, this discourse community provides opportunities for learning and reflection on teaching with inquiry.

For teachers who are successful and become NBCSTs, their role in the community often shifts to that of mentor or a helpful resource for other candidates. For those who do not achieve certification, the process can begin again as they retake portions of the certification process in a second, and possibly third, attempt to achieve certification. Alternatively, they may disengage from the process.

While many teachers do change their conception and enactment of inquiry, not all do. For many, the process is one of documenting their accomplished teaching. In this study, four of the twelve interview participants experienced considerable change and four saw minor changes in their conceptions and enactment of inquiry. For the remaining four, no change was reported.

It is difficult to establish a strong link between the NB process and disciplinary trends. However, some tentative explanations can be explored. One explanation is that, for some teachers, the NB certification process may have a normalizing effect on teachers' conception and use of inquiry. Since instructions for portfolio construction are standard across disciplines this could lead to some teachers adopting the NB vision for inquiry.

It is thought that teachers who experienced considerable change in their conception or enactment of inquiry (i.e., Donna, Jane, Scott, and Tom) would be more likely to be influenced by the certification process. Scott provides an example that supports this hypothesis. For him, the structure of the NB documents shaped his thinking about inquiry. He states:

*Thinking through the steps the way that they have the three video segments, where there was the planning stage, the data collection stage, and then the analysis stage, and then to make sure that all three of those things actually work.*

However, Tom, who teaches both biology and physics, offers disconfirming evidence to this idea. While he stated that the certification process led to considerable changes in his conception and enactment of inquiry, he held two differing conceptions for biology and physics. In the case of physics his conception, enactment, and goals differed from the more experimental focus of the NB resource materials. It may be that other contextual and cultural factors are more influential in his thinking and enactment of inquiry.

From a social perspective, learning can be seen as enculturation into the practices and thinking of a community (Driver, Asoko, Leach, Mortimer, & Scott, 1994). From this perspective the NB certification process was a learning experience for many of the participants in this study. As found by Lustick and Sykes (2006) in his study of NB AYA *Science* candidates, the portfolio process lead many teachers to “*learn... to align their practice more closely with National Board’s conception of scientific inquiry and teaching.*” He hypothesized that this may have been due to the framework for inquiry provided by NB documents and would have more influence on teachers inexperienced with inquiry. I agree with this assertion and found similar trends.

Four of the twelve participants experienced no change as a result of the certification process. Teachers who experienced no change are unlikely to be influenced by the NB vision of inquiry in any appreciable way. There would, therefore, be no impact on how inquiry is used across disciplines for these individuals. Insufficient data

exist for teachers who experienced only minor changes but it may be the certification process resulted in small movement towards the NB vision.

Finally, similar to Karaman's (2007) study of NBCSTs, for some participants in this study the certification process confirmed their use of inquiry. For example, Sarah said:

*"It was nice to see that it was so supported in the National Board and that sort of helped to keep me motivated that, yes, this is how we're supposed to be doing science."*

Amy stated a similar experience and felt that certification provided tangible evidence of her teaching abilities and formal recognition that she was an accomplished teacher. For both teachers, the NB certification process may have served to strengthen their views of inquiry.

Having worked with over sixty NBCSTs in this study, and successfully going through the certification process myself, and mentoring new candidates, I believe it is a valuable professional development opportunity. It is, however, a different experience for each participant and depends upon the context of their teaching situation and the discourse communities in which they participate.

#### *Professional development.*

Apart from the National Board certification process, teachers may also take part in professional development on teaching with inquiry. Considerable research has been done on professional development and inquiry, although none was found that discussed disciplinary differences. Because teachers' conceptions, enactment, and goals for inquiry

exist in a dynamic setting that is confounded by the varied contexts, the findings to the influence of professional development are constrained. In addition, having a sample size of twelve participants also limits discussion on the role of professional development has on the use of inquiry across the disciplines. Therefore professional development was not included in this discussion.

### *Summary*

In this chapter, findings were presented to describe disciplinary differences in how teachers use inquiry. The situative framework was used to provide a structure for exploring the context and discourse communities that offer possible explanations about why these differences existed. However, no two teaching contexts are exactly the same and it is methodologically difficult to look at any one influence in isolation. Their complex and interrelated nature must be viewed as a dynamic system in which different contextual and discourse communities shape teachers' conceptions, enactment, and goals for inquiry. However, even within this complexity, trends emerged that were reported which suggest differences across disciplines in how teachers approach inquiry.

## Chapter Seven: Implications and Future Research

With the emphasis placed on inquiry in the science education reform community, this study adds potentially valuable insights to our knowledge about teaching with inquiry in secondary science education. It presents new information about how context varies across disciplines and how this can result in differences in how inquiry is used in biology, chemistry, earth science, and physics. In this chapter a comparison of the disciplines of biology and physics is presented to illustrate how differences emerge within specific disciplines. Practical implications and implications for researchers studying inquiry are then proposed. Finally, directions for future research are suggested.

### *Theory of Disciplinary Differences in Secondary Science*

Like much research into teaching and learning, inquiry and disciplinary differences are surrounded by a complex set of influences and interrelationships. To make sense of this complexity I conclude with a discussion of a possible theoretical model based on the framework of situated cognition. As a means to make the discussion more accessible and manageable, two disciplines are considered, biology and physics.

The decision to compare biology and physics was made based on a desire to emphasize the development of theory rather than the disciplines themselves. Biology and physics represent disciplines with the most explanatory power based on findings in this study. By selecting biology and physics, the intent is not to minimize the importance of chemistry and earth science. Both were crucial in understanding the influences on teachers' use of inquiry. Rather, the rationale was to show how teachers' conceptions, enactment, and goals for inquiry can vary between two disciplines and to seek possible

origins for those differences. In doing so it is possible to provide a more concise and focused description of why these differences exist.

The situative perspective forms the theoretical basis for this discussion. As described earlier, the structure of the discipline, student characteristics, and testing and curriculum make up the contextual factors found in this study and in the literature. Based on the findings in this study the *context* in which inquiry teaching takes place is seen to be the more immediate and visible influence on how inquiry is taught. In this sense teachers are more aware of how context influences their teaching than they are of the discourse communities in which they participate and more data about the contexts influencing inquiry emerged in participant interviews.

In addition to the role of context, biology and physics teachers have been and are members of various *discourse communities*. The science education community is one example that contributes to disciplinary differences in the use of inquiry. Past discourse communities also include NBCSTs' experiences with inquiry as students, previous scientific experiences, and pre-service induction experiences. Current communities include the school and NB community. Each contributes, although to varying degrees, to disciplinary differences.

A possible way to view context and discourse communities is in how they support inquiry. It appears that contextual factors are more likely to place constraints on the enactment and goals of inquiry. As a result, context plays a prominent role in teachers' use of inquiry. For example, testing and curriculum have a major influence on International Baccalaureate, Advance Placement, and many biology courses. Teachers in

these courses tend to approach inquiry in different ways due to the context of testing and curriculum.

Discourse communities tend to have a less pronounced influence than the contextual factors like student characteristics or testing and curriculum. In many cases these communities, such participation in scientific research, added a depth to their conceptions, enactment, and goals for inquiry. For example, emphasizing students' use of inquiry to approximate the work of scientists in the real world. In many cases it was found that conceptions were influenced more by discourse communities while context had a greater influence on enactment and goals for inquiry.

In order to show how both the context and discourse communities can lead to disciplinary differences in teachers' conceptions, enactment, and use of inquiry, both biology and physics are presented. Note that only influences that appear to influence disciplinary differences in how biology and physics teachers approach inquiry are included in this discussion.

### *Biology.*

Findings from both the statistical analysis and participant interviews suggested that high school biology teachers tend to approach inquiry with an emphasis on the theme of *Students Conducting Scientific Investigations*. Figure 5 illustrates how influences leading to this theme are organized and interact.

In Figure 5 contextual factors are shown with arrows pointing to *Teaching with Inquiry*, located in the center of the figure. This is to indicate the more pronounced and direct influence they have on biology teachers' use of inquiry. Further away are the

discourse communities in which teachers participate or have participated. They have a less direct influence on teachers' use of inquiry, and are often mediated through contextual factors.

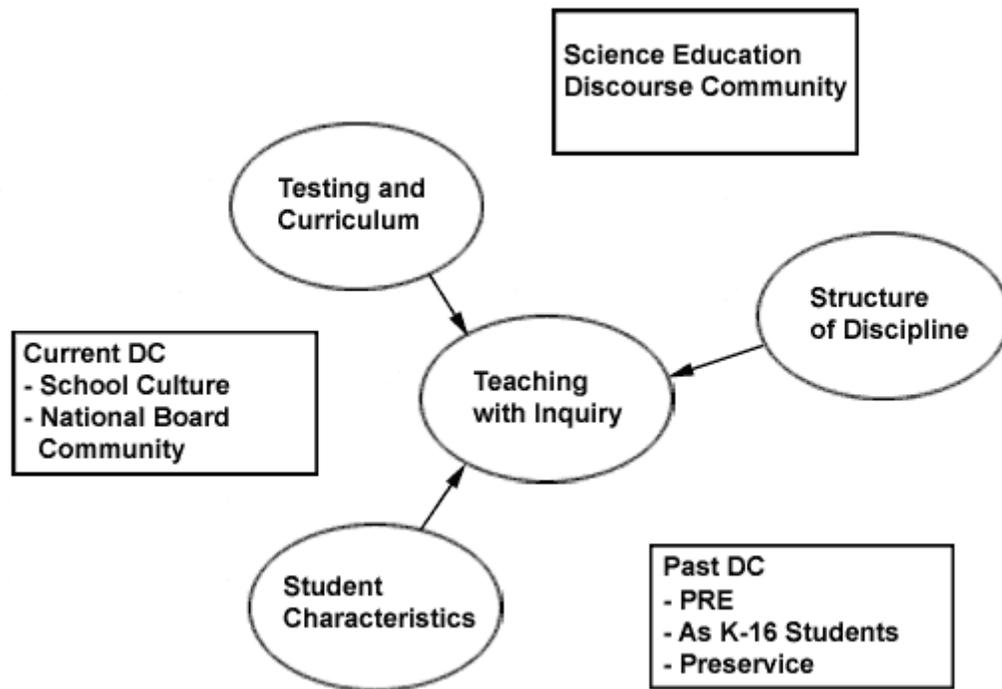


Figure 5. Organization and interaction of influences leading to the theme of Students Conducting Scientific Investigations

Contextual factors found in this study tended to constrain how teachers approached inquiry. Each factor is described briefly below.

- Structure of the Discipline of Biology – in this study three teachers stated that inquiry was more difficult in biology than in chemistry and physics. Considering that there were only four teachers who taught biology and another subject, this is noteworthy. In addition, biology teachers tended to

conducting inquiry activities of a longer duration than other subjects, which may be based in the nature of topics that are investigated.

- Student Characteristics – biology tends to be a required course in most situations. As a result all students take biology leading to a wide variety of ability levels and interest in science. Further, biology tends to be taught in ninth or tenth grade with students having fewer experiences with science and inquiry.
- Testing and Curriculum – for biology, testing and curriculum have a large influence since biology tends to be the discipline most commonly selected for high stakes testing.

Discourse communities are seen to be less constraining and more likely to enable teachers to approach inquiry. School culture could constrain the use of inquiry but was largely seen as enabling in this study.

- Science Education Community – historically biology was involved in a struggle to be considered a “hard science” like chemistry and physics until the mid-1960s. During this time an emphasis was placed on experimentation and quantitative aspects of biology in an effort to gain the status held by the chemistry and biology.

The current science education community is often perceived as encouraging a more “open” form of inquiry. This tends to align with biology teachers conceptions of inquiry who are more likely to allow

student choice of research questions and variables and engage in longer term inquiry experiences.

- Past and Present Discourse Communities – in both biology and physics the discourse communities in which teachers participated, or have participated, tend to have a less visible influence on the broader categories used in this study. Overall, discourse communities tended to support teachers' use of inquiry along the lines of disciplinary trends within the context of their teaching situation. The exception was the NB discourse community which tended to promote an approach to inquiry similar to the theme of *Students Conducting Scientific Investigations*. Because of past and present discourse communities were not as prominent in the data for this study, they are not reported here.

Together, these factors lead to a trend of biology being taught with an emphasis on experimentation and placed under the theme of *Students Conducting Scientific Investigations*. This involves an emphasis on designing and conducting investigations or experiments in their enactment and goals for inquiry.

#### *Physics.*

In contrast, the discipline of physics is situated within a different context, although many of the discourse communities are similar.

- Structure of the Discipline – high school physics teachers tended to emphasize the use of mathematics and modeling in this study. For example, in physics tasks tend to be well structured with more readily

verifiable knowledge. A potential reason that well-defined domains, like physics, have been the subjects of numerous studies about student misconceptions is because a student's response can be verified as correct (Alexander, 1992).

- Student Characteristics – physics is usually an elective course and therefore made up of a self-selected group of students. As a result classes tend to consist of more motivated students with more developed academic abilities. Because physics tends to be taught after students have taken other science classes, students have been exposed to more scientific knowledge and inquiry experiences.
- Testing and Curriculum – for physics, testing and curriculum are not as constraining as with biology, with the exception of IB and AP Physics courses.

The discourse communities for physics are similar to biology with the exception of the Science Education Community.

- Science Education Community – physics was one of the first disciplines, closely followed by chemistry, to secure a place in school science. With a strong quantitative approach, it was not necessary for physics to justify itself as a hard science.

As a result of the above factors physics tends to be taught with an emphasis constructing mathematical model of natural phenomena and in this study placed under the theme of *Modeling*. In portfolio analysis there was a greater diversity of approaches to

inquiry with about one third being placed under the theme of *Students Conducting Scientific Investigations*. This may be due to the less constrained contexts in which physics is taught affording a greater diversity of approaches. In addition, the Physics First movement may also have resulted in younger students for some participants in the quantitative analysis. However, in participant interviews participants were almost exclusively categorized under the theme *Modeling*.

#### *Summary.*

Physics and biology were presented separately in this section as a means to compare the two disciplines and illustrate how and why disciplinary differences may exist. However, it is important to note that the difference was between disciplines and not necessarily individuals. As seen several times in this study, an individual teaching in more than one discipline can hold multiple conceptions for inquiry based upon the context of the discipline. It is therefore important to stress that the use of inquiry is highly contextualized.

As shown in the comparison of physics and biology, understanding the influences leading to disciplinary differences is challenging due to the complex and dynamic nature of teachers' use of inquiry. Still, through this complexity trends do emerge. These trends have important implications for both the science education research community and teaching with inquiry.

#### *Research Implications*

For researchers studying inquiry at the secondary level, a primary implication is the need to take into account the role disciplinary differences play in teachers' concepts and enactment of inquiry. Research studies frequently consider participants from only

one discipline, often for practical, logistical, and theoretical reasons. However, there is a need to exercise caution in generalizing findings to other science disciplines.

As result of the findings in the present study, it is recommended that researchers address the influence disciplinary differences may have in their research design or be clear in stating that findings may not generalize to other disciplines. Researchers may also want to consider how disciplinary differences influence other aspects of science teaching. The findings presented here offer a starting point for considering how context and discourse communities can shape instruction. While there will be commonalties such as student characteristics and the structure of different disciplines, there will also be differences. What is important is how these differences translate into teachers' conceptions, enactment, and goals for instruction. The trends found in this study suggest disciplinary differences may exist in other areas of instruction. For example, the same approach could be applied to the use of demonstrations or technology use in science teaching.

An intriguing population for study are hybrid teachers who teach in more than one discipline. In this study, these teachers often held different conceptions depending on their discipline. These conceptions tended to follow the disciplinary trends identified in this study. Therefore, researchers should be aware that teachers' conceptions of inquiry are flexible and dependent upon a variety of contextual and cultural factors.

Three out of the four hybrid teachers held differing conceptions of inquiry depending on the discipline they were teaching. For example, in Table X, Tom would approach inquiry in biology as students conducting scientific investigations. However, when he taught with inquiry in physics, he focused on students collecting data to develop

mathematical models of a physical phenomenon. Of the four hybrids, only Allen was consistent in his approach to inquiry across disciplines.

Table 29

Hybrid Teachers and Inquiry

	Biology	Chemistry	Earth Science	Physics
Tom	SCSI			Modeling
Allen	SCSI	SCSI		
Jane	SCSI			Content/Modeling
Cathy	SCSI	Content	Content	

A final implication is that hybrid teachers may hold conceptions about inquiry that are different from how they actually enact inquiry in their classrooms. In interviews, when hybrid teachers described their general conception of inquiry, it was often different from their enactment. They often tended towards one of the disciplines in which they taught. Researchers should be aware of these differences in the development of interview protocols and other methodologies relying on self-report data.

*Practical Implications*

Although this study selected the NSES vision of inquiry as a baseline to allow for comparisons between disciplines, no single approach to inquiry is being advocated in this study. Rather, this study highlights the diversity of ways that teachers successfully teach within a variety of visions of inquiry. Acknowledging these differences, which tend to follow trends across disciplines, may lead to more targeted and relevant professional development and curriculum design.

Teachers' use of inquiry originates in the context of their teaching and the communities in which they participate. From the standpoint of professional development, simply presenting a model of inquiry, even within an individual discipline, may alienate teachers with other conceptions of inquiry. Therefore, one potential implication is to assist teachers in understanding their approach to inquiry and alert them to other approaches.

From a practical perspective, findings from this study support the idea of having discipline-specific professional development. This might take the form of initial mixed discipline discussions and activities, but ultimately biology, chemistry, earth science, and physics need to have time together to deal with issues specific to their disciplines. This is not to say that individual disciplines will have homogenous approaches to inquiry but it is likely the contextual influences will be similar.

An additional implication is that general discussions about inquiry may not result in changes in teachers' ideas or use of inquiry. As seen in this study, when asked to define inquiry, teachers often offered vague and somewhat idealistic responses. While this is useful information and does appear to influence enactment, it was the discussion of specific enactments of inquiry where teachers gave detailed descriptions. Therefore, in any professional development situation it is important to provide examples that are relevant to teachers' discipline.

Although not an interview prompt, five out of the twelve participants expressed a concern that inquiry was encouraged to be "open" in nature. If this perception is common in the general science teaching population, it is likely that it discourages many teachers from attempting inquiry or leads to them avoiding professional development or

curriculum that promotes inquiry. The implication is that this perception may result in many teachers being reluctant to embrace inquiry when they believe that it is not possible in their classrooms.

As discussed earlier, no single vision of inquiry is being advocated here. Rather than promoting a consensus view of what inquiry should look like, it may be more appropriate to encourage a vision for individual disciplines based upon the context and communities in which they are situated. For example, biology students may be younger and need more time learning how to conduct scientific investigations. Physics students may be older and perhaps consist of more students who wish to continue on in science after high school. The context of both situations suggests different approaches to teaching with inquiry.

### *Summary*

Assuming inquiry should be a central theme of science instruction, a prominent proposal made in science education reform documents, a larger question is how to get secondary science teachers to use inquiry in their teaching practices. Research consistently reveals that little inquiry takes place in secondary science classrooms in the United States (American Association for the Advancement of Science, 1992; Lotter, Harwood, & Bonner, 2006; National Research Council, 1996; Wells, 1995). The present study suggests possible reasons this may be and suggests potential remedies. First, a more specific discipline-based message is needed to encourage the use of inquiry. Further, this message needs to match the context of teachers' practice. Second, specific examples need to be made available to teachers that explicitly address the perception that inquiry needs to be taught in an "open" manner and can take place over short timeframes.

### *Future Research*

In this study, evidence was found suggesting that disciplinary trends exist between biology, chemistry, earth science, and physics disciplines. Because the research on this topic is sparse, further studies are needed in a number of areas. These include studies with different populations and the use of additional methodologies. In addition, disciplinary differences in teachers' views of the nature of science, the influence on teachers' conception and enactment of inquiry for students with different academic abilities, and teachers' perceptions about science reform efforts could offer new and potentially valuable information on teaching with inquiry.

NBCSTs provided an ideal group to study because of the consistency in the requirements for the construction of their portfolio entry on teaching an inquiry lesson. NBCSTs, however, represent a select group of teachers and, as a result, the findings here may not generalize to other secondary science teachers. Therefore, more studies are needed with different populations of teachers to determine if disciplinary differences exist outside of the NBCST community. Such studies have the potential for being applicable to a larger group of teachers.

In addition to studies with different populations of teachers, different methodologies would also provide further insights into differences across disciplines. In particular, participant interviews combined with classroom observations would add to our understanding, although it will likely be necessary to work with a more limited sample due to the resources and time required for such research. This might include exploring how different disciplines approach inquiry over a variety of topics and timeframes. In

addition, research could look at specific areas such as disciplinary differences in how teachers incorporate NOS into their teaching with inquiry.

A critical question about teachers' views on the nature of science is whether there are disciplinary trends or views are more universal (Lederman, 2007). Future research with a larger sample and a greater number of VOSTS questionnaire items is needed to answer this question. However, data in this study suggest that trends may exist within disciplines. The methodology used in this study, coupled with classroom observations, could offer further insights into disciplinary differences across a multiple activities, topics, and classes.

Student ability represents another potentially important future research question. In this study, a weak statistical link was found between class ability and teachers' use of inquiry. Because it did not address the primary research questions and due to the low power of the t-test and large effect size, the results were not presented in this dissertation. However, along with the weak statistical results, student ability was found in participant interviews as a contextual factor influencing teachers' use of inquiry. Therefore, a study focusing exclusively on student ability and teachers' use of inquiry could prove informative for curriculum design and professional development.

Finally, teachers' perceptions about the science education reform vision for inquiry offer another area where future research is needed. The concern that "open" or unrestricted inquiry is the intent of reform efforts was common in the current study. Future research on how this perception developed and is maintained could be useful in getting more teachers to believe that inquiry is something that could work in their classrooms.

### *End of Study Researcher Positionality*

At the close of this dissertation, I would like to step outside the study and reflect upon my findings in the broader context of national policy on science education. I do so with the benefit of insights and questions put forth by my dissertation committee during my oral defense. This is an opportunity for me to discuss some of the larger issues surrounding inquiry teaching and learning in a more open manner and, at the same time, consider how I have changed as a researcher.

From this study on NBCSTs and inquiry, I have come to appreciate the complex and dynamic nature of inquiry teaching and learning. My understanding of the role of context and culture on teachers' use of inquiry has broadened and deepened as a result of working with over sixty teachers in this study. While the contexts and interrelationships were complex, trends emerged which led me to speculate about the role and future of inquiry in science education.

Inquiry is often thought to allow students to become more motivated, creative, and better critical thinkers. My belief that this is the case remained strong, and may have become stronger, after completing my research. These beliefs were also common in the teachers I spoke with and were often mentioned when I asked why they felt inquiry was important. Participants commonly cited student motivation, creativity, and learning to think like scientists as goals of inquiry.

While most teachers believed that inquiry was beneficial for students, the context of the classroom shaped and often limited how frequently they were able to conduct inquiry activities with their students. Conversely, for some the context served to promote their

use of inquiry by removing limitations. Clearly, context had a powerful influence on teachers' conceptions, enactment, and goals for using inquiry.

Context also served to influence when and how students learned the various aspects of inquiry. Trends in this study suggested that, as students progressed in their grade level, different inquiry experiences became available. How to increase the likelihood that all students will have these experiences touches on national education policy and teachers' ability to provide these opportunities.

### *The Role of Context and Community*

During the pilot phase of this study, sociocultural theory guided my design and analysis. As I began the full study, it became apparent that I needed a more specific theoretical framework to interpret the varied contexts and communities influencing teachers' conceptions and enactment of inquiry. Although I was comfortable with sociocultural theory, the situative perspective appeared more appropriate and specific to the data I was generating. I therefore shifted to the situative perspective.

From this study, three primary contextual features arose that may offer insights into how national policy can influence teachers' use of inquiry. They are the relationship between student grade level and course sequencing, NB certification, and the interaction between testing and inquiry.

#### *Student grade level, course sequencing, and inquiry.*

Student grade level appears to be related to teachers' conceptions, enactment, and goals for inquiry. Due to the manner in which grade level coincides with the various disciplines, students are likely to experience different approaches to inquiry as they progress from biology or earth science to chemistry and then to physics.

In general, biology and earth science are taught to students in ninth and tenth grade. Chemistry and physics are often taught in the higher grades, with chemistry typically taught to eleventh graders and physics to twelfth graders. Based on these trends it appears that students who continue taking science courses throughout their high school career are likely to move through several different enactments of inquiry.

Without intending to imply that certain forms of inquiry are of more value than others, it appears that, as students progress through a sequence of science courses they move from learning to conduct scientific investigations towards inquiry as a means to teach content and develop modeling skills. The relationship between grade level and approach to inquiry activities is illustrated in Table 30.

Table 30

Grade Level and Predominant Form of Inquiry

	Biology	Earth Science	Chemistry	Physics
General Grade Level	9 <sup>th</sup> /10 <sup>th</sup>	9 <sup>th</sup> /10 <sup>th</sup>	11 <sup>th</sup>	12 <sup>th</sup>
Major Form of Inquiry	SCSI	SCSI	Content	Modeling

Based on this trend, several implications for student learning arise. First, students who do not continue after earlier coursework are not likely to have experienced varied enactments of inquiry. As a result, students who do not take additional science courses after meeting graduation requirements may end up with limited views of scientific inquiry. Based on the trends identified in this study, it is probable they would only have experienced inquiry focused on learning to conduct scientific investigations.

Grade level appears to be one of the primary contextual factors influencing how students are likely to experience inquiry. However, as I have found throughout this study, inquiry takes place against a backdrop of multiple contexts that often interact and influence each other. While grade level appears to be an important factor, other factors such as testing are present. Testing represents a related and influential contextual factor.

*Testing and inquiry.*

Testing emerged as a powerful contextual factor that shaped both the type and frequency of inquiry in this study. This was most apparent for biology teachers and those teaching AP and IB courses. For these courses, testing primarily influenced the frequency with which inquiry took place. From a national policy standpoint, testing represents a contextual feature that can be used to encourage the use of inquiry.

Course sequencing at the high school level and No Child Left Behind (NCLB) legislation result in biology being most affected by testing. For tests that contain items about inquiry, it is likely testing results in more teachers using inquiry in their teaching. Because biology tends to be taught in either ninth or tenth grades it is often a required course for high school students.

It may also be possible that biology teachers' use of inquiry is constrained by testing. A biology teacher in this study spoke of doing "*lots of practice with designing hypothetical experiments*" in order to pass the state tests. This may indicate that some biology teachers may spend more time on preparing students to answer multiple choice questions about inquiry rather than doing inquiry. It should be noted that the biology teacher mentioned also incorporated one or two student designed investigations into the course.

Testing is a contextual factor that could be shaped by national policy. For tests that assess students' inquiry knowledge and abilities, this may represent a way to encourage more frequent use of inquiry in high school science classes. However, much would rely on the ability of tests to assess students' understanding of inquiry. In the current context, biology would appear to be the primary course where this would be possible.

AP and IB courses also demonstrate the influence of testing on teachers' use of inquiry. Inquiry is not a prominent part of the AP curriculum, which primarily focuses on content knowledge. In contrast, inquiry is a central component of the IB curriculum and assessments. In this study, IB teachers reported more frequent use of inquiry than their AP counterparts. Here, the influence of testing influences both the type and frequency of inquiry. Since both AP and IB are most often taken by highly motivated students who wish to go on in science, AP and IB may not generalize to other courses. However, they do show how testing can influence teachers' use of inquiry.

Combined with the context of a progression of disciplinary grade level and approaches to inquiry and the importance of professional development activities, testing represents an additional tool policymakers have to increase the use of inquiry.

*National Board and inquiry.*

Of the twelve participants interviewed, one third experienced considerable changes in their conceptions and enactment of inquiry as a result of the NB certification process. Another third experienced minor changes. Similar trends highlighting teacher learning from the AYA Science certificate area have been found studying NBCSTs in

recent research (Lustick & Sykes, 2006, Park & Oliver, 2008). For many teachers, the NB certification experience serves as a source of change in their teaching with inquiry.

Given that inquiry teaching is not a frequent feature of secondary science classrooms, these results are encouraging. They demonstrate that a professional development experience of sufficient rigor and supported with guidelines, rubrics, and teaching standards can lead to changes in teachers' use of inquiry. The challenge is in finding a manageable way to translate these successes to a wider range of science teachers. Several key contextual factors emerged in the current study that may provide insights into how this might be accomplished.

Teachers face a number of barriers that can limit their use of inquiry. For example, time, testing, beliefs about students' capabilities, and access to materials are frequently cited by teachers. NB certification often allows teachers to temporarily suspend some of these limitations. This gives teachers the freedom and impetus to use inquiry in their classroom in new and perhaps more extensive ways.

The nature of NB certification also provides a structured and reflective context for teachers to examine their own use of inquiry and student learning. As they develop their portfolio entry on inquiry they must discuss their goals, planning, interactions with students, and reflect on learning that took place. Videotaping their teaching, a first for many teachers, allows teachers to step back and observe themselves and students doing inquiry. The reflective element of the portfolio encourages teachers to think about how they will apply what they have learned to their teaching. Together, these elements can lead to changes in how teachers use inquiry.

For a number of participants in this study, the materials provided by the NB were a source of learning. This was most evident for teachers who had limited experience with inquiry and did not have a model for teaching with inquiry or weren't satisfied with their current use of inquiry. As a result of the NB certification process, many teachers stated an increase in the amount of inquiry they conducted and in the sophistication of their use of inquiry.

The findings in the current study and previous research suggest that the NB certification process leads to change for many teachers. It can create space for teachers to think deeply about inquiry and try new ways of teaching. Further, the process often places teachers in a discourse community about teaching with inquiry made up of colleagues seeking certification, currently certified teachers serving as mentors, and others in the NB community.

#### *Inquiry and National Education Policy*

National and local policy has the potential to influence teachers' use of inquiry through professional development activities like the NB and through testing. However, the disciplinary differences in teachers' use of inquiry in biology, chemistry, and earth science also need to be taken into account in any policy initiative aimed at inquiry. Two major policy tools available to increase the frequency and the substance of inquiry teaching are discussed here based upon the findings in this study.

#### *NB certification and inquiry.*

In the current study, one third of participants interviewed underwent considerable change in their use of inquiry. This includes frequency of use in addition to changes in their approach to inquiry. For many participants, the amount of inquiry taking place

increased and became more sophisticated. NB certification is one potential national policy tool that could be effective in promoting the use of inquiry.

For almost all the participants interviewed, financial incentives were the major reason for seeking certification. Many states and school districts paid for certification and offered salary increases for teachers successfully achieving certification. Rewarding teachers for becoming NB certified is an effective policy tool to encourage teachers to seek certification.

For many teachers, the NB certification process is intimidating and requires too large a time commitment. As a result, the NB recently began offering the Take One! program. This allows teachers to focus on completing one portfolio entry. Their score for that entry is then banked towards future NB certification. For many teachers, this is a more appealing and lower-risk way to approach certification. For the Adolescent and Young Adult: Science certificate area NB selected the portfolio entry *Active Scientific Inquiry*. From a policy standpoint, the Take One! route to certification is an established, cost effective, school based, and effective professional development experience.

Research has shown that many teachers learn about inquiry and change the frequency and their enactment of inquiry as a result of the NB certification process. Further, teachers often become participants in discourse communities as they plan, implement, and prepare their portfolio. Mentors, colleagues, and others in the NB community can have a positive effect on teachers' conceptions and use of inquiry.

*Testing and curriculum.*

Testing can also serve as a policy tool for encouraging the use of inquiry. As seen with biology, AP, and IB courses this must be approached with care. The nature of the test may lead to limited enactments of inquiry or limit how much inquiry takes place.

A major element regarding the influence testing has on inquiry resides in how well the test can assess students' knowledge and inquiry skills. Improvement in assessments will be necessary for this to have a significant effect. If teachers are able to simply teach the process of scientific inquiry as content or through the design of hypothetical experiments the impact on inquiry teaching will be minimal. This is further complicated by the current movement towards tests made up of only multiple choice questions in an effort to save money and increase reporting. Therefore, developing assessment items that can measure students' skills and knowledge about inquiry needs to be an area of emphasis.

In the current study, the Nature of Science (NOS) was seldom mentioned in either portfolio analysis or participant interviews. Based on the VOSTS instrument, it was found that participants did have developed views of NOS but that they did not state them explicitly when discussing their enactment and goals for inquiry. The addition of test items on NOS may result in an increased presence in teachers' instruction for courses like biology.

Finally, discussions about a national curriculum have recently surfaced. For science, it is speculated that inquiry will hold a central role, as it does in the National Science Education Standards today. To be effective, it will be important that the

curriculum include targeted and relevant representations of inquiry to support the conceptions and goals for teachers in various disciplines.

### *My Role as a Researcher in Science Education*

Earlier in this dissertation I stated that I approached this dissertation from the perspective of a high school science teacher and a former research chemist. I can now add to that list my perspective as a science education researcher. The experience has changed the way I view teaching and learning in several important ways.

The process has made me more cautious and has led me to believe that assumptions need to be tested. There are often deeper meanings that require time and thinking. I now take a more critical look at situations and seek to understand the multiple contexts and communities involved. My exposure to sociocultural theory and the situative perspective now help me interpret the context and interactions in my classroom and school.

As a teacher, I've had the opportunity to read the scholarly work of many excellent researchers and learn about their thoughts, particularly on topics of high relevance to my dissertation, teaching with inquiry. This has influenced my own thinking concerning conducting research in science education, and how I might approach science teaching as a practicing researcher. As a practical matter, I am now better prepared to offer support on conducting science education research and teaching with inquiry to my colleagues across the disciplines.

## Appendices

### Appendix A: Portfolio Inventory Tool

#### 1. *“Identify questions and concepts that guide scientific investigations.”*

##### A. *Degree to which teacher supports students efforts to develop a research question.*

**5** – evidence that considerable effort is spent on the development of the research question (e.g. students receive instruction on choosing testable questions, students practice developing questions, teacher provides feedback on questions)

**4** – evidence that students received support in developing their research question (received some instruction on asking a testable question, received some feedback from teacher on question development)

**3** – some evidence that students received support in developing their research question (received some instruction on asking a testable question, received some feedback from teacher on question development)

**2** – minimal evidence that students received support in developing their research question (received some instruction on asking a testable question, received some feedback from teacher on question development)

**1** – there is no evidence that students received support in developing their research question.

##### B. *Degree to which students choose own question to investigate.*

**5** – students developed own questions based on own scientific interest and course curriculum

**4** – students developed own questions on a limited topic (e.g. energy, ecology, ...)

**3** – students could chose from a set of questions

**2** – students were given specific questions to research

**1** – all students work on the same research question provided by the teacher

#### 2. *“Design and conduct scientific investigations.”*

*A. Degree to which students engage in designing their scientific investigations.*

**5** – evidence that teacher provides considerable support for students designing scientific investigations (research outside sources, use of variables, control groups, procedures, use of instruments to collect data, multiple trials, safety, technology, relation of design to original question)

**4** – evidence that teacher provided a high degree of support (includes many of the above)

**3** – evidence that teacher provides some support (includes some of the above)

**2** – evidence of that teacher provides limited support (includes few of the above)

**1** – no mention of students’ design of their scientific investigation.

*B. Conducting scientific investigations.*

**5** – evidence that students collect and organize data, giving attention to almost all of the following: accurate observations, management of error, and correct use of measurement tools (glassware, stopwatches, rulers, electronic data tools), students revise their methodology during data collection when necessary.

**4** – evidence students collect and organize data and give attention to most of the following: (see above)

**3** – evidence that students collect and organize data and give attention to some of the following (see above)

**2** – little evidence that students collect and organize data from the investigation

**1** – no description of students’ collection and organization of data.

*3. “Use technology and mathematics to improve investigations and communications.”*

*A. Evidence that teacher encourages and supports the use of technology in students’ investigations.*

**5** – Evidence that students have access to a wide variety of technologies and frequently use them in their investigation (hand tools, measuring instruments, calculators, computers (for collection, analysis, display)).

**4** – Evidence that students have access to a variety and use them in their investigations.

**3** – Evidence that students have some access to technology and use them in their investigations.

**2** – Minimal evidence that students use technology.

**1** – No mention of technology.

**B. Evidence that teacher encourages and supports use of mathematics in students' investigations, where appropriate.**

**5** – Considerable evidence that students frequently use mathematics in their investigation (basic calculations, measurement, formulas, charts and graphs for communicating results, statistics).

**4** – Evidence that students frequently use mathematics in their investigation (see above).

**3** – Some evidence that students frequently use mathematics in their investigation (see above).

**2** – Limited that students frequently use mathematics in their investigation (see above).

**1** – No evidence of use of mathematics in investigations.

**4. *“Formulate and revise scientific explanations and models using logic and evidence.”***

**A. Students' work culminates in an explanation or model of the phenomena (physical or math).**

**5** – Considerable evidence that students' work culminates in an explanation or model of the phenomena.

**4** – Evidence that students' work culminates in an explanation or model of the phenomena.

**3** – Limited evidence that students' work culminates in an explanation or model of the phenomena.

**2** – Minimal evidence that students' work culminates in an explanation or model of the phenomena.

**1** – No evidence that students' work culminates in an explanation or model of the phenomena.

***B. Students review current scientific understanding, evidence, and logic to determine the best explanations or models.***

**5** – Considerable evidence that students review current scientific understanding, evidence, and logic to determine the best explanations or models.

**4** – Evidence that students review current scientific understanding, evidence, and logic to determine the best explanations or models.

**3** – Limited evidence that students review current scientific understanding, evidence, and logic to determine the best explanations or models.

**2** – Minimal evidence that students review current scientific understanding, evidence, and logic to determine the best explanations or models.

**1** – No evidence that students review current scientific understanding, evidence, and logic to determine the best explanations or models.

**5. “Recognize and analyze alternative explanations and models.”**

***A. Students are encouraged to consider alternative explanations for their conclusions or theories.***

**5** – Considerable evidence that students are encouraged to consider alternative explanations for their conclusions or theories.

**4** – Evidence that students are encouraged to consider alternative explanations for their conclusions or theories.

**3** – Limited evidence that students are encouraged to consider alternative explanations for their conclusions or theories.

**2** – Minimal evidence that students are encouraged to consider alternative explanations for their conclusions or theories.

**1** – No evidence that students are encouraged to consider alternative explanations for their conclusions or theories.

6. *“Communicate and defend a scientific argument.”*

A. *Students communicate about their investigation in writing.*

**5** – Considerable evidence that students communicate about their investigation in writing (summarizing data, using language appropriately, using diagrams and charts, explaining analysis)

**4** – Evidence that students communicate about their investigation in writing

**3** – Limited evidence that students communicate about their investigation in writing

**2** – Minimal evidence that students communicate about their investigation in writing

**1** – No evidence that students communicate about their investigation in writing

B. *Students defend their investigation and respond appropriately to criticism from peers or teachers.*

**5** – Considerable evidence that students consider and respond to criticism from peers and the teacher (peer review of investigations, feedback from teacher on investigation at various stages)

**4** – Evidence that students consider and respond to criticism from peers and the teacher.

**3** – Some evidence that students consider and respond to criticism from peers and the teacher.

**2** – Minimal evidence that students consider and respond to criticism from peers and the teacher.

**1** – No evidence that students consider and respond to criticism from peers and the teacher

C. *Students present their findings publicly.*

**5** – Considerable evidence that students present their investigation and findings publicly (e.g. an oral presentation or poster session).

**4** – Evidence that students present their investigation and findings publicly.

**3** – Some evidence that students present their investigation and findings publicly.

**2** – Minimal evidence that students present their investigation and findings publicly.

**1** – No evidence that students present their investigation and findings publicly.

## Appendix B: Interview Design and Protocol

### I. Introduction and Interview Agenda

#### Design:

- a. Introduction
  - i. Thanks for Participating
  - ii. Assure Confidentiality
  - iii. Permission to Audiotape
  
- b. Interview Agenda
  - i. General Information
  - ii. Past Scientific/Inquiry Experiences
  - iii. Questions about Portfolio and your Questionnaire
  - iv. Talk about inquiry and the AYA certification process.
  - v. Do you have any questions for me before we begin?

#### Protocol:

- a. Introduction
  - i. Thank you for participating in this study of *AYA Science* and inquiry.
  - ii. I would like to assure you that this conversation is confidential.  
Your name will not be included in any documents or reports.
  - iii. To assist with my data analysis I would like to ask your permission to audiotape our conversation. Will that be okay?
  
- b. Interview Agenda

There are four parts to the interview and it should take about 30-45 minutes.

  - i. The first part I'll collect some basic background information.
  - ii. Second, we'll talk about any past scientific inquiry experiences you have had.
  - iii. Afterward, we'll discuss your portfolio entry.
  - iv. Finally, we'll explore your ideas about inquiry and the NB certification process.
  - v. Any questions for me before we begin?

### II. Background Information

#### Design

- a. Background Information
  - i. Years teaching
  - ii. Urban, Suburban, Rural
  - iii. Current Classes Taught
  - iv. Education Background
  - v. Retake Status

Protocol

a. Background Information

I'd like to gather some background information now.

- i. How many years have you been teaching?
- ii. How would you describe your school, for example urban, suburban, or rural?
- iii. What classes are you currently teaching?
- iv. What is your education background?
- v. Did you achieve certification in the first year or did you need to retake any items? Which items did you retake?

III. Past Scientific, Inquiry Experience, and Professional Development

Design

a. Past Scientific and Inquiry Experience

- i. Length of experience.
- ii. Activities and role.
- iii. Learning gained from experience.
- iv. Influence on use of inquiry.

b. Professional Development

- i. Description of any professional development on inquiry.

Protocol

a. In this section we'll discuss your previous experiences with scientific research and inquiry.

- i. Please describe any previous experiences with scientific research or inquiry.
- ii. When did this take place? How long was the experience?
- iii. What did you do?
- iv. What did you learn?
- v. How did it influence your use of inquiry in the classroom?

b. Professional Development

- i. Could you briefly describe any professional development on inquiry you received?

IV. Portfolio Clarifications

- a. These will vary from person to person.

## V. *Official* and *Personal* Conception of Inquiry

### Design

#### a. *Official* Conception of Inquiry

- i. Conception of NB goals for portfolio entry two.
- ii. Student activity during inquiry.
- iii. Student learning during inquiry.
- iv. Teacher activity during inquiry.
- v. NB as a realistic vision of inquiry.
- vi. Discuss example from participant's portfolio.
- vii. Inquiry in other classes (not used in portfolio).

#### b. *Personal* Conception of Inquiry

- i. Description of inquiry in participant's classroom.
- ii. Classroom use of inquiry (frequency).
- iii. Facilitators and limiters of inquiry.
- iv. Goals for student learning from inquiry.
- v. Components of an inquiry activity.
- vi. Levels of inquiry.

### Protocol

#### a. *Official* Conception of Inquiry

In this section we'll discuss inquiry from the perspective of the National Board.

- i. What do you think the NB want to see in an inquiry activity for portfolio entry two, *Active Scientific Inquiry*?
- ii. What are the students doing in an inquiry activity?
- iii. What are they learning?
- iv. What is the teacher doing?
- v. Is what the NB is asking realistic on a regular basis?
- vi. In your portfolio you used your \_\_\_\_\_ class.
- vii. How do you think your other classes would do with inquiry? Why didn't you use them in your portfolio?

#### b. *Personal* Conception of Inquiry

Now let's talk about your own thoughts about inquiry.

- i. For you **personally**, how would you describe inquiry as you use in your classroom?
- ii. How often do you do inquiry in your classroom?

- iii. What enables your use of inquiry? What limits it?
- iv. What are some of the things you want students to learn from your inquiry activities?
- v. For you, what makes a lesson plan inquiry-based?
- vi. The NB states, “*Accomplished science teachers use the entire spectrum of inquiry, from teacher-guided inquiry through student-driven investigations.*” do you agree?

## VI. Changes in Conception of Inquiry Resulting from NB Certification Process & Entry 2

### Design

- i. Discuss *Reflection* section in portfolio entry and change in thinking about inquiry.
- ii. Important aspects of NB process and change.
- iii. Difference in teaching an inquiry lesson after NB process.
- iv. Essential aspects of NB process.
- v. Current use of inquiry in classroom.
- vi. Importance of content knowledge.
- vii. Participants’ comments.

### Protocol

Let’s wrap up with a discussion on how your thinking and teaching with inquiry is different as a result of the National Board certification process.

- i. In your portfolio entry you reflected upon \_\_\_\_\_ saying \_\_\_\_\_. Are there any other ways your thinking about inquiry has changed as a result of the NB process?
- ii. What was it about the NB process that expanded or altered your ideas about inquiry?
- iii. How would you teach a lesson differently after going as a result of working on your portfolio?
- iv. What did you find most valuable about the portfolio process for Entry 2: *Active Scientific Inquiry*?
- v. Do you do more inquiry related activities now?
- vi. How important is content knowledge for inquiry teaching?
- vii. Anything you would like to add about the NB process and inquiry teaching?

## VII. Wrap-Up

- a. Thanks you for participating.
- b. Any questions?

Appendix C: Institutional Review Board

**UNIVERSITY OF MARYLAND, COLLEGE PARK**  
**Institutional Review Board**

**Renewal Application for Research Involving Human Subjects**

**Name, Department and E-mail Address of Principal Investigator or Faculty Advisor:**  
J. Randy McGinnis, Department of Curriculum and Instruction (EDCI), [jmcginni@umd.edu](mailto:jmcginni@umd.edu)

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**Name, Department and E-mail Address of Co-Investigator(s) (if applicable):**

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**Name and E-mail Address of Student Investigator(s) (if applicable):**  
Wayne Breslyn, [wbreslyn@umd.edu](mailto:wbreslyn@umd.edu)

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**Project Title:**  
*Factors influencing National Board Certified Teachers' conceptions of inquiry.*

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**IRB Application Number:**  
# 07-0671

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**Date IRB Approval Expires:**  
December 13, 2008

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**Name and Address of Person to Receive the Approval Documents**  
Wayne Breslyn, 1916 Stanley Avenue, Rockville, MD 20851

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**SIGNATURE SECTION**

The Principal Investigator, Co-Investigator, and Student Investigator, in signing this renewal application, certify that they have conducted research in accordance with the IRB-approved protocol and that any consent forms used in connection with the project have been retained by the Principal Investigator unless otherwise indicated in this renewal application.

<b>Principal Investigator or Faculty Advisor</b>	<b>Date</b>
<b>Co-Investigator (if applicable)</b>	<b>Date</b>
<b>Student Investigator (if applicable)</b>	<b>Date</b>

**Who Must Renew?**

*Please indicate YES or NO for each of the following questions. This will determine whether you need to submit a renewal application.*

1. Will future research activities involve obtaining data through intervention or interaction with human subjects?

YES  NO

2. Will future research activities involve obtaining identifiable private information about living individuals? (Information is identifiable if subjects can be identified directly or through identifiers linked to the subjects.)

YES  NO

3. Will future research activities include analyzing **identifiable** private information about living individuals?

YES  NO

\*\* If you answered yes to any of these 3 questions, your research project requires a complete renewal application, including responses for Sections 1-14. The instructions for Sections 1-14 are included on the attached pages. Submit the original, signed renewal application and a copy of the renewal application to the IRB Office.

\*\* If you answered no for **all** of the above renewal questions, check here.

Your research does not require IRB continuing review. Submit only one signed copy of this 2 page form.

**PLEASE SEND RENEWAL APPLICATIONS TO:  
Campus Mailing Address- IRB Office, Room 2100, Lee Building, ZIP 5125**

## **Instructions for Completing the Renewal Application**

If you would like to continue obtaining data from human subjects or collecting or analyzing identifiable private information for the project indicated above, your project must be reviewed and approved by the Institutional Review Board (IRB) before the expiration date for the previous IRB approval.

All changes to the approved research, which have occurred since the initial review or the last annual renewal, must be reported in your renewal application. University IRB policy and federal guidelines prohibit research involving human subjects beyond the IRB approval expiration date.

### **When to Submit Renewal Applications**

In general, non-exempt projects are approved for one year. For non-exempt research that was approved through expedited review, a renewal application should be submitted no later than 30 days prior to the last day of that one-year approval period. (For example, an application approved on June 30, 2007 would expire on June 30, 2008; a renewal application will be due at the IRB no later than June 1, 2008.) For non-exempt research that was approved through full Board review, a renewal application should be submitted by the application deadline for the IRB meeting scheduled for the month before the application expires. Please check the IRB meeting dates that are posted on the IRB website (<http://www.umresearch.umd.edu/IRB/IRBdates.html>). Exempt projects are approved for three years. A renewal application should be submitted for an exempt project no later than 30 days prior to the last day of that three-year approval period. (For example, an application approved on June 30, 2005 would expire on June 30, 2008; a renewal application will be due at the IRB no later than June 1, 2008.) If you have any question about renewal applications, please contact the IRB Office at 301-405-7326 or [IRB@deans.umd.edu](mailto:IRB@deans.umd.edu).

### **Contents of the Renewal Application**

1. **Project Description:** Include a summary of the project. Please do not provide a cut and paste of your entire initial application. State whether additional subjects will be recruited, and if so, indicate the number of additional subjects to be recruited.

The purpose of this study will be to explore and develop a model of factors influencing National Board Certified Teachers' (NBCTs) conception of inquiry-based teaching and learning. The study will use a mixed methodology approach involving portfolio analysis, questionnaire, and interview. The central question is: What are the conceptions of inquiry held by NBCTs and how did these change as a result of their participation in the National Board (NB) certification process? Data will be collected through analysis of participants' NB portfolio entry *Active Scientific Inquiry* (a 13 page document written by the NBCT), a survey (the Views of Science-Technology-Society instrument), and interviews.

Participants will be protected through confidentiality of all tape recordings (code numbers) and names will be changed in transcripts. Participation will be voluntary and participants will sign a consent form if they agree to participate in the study. The consent form will explain the research project and the voluntary nature of their possible participation in the portfolio analysis, survey, and interviews. Participants will be informed that they may withdraw from the study at any time without penalty. A total of 12 additional subjects will be recruited for the project.

No additional subjects will be recruited.

**2. Investigator Information:** Please state whether the Principal Investigator has changed or whether additional investigators, including student investigators, have been added.

The Principal Investigator has not changed for the study. No additional investigators have been added to the project.

**3. Project History:** Indicate whether the project was undertaken and how many subjects have participated. Summarize what you have learned thus far.

Results from a pilot study involving three NBCTs (subdisciplines including biology, chemistry, physics) suggest that the portfolio analysis inventory is valid, reliable and sensitive to teachers' varying enactments and conceptions of inquiry. In addition, instruments used to analyze teachers' views of the nature of science and previous scientific research experiences were effective. Further, interviews provided support for the analysis of quantitative data and provided rich description of teachers' conceptions of inquiry. While the sample size was small (n=3) tentative insights include the influence of content knowledge on use of inquiry, the importance of establishing the context from which teachers discuss their conceptions of inquiry, and the National Board portfolio entry as a stimulus for inquiry teaching.

**4. Problem History:** Provide a summary of any adverse events and any unanticipated problems involving risks to subjects or others and any withdrawal of subjects from the research or complaints about the research since the last IRB review. If there have been problems, describe how they were handled.

There have been no adverse events involving risks to subjects. No subjects have withdrawn from the study and there have been no complaints since the last IRB review.

5. **Additional Information:** Provide a **summary** of any relevant literature and interim findings, state whether there are any multi-center trial reports (if so, attach the report(s) to this application), and include any other relevant information, especially information about risks associated with the research.

A summary of relevant literature is listed below. There are no multi-center trial reports. There are no changes to the risks associated with this research project.

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society (VOSTS)". *Science Education* 76(5), 477-91.

Lustick, D., & Sykes, G. (2006). National Board Certification as Professional Development: What Are Teachers Learning? *Education Policy Analysis Archives*, 14(5).

National Research Council. (1996). *National Science Education Standards*. Washington D.C.: National Academy Press.

Park, S. & Oliver, J. S. (2008). National Board Certification (NBC) as a catalyst for teachers' learning about teaching: The effects of the NBC process on candidate teachers' PCK development. *Journal of Research in Science Teaching* 45(7), 812-834.

Strauss, A. & Corbin, J. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (2<sup>nd</sup> ed.). Thousand Oaks, California: Sage Publications, Inc.

6. **Approved Changes:** Indicate whether the IRB has approved any modifications in recruiting procedures, study procedures, types or number of subjects, or the consent process **since the previous annual IRB approval**. If so, for each modification approved during the past year, please provide each of the following:

- a) the date of modification approval,
- b) a description of the change and reasons for the change, and
- c) an indication of whether the change led to a change in the consent form or an additional consent form; if so, describe the change or provide the new consent form.

An addendum was approved on May 20, 2008 From the Approval Memorandum:

“Approval of request, submitted to the IRB office on May 14, 2008, to (1) replace the Views of the Nature of Science Questionnaire (VNOS) with a modified version of the Views of Science-Technology-Society (VOSTS) instrument (2) use a revised consent form which includes changes to the “What will I be asked to do?” section.”

**7. Changes Implemented without IRB Approval:** Indicate whether there were any amendments or modifications since the last review that the IRB did not approve. Please explain why these changes were made prior to IRB approval.

No changes were implemented without IRB approval.

**8. Request for approval of new changes:** Indicate whether you are now requesting any modifications to recruiting procedures, study procedures, types or number of subjects, or the consent process **for which you have not yet received approval**. For each such change, please provide each of the following:

- a) a description of the change and reasons for the change,
- b) a copy of any relevant instruments, and
- c) an indication of whether the change will necessitate a change in the consent form or an additional consent form; if so, describe the change or provide the new consent form.

Specific Changes:

Less data will be collected from the participants. Specifically:

I will no longer be collecting portfolios from participants or asking participants to provide scores from their National Board assessment exercises.

Remove the text *“There are three parts to the study. First you will be asked to provide a copy of your portfolio entry for Active Scientific Inquiry and National Board content area Assessment Center scores to the researcher via email. Second, you will be asked to complete the Views of Science-Technology-Society (VOSTS) survey, a multiple choice survey instrument. Finally, you will be asked to be interviewed twice to clarify and extend portfolio analysis and VOSTS survey responses”* from the Informed Consent Document.

Replace with: *There are two parts to the study. First you will be asked to complete the Views of Science-Technology-Society (VOSTS) survey, a multiple choice survey instrument. Second, you will be asked to be interviewed twice to clarify VOSTS survey responses and discuss your ideas about teaching with inquiry.*

Rationale for Change and Risks to Subjects:

Participants will no longer be asked to provide their portfolio entry or National Board content area Assessment Center scores. As a result, references to the portfolios must be removed from the Informed Consent form. The change will not result in any additional risk to subjects.

Supporting Documents Attached:

Updated Consent Forms

**9. Data Location:** Indicate the specific location (building and room number) in which the official records of this research project will be retained. Please note that as per the University of Maryland policy on records retention and disposal, all human subject files, including work done by faculty, staff, and students, must be retained for a period of no less than 10 years after the completion of the research and can then be destroyed. Human subject files include IRB applications, approval notices, consent forms, and other related documents. For more information on records retention, go to: [http://www.dbs.umd.edu/records\\_forms/schedule.php](http://www.dbs.umd.edu/records_forms/schedule.php) (Faculty and Academic Records) or contact Michelle Solter Evers, Assistant to the Director of Business Services at 301.405.9277 or [mevers@mercury.umd.edu](mailto:mevers@mercury.umd.edu).

Information will not be recorded in such a manner that subjects can be identified, directly or through identifiers linked to subjects. The sources will not be publicly available. Written materials will disguise the identity of the subjects and the location of the person being interviewed. Participants will not be identified by name in the transcripts or research report (names will be changed).

Audio tapes and notes gathered during the course of the research will be stored by code number at the researcher's home and will be kept in a securely locked metal cabinet. Electronic copies of portfolios and transcripts will be stored on the researcher's computer. The researcher will be the only person with access to the data, both hard copies and electronic.

The study will take approximately twelve months. Data will be stored in a locked secure metal file cabinet and on a computer hard drive at the researcher's home for 10 years after the study (2019). Hard copy data will then be destroyed via a shredder and electronic data will be erased on the hard drive of the researcher's computer.

**10. Consent Forms:** Note how many consent forms you will be using. If more than one, provide a list. For each consent form, please provide:

- a) a stamped copy of the previously approved consent form (do not send the original stamped consent form), and
- b) a blank copy of the consent form for which approval is now sought (for a new approval stamp). If changes in the consent form are requested in this application, also submit a copy of the proposed consent form with proposed changes highlighted. **(Please do not use color to highlight your changes.)**

Only one consent form will be used for this research project. Attached is a copy of the previously approved consent form (from the May 20, 2008<sup>th</sup> addendum) and the current consent form with changes detailed item #8 above.

**11. Health Insurance Portability and Accountability Act (HIPAA):** Indicate whether any HIPAA compliance issues exist that were not previously reported to the IRB. For more information on HIPAA, go to: <http://www.hhs.gov/ocr/hipaa/>

There are no HIPAA compliance issues in their project.

**12. Conflict of Interest:** Indicate whether any conflict of interest issues exist that were not previously reported to the IRB. If there is a new conflict of interest issue, describe the potential conflict of interest, including how such a conflict would affect the level of risk to the study participants. Please consult the University of Maryland policy on conflict of interest as defined by the University of Maryland Policies and Procedures III-1.11 and II-3.10. The policy may be viewed at:

<http://www.usmh.usmd.edu/Leadership/BoardOfRegents/Bylaws/SectionIII/III111.html>

There are no conflicts of interest in this project.

**13. Funding Source/Research Support:** Provide the names of any organization, including Federal agencies, providing support (e.g. funding) for the research.

This project receives no funding or support.

**14. Checklist:** Double check to determine that all information required in the previous thirteen points is included. **Missing information may result in delayed IRB review.**

Project Description    
Investigator Information    
Project History    
Problem History    
Additional Information    
Approved Changes During Past Year    
Changes Implemented Without IRB Approval    
Request for Approval of New Changes    
Data Location    
Consent Forms and list of consent forms (if more than one)    
HIPAA    
Conflict of Interest    
Funding Source

**Note:** Please do not include an original or copy of your IRB approval letter with your renewal application.

## Staff member/Community member Informed Consent Form

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Initials \_\_\_\_\_ Date \_\_\_\_\_

### **CONSENT FORM**

<b>Project Title</b>	<i>Factors influencing National Board Certified Teachers' conceptions of inquiry.</i>
<b>Why is this research being done?</b>	<i>This is a research project being conducted by Wayne Breslyn at the University of Maryland, College Park. We are inviting you to participate in this research because you are a National Board Certified Teacher in the area of Science: Adolescent and Young Adulthood. The purpose of this study will be to explore and develop a model of National Board Certified Teachers' (NBCTs) conception of inquiry-based teaching and learning. Findings will help design more effective professional development for science teachers.</i>
<b>What will I be asked to do?</b>	<i>There are two parts to the study. First you will be asked to complete the Views of Science-Technology-Society (VOSTS) survey, a multiple choice survey instrument. Second, you will be asked to be interviewed twice to clarify VOSTS survey responses and discuss your ideas about teaching with inquiry. Interviews will be audiotaped. The research will take place via email and telephone. The duration of your involvement will be approximately two hours.</i>
<b>What about confidentiality?</b>	<i>We will do our best to keep your personal information confidential. To help protect your confidentiality: (1) your name will not be included on the surveys or other collected data; (2) a code will be placed on the survey and other collected data; (3) through the use of an identification key, the researcher will be able to link your survey to your identity; and (4) only the researcher will have access to the identification key. If we write a report or article about this research project, your identity will be protected to the maximum extent possible.</i> <i>Audiotapes of interviews will be kept in a locked metal file cabinet at the researcher's home, accessible only to the researcher. Tapes will be destroyed after six years.</i> <i>Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.</i>
<b>What are the risks of this research?</b>	<i>You may experience some level of stress through you participation in the interviews. You will be able to review transcripts to potentially reduce any anxiety about your comments in the interviews. You may withdraw from the study at any time without penalty.</i>

<b>Project Title</b>	<i>Factors influencing National Board Certified Teachers' conceptions of inquiry.</i>	
<b>What are the benefits of this research?</b>	<i>This research is not designed to help you personally, but the results may help the investigator learn more about science teaching and scientific inquiry. We hope that, in the future, other people might benefit from this study through improved understanding of science teaching.</i>	
<b>Do I have to be in this research? Can I stop participating at any time?</b>	<i>Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.</i>	
<b>What if I have questions?</b>	<p><i>This research is being conducted by Wayne Breslyn at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Dr. J. Randy McGinnis at: The University of Maryland, Science Teaching Center, Department of Curriculum &amp; Instruction Room, 2226 Benjamin, University of Maryland, College Park, Maryland 20742, 301405-6234 or <a href="mailto:jmcginni@umd.edu">jmcginni@umd.edu</a></i></p> <p><i>If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: <b>Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742;</b> (e-mail) <a href="mailto:irb@deans.umd.edu">irb@deans.umd.edu</a>; (telephone) 301-405-0678</i></p> <p><i>This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.</i></p>	
<b>Statement of Age of Subject and Consent</b>	<i>Your signature indicates that: you are at least 18 years of age;; the research has been explained to you; your questions have been answered; and you freely and voluntarily choose to participate in this research project.</i>	
<b>Project Title</b>	<i>Factors influencing National Board Certified Teachers' conceptions of inquiry.</i>	
<b>Signature and Date</b>	<b>NAME OF SUBJECT</b>	
	<b>SIGNATURE OF SUBJECT</b>	
	<b>DATE</b>	

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