A Comparison of Exemplary Biology, Chemistry, Earth Science, and Physics Teachers' Conceptions and Enactment of Inquiry

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Abstract

Teachers' use of inquiry has been studied largely without regard for the disciplines in which teachers practice. As a result, there is no theoretical understanding of the possible role of discipline in shaping teachers' conceptions and enactment of inquiry. In this mixed-methods study, conceptions and enactment of inquiry for 60 National Board Certified Science Teachers (NBCSTs) across the secondary science disciplines of biology, chemistry, earth science, and physics were investigated. A situated cognitive framework was used. Through the analysis of portfolio text (n=48) and participant interviews (n=12) themes emerged for participants' conceptions and enactment of inquiry. Findings suggested that disciplinary differences exist between NBCSTs' conceptions and enactment of inquiry. Further, individuals teaching in more than one discipline often held different conceptions of inquiry depending on the discipline in which they were teaching. A key implication was the critical importance of considering the discipline in understanding science teachers' varied conceptions and enactment of inquiry.

A Comparison of Exemplary Biology, Chemistry, Earth Science, and Physics Teachers' Conceptions and Enactment of Inquiry

Inquiry has been a longstanding area of sustained research and discussion in the science education community worldwide. Even with widespread agreement that inquiry should be a meaningful part of students' science education, the amount of inquiry present in science classrooms is limited (Abd-El-Khalick et al., 2004; Fenichel & Schweingruber, 2010; National Research Council, 1996). Barriers such as a lack of planning and instructional time, insufficient materials, and inadequate professional development have frequently been cited in the research literature. Further, competing definitions of inquiry can also act as a barrier to teachers' use of inquiry. While these barriers have received considerable attention, the influence of the science discipline on teachers' use of inquiry has been largely ignored. Research at the secondary departmental level (e.g., English, math, and science) has shown that disciplinary differences do exist and do influence instruction (Grossman & Stodolsky, 1995). However, there is little research on differences within science departments, and none on disciplinary differences in science teachers' conceptions and enactment of inquiry.

The purpose this study was to examine the fundamental issue of whether science discipline influences teachers' conceptions and enactment of inquiry. We used the framework of situated cognition to guide and interpret our investigation of how biology, chemistry, earth science, and physics teachers' conceptions and enactment of inquiry may be influenced by discipline. The situative perspective (Brown, Collins, & Duguid, 1989; Greeno, 1997; Putnam & Borko, 2000) has been found to be a productive framework for exploring contextually and socially rich settings such as those found in classrooms where teachers practice. Because our study focused on teachers' conceptions, enactment, and goals for inquiry teaching, both context and culture were important constructs to include in our analysis. We analyzed portfolios from 48 National Board Certified Science Teachers (NBCSTs) and participant interviews with 12 additional NBCSTs to identify and describe differences in teachers' conceptions and enactment of inquiry and to investigate the possible influence of the context of science discipline on teachers' use of inquiry.

Context of the Study

Exemplary teachers, in this study NBCSTs, were selected to study teachers' conceptions and enactment of inquiry. In the United States, the National Board for Professional Teaching Standards (NBPTS) offers an advanced teaching credential for K-12 teachers. Others have shown the use of exemplary teachers to be appropriate participants for research on science teaching (Friedrichsen & Dana, 2005; Fraser & Tobin, 1987). NBCSTs have been recognized as accomplished teachers through a widely respected, standards based, voluntary certification process. Because these teachers are established, many of the issues faced by preservice or new teachers, such as classroom management and content knowledge, are minimized. This, along with the rigorous certification process, allowed for a focused investigation of NBCTS' conceptions and enactment of inquiry.

NBCSTs are certified in one of four areas: biology, chemistry, earth science, or physics. This presents an opportunity to study teachers' conceptions and enactment of inquiry within the context of each science discipline. Requirements for NB portfolio construction are identical for biology, chemistry, earth science, and physics certificate areas, making valid comparisons between disciplines possible. In addition, to triangulate findings from the analysis of portfolios, additional NBCSTs were interviewed about their use of inquiry in the classroom context. Therefore the sample consists of two tiers: a large sample made up of 48 NBCTs for portfolio analysis and a smaller group of 12 NBCSTs for focal studies.

Recent research showed that the NB certification process results in gains in teachers' understanding of inquiry (Lustick & Sykes, 2006; Park & Oliver, 2008). The comprehensive nature of the NB certification process, including an entire portfolio entry documenting the teaching of an inquiry lesson or unit, provided access to data that would otherwise take considerable time and resources to obtain. In addition to a sizeable sample, NB portfolios provide:

- 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* (NBPTS, 2008).
- Descriptive, analytical, and reflective commentary by teachers (13 pages) about their inquiry teaching based on video of themselves and students engaging in inquiry.

For the portfolio entry, *Active Scientific Inquiry*, NB provided guidelines, a rubric on how the entry was assessed, and relevant NB standards. These documents provided NBCSTs with a structure as they planned and composed their portfolio. As a result the portfolio entries analyzed in this study tended to follow a similar format. That included sections on planning the inquiry lesson or unit and the goals of instruction. In addition, science teachers included a description of three video segments consisting of students planning the investigation, collecting data, and analyzing and interpreting their results. The final section featured teachers' reflections upon their inquiry lesson. The format and topics addressed ensured consistency across participants' portfolio entries and supported consistent portfolio analysis for this study.

In constructing their portfolios, the science 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 or weeks. Based on the depth of the data, the portfolio analysis instrument was believed by the researchers to provide a valid and reliable measure of teachers' conceptions and enactment of inquiry.

NBCSTs represent an important and growing source of influence and leadership in schools which could play an important role in reform efforts in science education. An understanding of teachers' conceptions and enactment of inquiry is central to reform-oriented curricular and professional development efforts.

Rationale and Research Questions

Professional development leads to changes in teachers' conceptions about inquiry (Luft, 2001; Lustick & Sykes, 2006; Park & Oliver, 2008; Supovitz & Turner, 2000). Still, limited time, insufficient materials, 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 as effectively as possible. In order to do so, knowledge of how the context of discipline influences teaching with inquiry is crucial.

The study centered on two primary research questions:

1. *How does exemplary secondary science teachers' discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?*
2. *How does teaching in more than one science discipline influence exemplary secondary science teachers' conceptions and enactment of inquiry in each of those disciplines?*

At the departmental level in secondary schools (e.g., English, math, and science) research has shown that disciplinary differences exist and influence instruction (Grossman & Stodolsky, 1995). In the current study it was thought that such differences also may exist between the disciplines of biology, chemistry, earth science, and physics within science departments.

Disciplinary differences can be found in the realm of professional scientific inquiry. Knorr-Cetina (1999) studied a group of molecular biologists studying protein synthesis and a group of high-energy physicists working with particle colliders. Molecular biologists were found to be more experiential and individualistic. In contrast, high-energy physicists worked in larger collaborative groups, focused more on semiological aspects of inquiry, and placed less emphasis on the empirical. While there are large differences between inquiry in the secondary classroom and professional laboratories, it does suggest that disciplinary differences may also be present at the secondary level.

According to Schwab (1968) some fields consist of more extensive knowledge and tend more towards fundamental principles than other fields. This can be seen in physics where tasks tend to be well structured with more readily verifiable knowledge. As a result, one reason well-defined domains, like physics, have been the subject of numerous studies about student misconceptions is because a student's response can be verified as correct (Alexander, 1992). We believe that it is likely differences also exist in teaching with inquiry across science disciplines.

Initially, research centered upon identifying and describing disciplinary differences in teachers' conceptions and enactment of inquiry. During the study, unanticipated findings arose about teachers' multiple conceptions and enactments of inquiry. Due to the potential importance of these findings, teachers' multiple conceptions of inquiry became an additional focus of the study.

Theoretical Framework

Developing an understanding of the role of discipline in teaching with inquiry requires a theoretical framework to manage both the complex nature of teaching and the many contextual factors present in the classroom environment. In this study we used situated cognition as our theoretical framework because it is sensitive to the contextual and cultural aspects of teaching. Previous research in science education has found the situative perspective to be a valuable tool for studying teaching (Crawford, 2007; Friedrichsen & Dana, 2005; Windschitl, 2004) and professional development (Borko, 2004).

The situative perspective posits that knowledge cannot be separated from the context in which it occurs (Brown, Collins, & Duguid, 1989). Based on this framework, in this study we expected that the context of discipline would have a strong influence on teaching with inquiry. Although discipline is the primary interest, other contextual factors such as curriculum and preservice experiences also need to be taken into account, as they are relevant contextual features. The importance of adopting a situative perspective to study teachers' ideas about science in the pedagogological context where they occur was shown in a study of Mexican primary school teachers' understanding of the nature of science by Guerra-Ramos, Ryder, & Leach (2010). They argued that the situative perspective allowed them to take into account the context in which participants' ideas about the nature of science were located. Similar to the work of Guerra-Ramos et al., setting was an essential component for us to consider in our study that examines possible connections between conceptions of inquiry and the discipline of the science teacher.

In our study, the specific context of discipline was investigated. Conceptions were thought of as growing out of beliefs about teaching and learning and prior exposure to inquiry such as in preservice training, professional development, and past experiences doing inquiry.

Situated cognition offered a framework for interpreting that complexity. Informed by a situative framework, this study centered upon two key constructs: inquiry and teachers' conceptions.

Inquiry

Over the past several decades a rich literature on inquiry, the nature of science, and teachers' conceptions has developed (Brickhouse, 1990; Keys & Bryan, 2001; McGinnis, Parker, & Graeber, 2004). Despite this body of research, our current theoretical understanding of teachers' conceptions and enactment of inquiry does not consider the discipline in which they teach. Therefore, our study sought to understand the possible relationship between the disciplines of biology, chemistry, earth science, and physics and teachers' conceptions and enactment of inquiry.

Inquiry is defined in many different ways in the literature and by science teachers. We needed to decide upon a definition that was useful to guide the design of the study. 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). Confusion about the meaning of inquiry may in part have a negative influence on its use in the classroom. DeBoer (2004) stated

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

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., Krajcik, Blumenfeld, Marx, & Soloway, 1994), and "minds-on" inquiry (Duschl & Gitomer, 1997). For this study, we decided that the *National Science Education Standards* offered a useful vision of inquiry. The standards were developed over several years with extensive 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, we believed that they could be considered a consensus view of inquiry for K-12 science education. Consequently, the definition of inquiry presented in the *Standards* was used to conceptualize the design of the study and develop instrumentation.

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 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 engage in their practices of studying the natural world.

In the *National Science Education Standards* (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. In this study, the NB portfolio entry, *Active Scientific Inquiry*, provided data on teachers' goals 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 guidelines or scoring rubric, 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, we hold the belief that they interact to form teachers' visions of inquiry. In this study, participant interviews were used to explore this interaction and provide additional data about teachers' conceptions of inquiry.

Teachers' Conceptions and Enactment of Inquiry

A plethora of research has been conducted on inquiry and teacher beliefs (Brickhouse, 1990; Kane, Sandretto, & Heath, 2002; Nespor, 1987; Pajares, 1992) and conceptions (Lederman, et al., 2002; Lotter, Harwood, & Bonner, 2007; Wallace & Kang, 2004) about inquiry and the nature of science. Still, 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."*

One inadequately understood aspect is the influence of discipline on teachers' conceptions of inquiry. In this study participants' conceptions were defined as mental images of what they termed *inquiry*. Conceptions are seen as growing out of beliefs about teaching and learning and past experiences with inquiry such as preservice training, professional development, and past experiences doing inquiry.

In an in-depth study of three secondary science teachers, Lotter, Harwood, and Bonner (2007) constructed a model made up of a limited number of core conceptions. Their model consisted of teachers' knowledge and beliefs about science, the learning process, students, and effective instruction. Similarly, the current study sought to understand an additional dimension influencing teachers' conceptions of inquiry: the role of discipline.

Little attention has been given to the conceptions of inquiry held by teachers with classes in more than one discipline, however. Several studies have found that teachers can hold varying conceptions depending on the context in which they teach. Wallace and Kang (2004) observed 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 that 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.

Studying the science teaching orientations of four highly regarded biology teachers, Friedrichsen and Dana (2005) observed that teachers' orientations differed depending on the course being taught. They reported that science teaching orientations were complex and included affective domain goals, general schooling goals, as well as subject matter goals. From these findings, we wondered whether science teachers who taught in different disciplinary contexts might hold different conceptions and enactment of inquiry. Furthermore, we wondered if science teachers who taught more than one discipline could hold different conceptions and enactments of inquiry in each disciplinary context.

Design of Study

We used a coordinated mixed-methods design in this study (Greene, 2001). According to Greene, different methods are planned and implemented in a generally separate manner. In this study the *PII* analysis, the analysis of portfolio text, and participant interviews were conducted sequentially and could be considered to be individual activities. While each was informed by previous phase of the study, the methods were not mixed until overall inferences were being made. In this sense, each method in the coordinated design contributed to triangulation, complementarity, and expansion of the influence of discipline on teaching with inquiry. Table 1 provides a summary of the study workflow.

Table 1
Study Workflow

Phase	Description	Sample	Purpose	Analysis
I	Statistical Analysis of Portfolios	48 portfolios from 2007 NBCSTs	Establish existence of disciplinary differences on specific aspects of inquiry.	ANOVA based on data from *Portfolio Inventory Instrument* (*PII*)
II	Text Analysis of Portfolios	48 portfolios from 2007 NBCSTs	Define emerging themes for goals and enactment of inquiry.	Inductive analysis of portfolio text for goals and enactment of inquiry.
III	Analysis of Participant Interviews	12 NBCSTs from 2008	Build on findings from Phase 1 & 2 with data outside context of NB portfolios.	Inductive analysis interview text on goals, enactment, and general conception of inquiry.

As described in Table 1, in Phase I portfolio entries for 48 NBCSTs achieving certification in 2007 were analyzed using a researcher-crafted instrument. During Phase II text from portfolios was analyzed for emerging themes. Based on findings from portfolio analysis, 12 NBCSTs achieving certification in 2008 were interviewed in Phase III.

Participants

Participants were selected from a national population of NBCSTs who achieved certification in 2007 and 2008. All participants were certified by the NB in the *Adolescent and Young Adult: Science* (*AYA Science*) area prior to the study. In addition, each participant 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 certification process. As a way to answer our research questions, we selected our participants by using a stratified random selection procedure based on the science discipline in which they were certified (biology, chemistry, earth science, or physics).

NBCSTs have successfully completed a rigorous and uniform professional development experience.[1] The certification process is time consuming and only about 40 percent of candidates achieve certification the first year; about 65 percent do so by the end of the three-year cycle (NBPTS, 2009). In addition, teachers spend from 200 to 400 hours to complete their portfolio. Of the four portfolio entries required for *AYA Science* certification, the entry *Active Scientific Inquiry* was of interest in this study. All NBCSTs received identical portfolio instructions, standards, and rubrics for the portfolio construction process. Because of this substantial and uniform treatment, NBCSTs are an ideal population for study.

Two groups of NBCSTs were selected for the study. Table 2 details the disciplines of participants in each group organized by NB certification area.

Table 2

Participants

	Biology	Chemistry	Earth Science	Physics	Total
Pilot Study	1	1	-	1	3
Phase I & II: Portfolio Analysis	12	13	10	13	48
Phase III: Participant Interviews	3	3	3	3	12

Two Earth Science portfolios were incorrectly labeled resulting in an unequal number of portfolios for analysis.

Phase I: Statistical Analysis of Portfolios

The first phase of the main study consisted of analysis of the NB portfolio entry, *Active Scientific Inquiry*, for each of the 48 NBCSTs. Participants were selected using stratified random sampling from a national population of 282 NBCSTS achieving certification in 2007.

Portfolios were read a total of four times by the first author and teachers' enactment of inquiry was rated using the *Portfolio Inventory Instrument* (*PII*). Tentative findings were shared in a regular and ongoing manner with the second author, and when differences of interpretation arose (infrequent and minor) negotiation ensured to arrive at a shared view.

Portfolio Inventory Instrument (PII).

Each portfolio was analyzed using a researcher crafted inventory. 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 determined 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.

The *PII* was designed to measure teachers' enactment of inquiry as described in their written commentary for the portfolio entry: *Active Scientific Inquiry*. Each item of the *PII* was developed based on the description of the *Abilities Necessary to do Scientific Inquiry* in the National Science Education Standards (NRC, 1996, pp. 175-176) for grades nine through twelve. Table 3 provides a list of *PII* items. Each item number corresponds to the headings in NSES for *Abilities Necessary to do Scientific Inquiry*.

Table 3

Description of PII Items

Item	Description
1A	Degree to which teacher supports students' efforts to develop a research question.
1B	Degree to which students choose own question to investigate.
2A	Degree to which students engage in designing their scientific investigations.
2B	Conducting scientific investigations.
3A	Evidence that teacher encourages and supports the use of technology in students' investigations.

3B	Evidence that teacher encourages and supports use of mathematics in students' investigations, where appropriate.
4A	Students' work culminates in an explanation or model of the phenomena (physical or math).
4B	Students review current scientific understanding, evidence, and logic to determine the best explanations or models.
5A	Students are encouraged to consider alternative explanations for their conclusions or theories.
6A	Students communicate about their investigation in writing.
6B	Students defend their investigation and respond appropriately to criticism from peers or teachers.
6C	Students present their presentation publicly.
7A	Students develop and test a hypothesis in their investigation.

Since the instrument was based on the *NSES,* a consensus document developed by science educators and experts in the USA, it is expected to have a high degree of face and content validity. While there are other possible items that could be considered inquiry, the decision to limit the *PII* based on the NSES was made to allow for a consistent and manageable instrument.

We consulted with a university statistician before setting our sample size (N=48) to ensure that we meet the criteria for use of the ANOVA. For a sample size of 48 participants we learned it would be necessary to have 12 in each of the four disciplines 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. Power analysis was conducted with G*Power 3 power analysis software (Faul, Erdfelder, Lang, & Buchner, 2007). 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.

First, portfolios were read and scored using the *PII* developed and tested in the pilot study. Each item in the inventory was rated from one to five. 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. These 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. After the first reading was completed a refinement of the *PII* was conducted to address any ambiguities within the instrumentation.

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, clarifications were made to the *PII*. During the third reading a similar process was conducted, resulting in further refinement of the data collection process.

A fourth reading was conducted by the first author and then shared for comment with the second author to generate the final scores that were used in the statistical analysis. Afterwards, ten portfolios were selected at random and scored. The scores were compared to corresponding scores from the fourth reading. An Intraclass Correlation Coefficient was conducted to document consistency in scoring portfolios.

Phase II: Portfolio text analysis for emerging themes.

Portfolios were also read a total of four times by the first author and coded in an analytical inductive manner (Charmaz, 2005) to identify and describe emerging themes about teachers' goals and enactment of inquiry. Starting with initial codes suggested by the pilot study, four readings of each portfolio were used to identify analytical categories which were then refined through an iterative process over a three month period. The second author was appraised by the first author at multiple points during the coding process. Portfolios from Phase I were also used in Phase II.

As coding progressed by the researchers, a set of themes emerged for teachers' goals and enactment of inquiry. In about half of the portfolios, teachers could be placed in more than one theme. Therefore, after considerable debate and discussion between the researchers, the decision was made to assign participants a primary and secondary theme based upon the degree to which the theme was present in portfolio text.

An example of the coding process for an inquiry lesson about muscle fatigue is provided as a way to illustrate how decisions were made in assigning participants to categories. Paul, a NB certified biology teacher, prepared his portfolio entry based on an inquiry lesson in his anatomy and physiology course. While similar to other portfolios analyzed, his portfolio was particularly instructive as it contained both a primary and secondary goal for the inquiry lesson. Therefore the analysis sought evidence to decide between the competing primary themes.

In the initial reading, portfolio text was underlined and assigned preliminary codes related to teachers' goals and enactment of inquiry. Codes relating to inquiry were identified for the entire set of portfolios. Examples include *Students as Scientists*, *Conducting Scientific Investigations*, *Problem Solving*, *Critical Thinking*, *Modeling*, *Science Content Knowledge*, and *Lab Skills*. For example, Paul's statement "*I feel this is important because this allows students to be scientists.*" was coded as *Students as Scientists*. The code *Science Content Knowledge* was assigned to the text "*…justify how carbon dioxide production relates to muscle fatigue…"* as it related to biology content knowledge.

In the second reading, codes were refined and collapsed into larger, more inclusive themes. For Paul, two themes found throughout his portfolio were *Conducting Scientific Investigations* and *Science Content Knowledge*. These two themes were underscored in his goal to "*provide experiences for students to build this important concept, they design, conduct, and analyze a controlled experiment that tests the effects of human muscle fatigue.*" This goal encompassed both the biology content of muscle fatigue and students designing and conducting scientific investigations. Text throughout his portfolio supported both themes although the theme of *Conducting Scientific Investigations* was more frequent.

During the third reading, categories were further consolidated and an initial primary theme was assigned to each portfolio. Five primary themes resulted: *Students Conducting Scientific Investigations*, *Science Content Knowledge*, *Modeling*, *Problem Solving*, and *Other*. At this point in coding, Paul's goals and enactment of inquiry were most strongly aligned with the theme of *Students Conducting Scientific Investigations*. Throughout the text there were references by Paul to his students forming a hypothesis, designing and conducting controlled experiments, manipulating variables, reflecting on possible errors, and coming to conclusions. In contrast, science content knowledge was mentioned less frequently. This may be because, as noted in his portfolio, Paul emphasized content knowledge prior to the inquiry lesson. Therefore, while science content knowledge was important to him, he placed it outside of the inquiry experience. Instead, inquiry was centered on students learning to conduct scientific investigations.

A fourth and final reading of portfolios was conducted and primary and secondary themes were assigned to each of the 48 portfolios. At the conclusion of the analysis all 48 portfolios were placed in one of five categories as the primary theme for their goals and enactment of inquiry. When present, secondary themes were also assigned. For Paul, the theme *Students Conducting Scientific Investigations* was assigned as the primary theme. *Science Content Knowledge* was assigned as the secondary theme.

Phase III: Participant Interviews

After Phase I and II of the study were complete, a second group of NBCSTs were recruited to serve as more in-depth focal case studies. Semi-structured interviews took place by phone with e-mail for follow-up questions and clarification (see Appendix A for the interview protocol). A second interview was conducted when necessary to clarify earlier responses. Prior to the interviews, as a way to enhance data collection, the participants received an e-mail with an outline of topics that would be discussed in the interview. Table 4 provides background information for each participant.

Table 4

Participants

Participant	NB Cert	Years	Bachelors	Masters	Context
Amy	Biology	5	Biology	None	Suburb/Urban
Scott	Biology	9	Biology (Chem minor)	Teaching	Suburban
Tom	Biology	10	Biology	Curric & Inst	Rural
Allen	Chemistry	11	Biology (Chem minor)	Teaching	Suburban
Anita	Chemistry	5	Biology	Teaching	Suburban
Peter	Chemistry	11	Biology	Curric & Inst	Rural
Cathy	Earth Sci	8	Laboratory Medicine	Science	Suburban
Donna	Earth Sci	14	Earth Science	Science Ed	Rural
Sarah	Earth Sci	8	No data.	Earth Science	Rural
Carl	Physics	6	Physics	Teaching	Suburban
Diane	Physics	30	Biology and Education*	Science Ed	Suburban
Jane	Physics	8	Biology	Biology Ed	Urban

* Diane also held minors in chemistry and physics.

A central component of the interview was a discussion about an inquiry lesson or unit of participants' choosing. For participants teaching in more than one discipline, a lesson for each discipline was discussed. After first exploring participants' general conception of and goals for inquiry, a specific inquiry lesson plan or unit they had taught in their own classroom was discussed in detail. This included a detailed description of the goals for the lesson, what the students were asked to do, and probing questions to clarify and elicit further details when appropriate. The interview concluded with participants being given the opportunity to comment on inquiry and the NB certification process.

The interviews were transcribed and analyzed immediately, allowing data collection and analysis to build upon each other in a grounded theory fashion. Transcription and analysis were used to inform future participant interviews and make modifications to the interview protocol where necessary to enhance the richness of the data collection.

Results/Findings

Results are presented by disciplinary area to address the primary research question "*How does exemplary secondary science teachers' discipline (biology, chemistry, earth science, or physics) influence their conceptions, enactment, and goals for inquiry-based teaching and learning?* Data from the *PII*, inductive analysis of portfolio text, and findings from participant interviews are presented for each discipline. Although participant interviews were conducted in the final stages of the study, they are presented first within each discipline to establish emerging themes and allow for a more concise presentation.

Biology

Portfolio analysis and participant interviews revealed that biology teachers in this study tended to approach and enact inquiry with an emphasis on the theme *Students Conducting Scientific Investigations* (*SCSI).* For the theme *SCSI*, investigations reported by the participants typically consisted of students asking a question, generating a hypothesis or testable question, 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. Teaching students about the process of scientific investigations is the central goal for *SCSI*.

Learning science content could also take place but it was not the primary purpose of inquiry-based instruction.

Participant Interviews

In addition to the three teachers with NB certification in biology, three additional teachers certified in other areas also taught biology courses. As a result data for six teachers were available for biology. Based on participant interviews, four of the six teachers were placed in the category of *SCSI*. Two were placed in *Content*.

Under the theme of *SCSI*, students often began with a question or hypothesis. For example "*My goal was for them to first of all, take a look at the question, the hypothesis…" (Tom, NB Certification: Biology)" or "I wanted them to melt down their gel and somehow change something, some factor in each of the tubes." (Scott, NB Certification Biology).*

As was the case with most participants in this study, the science teachers held students 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 stated:

> *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.*

One possible reason for biology participants tending towards *SCSI* is due to the complexity they perceive in conducting inquiry in biology. For example, Tom, a biology and physics teacher believed that inquiry was easier to do in physics classes.

I suppose because there just so many more activities that I'm used to using or able to use in physics. ... 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 steps to get through them and it's more difficult to modify those.

Out of four teachers teaching biology and another discipline, three perceived inquiry to be more difficult in biology. It may be that the structure of the theme *SCSI* aids in managing the complexity. This assertion is supported by the length of time spent on inquiry. Of the biology teachers interviewed four of the six described investigations that took over one week. In contrast, for physics only one of four participants described longer-term activities. It may be that more time is required to do inquiry in biology due to the complexity of the investigations.

Table 5 provides a summary of biology participants interviewed. The first column lists each participant and their NB certificate area. In the second column the classes they 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 words 'inquiry teaching'*?" This provides participants' general view of inquiry apart from the context of a specific lesson plan or discipline.

Table 5

Participants' Conception, Enactment, Goals for Inquiry in Biology Participants

Participant (Cert. Area)	Teaching (2008-09)	General Conception	Enactment	Goals	Overall Theme
Allen (Chemistry)	AP Biology, Chemistry	"*creation of a worthwhile problem which the students are capable of solving*"	SCSI	SCSI	SCSI
Amy (Biology)	Biology	"*students learn through discovery*"	Content	SCSI / real world connection	Content

Cathy (Earth Science)	Astronomy, Pre-AP Biology, Chemistry	*"I just think, thinking."*	SCSI	Content & Student Engagement	SCSI
Jane (Physics)	Biology, Physics	*"so they're coming up with a hypothesis, coming up with a purpose."*	Content	Content	Content
Scott (Biology)	Biology	"*students … should be able to plan, data collect, and do data analysis…"*	SCSI	SCSI	SCSI
Tom (Biology)	Biology, Physics	*"discover scientific facts or information"* *"makes the point concrete"*	SCSI	SCSI	SCSI

Our 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 was influential in deciding which theme best represents participants' conception of inquiry for that discipline. Participants' stated goals for the specific lesson plan are presented in the "Goals" column.

The last column, "Theme," is our 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 Table 5, were used to generate themes.

Although *SCSI* was more common among participants, there were two instances classified as *Content*. Jane approached inquiry as *Content*, although her general conception of inquiry was similar to *SCSI*. With Jane, who recently shifted to teaching biology, a lack of experience with the discipline may have led her to focus on content knowledge.

Amy, a ninth grade biology teacher, believed that middle school science classes did little to prepare students for thinking about and doing scientific activities. As a result, she found it took 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.*

One possibility is that her students' lack of previous experience with inquiry led her to focus on biology content knowledge.

Portfolio Text Analysis

Similar to participant interviews, the analysis of portfolio text for biology teachers predominantly followed the theme *SCSI* as shown in Table 6. Only one participant was categorized under *Content*. An additional participant who focused on technical lab procedures was classified as *Other*.

Table 6

Primary Goals and Enactment of Inquiry for Biology Participants

Discipline	SCSI*	Content	Modeling	Problem Solving	Other
Biology	10 (83%)	1 (8%)	--	--	1 (8%)

*Students Conducting Scientific Investigations

Curricula, student ability, geographic context, and grade level did not explain the trend found in the data. Participants represented a range of curricula (one AP, two IB, six general biology, two anatomy/physiology, and one forensics/bioethics), student abilities (seven high, two average, and three low), and geographical contexts (two rural, four suburban, two urban, four no data). There was also a range of grade levels (five 9th, seven 10th, eight 11th, seven 12th) with many classes having two or more grade levels present. These contextual factors did not appear to influence teaching with inquiry with 83% of participants being categorized as *SCSI*.

PII Analysis

PII analysis revealed that biology teachers were more likely to offer students a choice of the question they would investigate than all other disciplines and were more likely to support students' questioning than chemistry and physics participants. In addition, biology teachers were also more likely to discuss the use of a hypothesis in their portfolios than chemistry or physics teachers. Significant results are presented in here.

An analysis of variance found a significant difference, $F(3,44) = 4.31$, $p = .010$, between groups for teachers' 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 ($M = 1.38$, $SD = 0.65$).

An analysis of variance found 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 ($M = 1.38$, $SD = 0.65$).

An analysis of variance found 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.

Our *PII* analysis resulted in a finding that was consistent with the finding from our portfolio text analysis and participant interviews. That is, most biology teachers in our study approached inquiry with an emphasis on the actual process of the investigation. This is seen in the emphasis on students developing their own question or generating a hypothesis, something rarely mentioned in chemistry and physics.

Summary

Together the three data sources support the notion that biology teachers are more likely to approach and enact inquiry under the theme of *SCSI*. Data from participant interviews suggested that biology was more challenging for the teachers to teach with inquiry. As a result, it is plausible to conjecture that approaching inquiry as a *SCSI* theme was necessary to provide them structure in their practices.

Chemistry

Chemistry teachers in our study were more likely to be categorized under the theme of *Content* although *SCSI* was also a frequent theme. In both participant interviews and the analysis of portfolio text the theme *Content* was found to be about twice as frequent as *SCSI*.

For the theme *Content*, the acquisition of science content knowledge was emphasized as the primary role of inquiry. While students could develop their own procedures, select variables to investigate, or work with mathematical equations, the predominant goal by the teachers was the development of subject specific content knowledge rather than on the process of conducting scientific investigations.

Participant Interviews

As shown in Table 7 of the four participants interviewed, two were classified under the theme *Content*. One was placed in both *Content* and *SCSI*. The other was classified as *SCSI*.

Table 7

Participants' Conception, Enactment, Goals for Inquiry for Chemistry Participants

Participant (Cert. Area)	Teaching (2008-09)	General Conception	Enactment	Goals	Overall Theme
Peter (Chemistry)	IB Chemistry	"*for IB anyway, they have to do a series of planning or design labs"*	SCSI	Content	SCSI & Content
Allen (Chemistry)	Chemistry	"*creation of a worthwhile problem which the students are capable of solving"*	SCSI	SCSI	SCSI
Anita (Chemistry)	Chemistry	*"trying to figure a problem out"* *"more likely to be remembered"*	Content	Content & Problem Solving	Content
Cathy (Earth Science)	Chemistry	*"I just think, thinking."*	Content	Insufficient data	Content

In her interview Anita (NB Certification: Chemistry) chose to discuss an inquiry lesson where students use Alka-Seltzer tablets to study rates of chemical reactions. Her description of the inquiry lesson doesn't consist of the highly structured scientific investigation found for most biology teachers. There is no mention of a hypothesis and manipulating variables, for example. Instead the emphasis is on students gaining knowledge about the rates of chemical reactions. She states:

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 content without the need for direct instruction. The focus is on the content knowledge. In this case the lesson serves as a substitute for more traditional instruction on chemistry content knowledge. In her description of an inquiry lesson in her AP chemistry class there is a similar emphasis. She explains "*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 Anita, like many chemistry teachers in this study, inquiry is primarily a means for students to develop content knowledge.

Peter represents a case where an external curriculum was influential in his use of inquiry. As a result, he was challenging for us to classify in our analysis system. His description of inquiry initially appears to be *SCSI*. He states:

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.

While his description of inquiry fits the theme of *SCSI* he later indicates the importance of the chemistry content knowledge gained through inquiry. 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.

> *Whenever 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.*

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.

> *Mainly I want them to have 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.*

Because both trends were found throughout the interview Peter was classified both *SCSI* and *Content*.

In contrast to Anita and Peter, Allen approaches inquiry as *SCSI*. Allen conceptualizes inquiry as consisting of a three-day cycle similar to how scientists conduct investigations. 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 are 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.

> *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, Allen has a very structured approach that guides his planning and teaching with inquiry. As a result, was categorized as *SCSI*.

Table 7 provides a summary of the themes found in participant interviews.

Portfolio Text Analysis

Table 8 shows eight of the thirteen chemistry participants were categorized under the theme *Content*. Four participants were placed under *SCSI* and one as *Other*. The portfolio in the *Other* category emphasized critical thinking.

Table 8

Primary Goals and Enactment of Inquiry for Chemistry Participants

Discipline	SCSI	Content	Modeling	Problem Solving	Other
Chemistry	4 (31%)	8 (62%)	--	--	1 (8%)

Participants represented a range of curricula (four AP, nine general chemistry), student abilities (eight high, four average, and one low), and geographical contexts (four rural, six suburban, two urban, one no data). There was also a range of grade levels (two 9^{th}, five 10^{th}, eight 11^{th}, nine 12^{th}) with many classes having two or more grade levels present.

No trends were found based on student ability or geographic context. Chemistry did have the most AP courses of all disciplines analyzed. Of the four AP teachers, three were classified as *Content* and one as *Other,* following the general trend for the discipline.

PII Analysis

The *PII* was developed to detect differences in teachers' enactment of inquiry. As a result, data on content knowledge was not collected. Since the chemistry teachers in this study tended to enact inquiry with an emphasis on content knowledge they are less likely to enact items measured with the *PII*. In this case, chemistry teachers were less likely than biology teachers to allow students choice of questions to investigation, support students' use of questioning, and discuss the use of hypotheses. In addition, chemistry teachers were less likely than physics teachers to use mathematics and modeling as part of teaching with inquiry.

Summary

Findings for the chemistry teachers in our sample consistently were categorized under the theme of *Content*. This is the case even though four participants taught within the structure of the AP program. Thus our findings suggest that curriculum may not be a primary influence in chemistry teachers' use of inquiry.

Earth Science

Similar to biology, earth science participants also tended to fall under the theme of *SCSI*. The theme *Content* was also present in one participant interview and one portfolio. Earth science differed from other disciplines in the age and abilities of students. Students were more likely to be in ninth grade and fewer participants described their classes as high ability.

Participant Interviews

Two of the three earth science participants interviewed were classified as *SCSI* and one was classified as *Content*. Donna provided an exemplar of earth science teachers' use of inquiry. In her interview she described an investigation about factors influencing 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 to 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.*

For Donna inquiry in earth science centered on teaching students how to conduct scientific investigations. This started with students deciding what variables they wanted to test, forming a hypothesis, manipulating variables, coming to a conclusion, and presenting their findings. The focus was on the process of the investigation with little mention of the science content.

Sarah also was classified as *SCSI* although high stakes testing influenced her use of inquiry. She cited the pressures of testing, stating that "*they have a high stakes state test to pass at the end of my course.*" Even so, her general conception, enactment, and goals for inquiry focused on *SCSI*, indicating that external requirements do not always lead to teachers focusing on content knowledge. Generalizing her goals to other inquiry lessons, Sarah states:

> *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.*

In contrast, Cathy, who taught astronomy, was classified under the theme *Content* based on her lesson about electromagnetic radiation. Describing her lesson she said:

> *… 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.*

For Cathy, students' understanding of light and energy was the most important outcome for her inquiry lesson. 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. Another possibility is the age of students. Both Donna and Sarah taught primarily ninth grade students whereas Cathy taught 11th and 12th. It may be that participants found the structured nature of the theme *SCSI* to be more manageable and appropriate for younger students. Table 9 provides a summary of participants interviewed.

Table 9

Participants' Conception, Enactment, Goals for Inquiry for Earth Science Participants

Participant (Cert. Area)	Teaching (2008-09)	General Conception	Enactment	Goals	Overall Theme
Donna (Earth Science)	Earth Science	Insufficient Data	SCSI	SCSI	SCSI

Sarah (Earth Science)	Earth Science	*"discover something during the lab" "how real science is done"*	SCSI	SCSI & Content	SCSI
Cathy (Earth Science)	Astronomy	*"I just think, thinking."*	Content	Content & Application	Content

Portfolio Text Analysis

Analysis of portfolio text also found *SCSI* to be the most common category for earth science teachers. In addition to *SCSI* one portfolio was categorized as *Content* while another was *Problem Solving*. Two portfolios were placed under the theme *Other*. The first described students taking measurements and the second dealt with making detailed observations.

Participants in Table 10 represented a range of curricula (six earth science, one environmental, one astronomy, one meteorology), abilities (three high, six average and one low), and geographical contexts (one rural, one suburban, two urban, six no data). There was also a range of grade levels (five 9th, three 10th, six 11th, six 12th) with many classes having two or more grade levels present.

Table 10

Primary Goals and Enactment of Inquiry for Earth Science Participants

Discipline	SCSI	Content	Modeling	Problem Solving	Other
Earth Science	6 (60%)	1 (10%)	--	1 (10%)	2 (20%)

Of note is that high ability classes made up a smaller percentage of courses for earth science when compared to other disciplines (Biology: 58%, Chemistry: 62%, Earth Science: 30%, Physics: 85%). In addition, three of the classes consisted of only ninth grades. A similar trend was found for participant interviews where two of the three teachers taught ninth grade students. Although this does not appear to influence how they were individually categorized, these are distinct contextual features for the discipline of earth science.

PII Analysis

Our statistical analysis of portfolios revealed only two differences between earth science and other disciplines. As previously reported, biology teachers were more likely to allow students a choice of questions to investigate than all other disciplines, including earth science. In addition, physics participants were more likely to use mathematics and modeling than earth science participants in this study.

We believe that the significant difference with biology indicates that biology teachers are more likely to approach inquiry with an emphasis on structured investigations than earth science participants. Data from portfolio text analysis support this notion. There was a greater range of themes (*SCSI*, *Content*, *Problem Solving*, *Other*) found for earth science. Finally, physics were more likely to use math and modeling than all other disciplines.

Summary

Based on participant interviews, portfolio text analysis, and the *PII* statistical analysis, earth science teachers tend to approach and enact inquiry as *SCSI*. The discipline of earth science provided more extreme examples of grade level and student ability. Even so, both did not appear to influence teachers' conception or enactment of inquiry.

Physics

Physics teachers in this study were more likely to be approach and enact inquiry with an emphasis on the theme *Modeling*. The theme *Modeling* most often involved the generation of mathematical equations to describe physical phenomena. In general, students were presented with a problem or system. They then decided what data to collect and designed a procedure. 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. In this study, only the participants teaching physics courses were found to represent the *Modeling* theme.

While there are similarities between *Modeling* and *SCSI*, there are important differences. For *SCSI* there is an emphasis on the structure of the investigation, often taking a form similar to the traditional scientific method taught in schools. Here the focus is on the process of conducting the investigation. This frequently includes generating a hypothesis or testable question, conducting the investigation with frequent mention of control groups and manipulating variables, conducting multiple trials, coming to a conclusion, and communicating results. In contrast, *Modeling* is more centered on observing physical phenomena, collecting data, and generating a relationship or equation that describes the phenomena.

Participant Interviews

Four physics teachers were interviewed. Two of these teachers taught biology courses as well as physics. In addition, two teachers taught lower ability physics classes. The theme of *Modeling* was found for all participants although two participants held alternate themes for their lower ability students.

When asked her general thoughts about inquiry, Diane (NB Certification: Physics) 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 lower ability 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.

We 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. It may that Carl perceived a need for more structure found with *SCSI* prior to students being able to engage in modeling.

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 create model highway barriers. Students were not involved with the generation of equations in this lesson. Table 11 provides a summary of participants interviewed.

Table 11

Participants' Conception, Enactment, Goals for Inquiry Physics Participants

Participant (Cert. Area)	Teaching (2008-09)	*General Conception*	Enactment	Goals	Overall Theme
Carl (Physics)	Active Physics	*"how real science is done"*	SCSI	SCSI	SCSI
	IB Physics		Modeling	Content & *"Accountability"*	Modeling
Diane (Physics)	Physics	*"more internalization if they have the thrill of discovering it"*	Modeling	Modeling	Modeling
Jane (Physics)	Physics	Insufficient Data	Modeling & Content	Content	Modeling & Content
Tom (Biology)	Physics	*"discover scientific facts or information" "makes the point concrete"*	Modeling	Modeling & Content	Modeling

Portfolio Text Analysis

Our analysis of the portfolio text supports our finding that the use of mathematics and modeling represent a trend in how physics teachers approach inquiry. Of the four disciplines, portfolios for physics participants were the most diverse of the disciplines analyzed. As shown in Table 12, many approached inquiry as *Modeling* but *Content* and *SCSI* were both also represented. One participant was listed under problem solving. While his students did engage in developing an equation for friction the emphasis was on approaching and solving problems. Therefore the decision was made to add a category for *Problem Solving*.

Table 12

Primary Goals and Enactment of Inquiry for Physics Participants

Discipline	SCSI	Content	Modeling	Problem Solving	Other
Physics	2 (15%)	4 (31%)	6 (46%)	1 (8%)	--

Participants represented a more focused range of curricula (two AP, one IB, ten general physics) and student abilities (eleven high, two average). Geographical contexts (one rural, six suburban, three urban, three no data) were similar to other disciplines as was the range of grade levels (three 9th, two 10th, nine 11th, ten 12th) with many classes having two or more grade levels present. Only one of the classes was exclusively ninth grade.

PII Analysis

Our PII analysis revealed that physics teachers were more likely to use mathematics in their instruction than teachers in all other disciplines. In addition, physics teachers were also more likely to include a strong modeling component in their portfolio description of inquiry. Appendix B lists results for each *PII* item.

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).

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.

For physics teachers the use of mathematics and emphasis on generating models of physical phenomena was more pronounced then all other disciplines. The results from *PII* analysis are consistent with both participant interviews and portfolio text analysis and support the overall theme of *Modeling* for physics participants.

Summary

Together the three data sources presented support our finding that physics teachers are more likely to approach and enact inquiry under the theme of *Modeling*. Data from participant interviews suggest that student ability may explain some of the variation seen in portfolio text analysis due to lower ability students being less likely to engage in *Modeling*.

Discussion

In our study of exemplary secondary science teachers, the context of discipline was found to be a major influence on participants' conceptions and enactment of inquiry. Situated within the classroom there a number of additional factors, such as curriculum, student ability, and preservice training which also may be influential. However, in this study, the structure of the discipline was the primary influence on teaching with inquiry.

Curriculum is one factor that that may influence inquiry-based teaching. Participants in this study taught within a range of curricula that included AP, IB, honors, and varying content.

For example, portfolios from biology participants consisted of two AP, one IB, one forensics/bioethics, and two anatomy & physiology courses. Even with these differing curricula biology participants overwhelmingly approached inquiry as *SCSI*. Likewise, curriculum seldom appeared to play a major role in teachers' conceptions or enactment of inquiry in chemistry, earth science, or physics.

On exception is Peter who taught IB Chemistry. For Peter the requirements of the IB program led him to enact inquiry as *SCSI*. As he stated "*it's required for IB so it's convenient, you know, it's not like I have any way around it".* In the interview it became apparent that Peter also approached inquiry with an emphasis on chemistry content. While the IB requirements were influential in his enactment, an equally important role of inquiry was building chemistry content knowledge. This indicates that while curriculum was not found to be a primary influence in this study, in certain cases it can have an impact. Even so, teachers' underlying conception and goals for inquiry will likely be expressed.

Student ability was another contextual feature with only a minor influence on teaching with inquiry. Portfolio text analysis did not show disciplinary trends based on student ability. For example, only 30% of students rated as high ability in earth science. In contrast, biology consisted of 58% high ability students. Even with the difference in abilities between disciplines both tended towards the theme *SCSI*. Further, within disciplines no trends in inquiry were found based on student ability. One exception was with Carl who focused on *SCSI* with his low ability physics students while using *Modeling* with his high ability IB students. This suggests that student ability may be influential in certain cases. Overall though, no trends were found for student ability.

Undergraduate degree did not appear to influence teachers' conceptions, goals, or enactment of inquiry. Eight participants interviewed held undergraduate degrees in biology. If undergraduate training were a primary influence in teaching with inquiry it would be expected that these participants would be categorized under the same theme. Data show that this did not occur. Of participants with undergraduate biology degrees, two of the three biology teachers were categorized as *SCSI*, two of the three chemistry teachers were classified as *Content*, and the two physics teachers were classified as *Modeling* (although one was also classified as *SCSI* for his lower ability physics class). This indicates that, even with similar educational backgrounds, teachers followed disciplinary trends for the class they taught rather than the discipline in which they were trained.

Student age, geographic context, and years teaching also did not appear to have a major impact on teaching with inquiry. Participants teaching in more than one discipline support this assertion. These hybrid participants held different conceptions and enactment of inquiry depending on the discipline they were teaching. At the same time their years teaching, preservice and inservice experiences, and geographic context remained constant. Of the four hybrid participants interviewed, three held multiple conceptions. Further, these conceptions tended to follow the disciplinary trends found in the larger study.

The science teachers in our study who taught more than one discipline, *hybrid* teachers, offer insights into how the structure of the discipline can influence teaching with inquiry. Although there is little research on disciplinary differences in how teachers approach inquiry, several studies have suggested that teachers can hold multiple conceptions of inquiry (Lotter, Harwood, & Bonner, 2007, Luft, 2001; Wallace & Kang, 2004). Tom, a hybrid teacher who taught biology and physics, was categorized as *SCSI* for his biology teaching and *Modeling* for physics. Like other hybrid teachers in the study, Tom found it more difficult to teach with inquiry in biology. Three of the four hybrid teachers teaching biology and another discipline also indicated inquiry in biology to be more challenging. All three approached inquiry as *SCSI* in biology, indicating that a structured approach to investigations may be necessary to manage the complexity of inquiry in biology.

Our analysis of the interviews of hybrid teachers suggests that the structure of the discipline was the primary reason for their approach inquiry being *SCSI*. Two of the teachers who also taught physics were categorized as *Modeling* and *Modeling/Content*. This may be because physics phenomena are more verifiable (Alexander, 1992) and readily studied through a modeling approach. The other taught chemistry and earth science and was categorized as *Content* for both. These hybrid teachers highlight the influence the structure of each discipline has on teaching with inquiry.

Implications

Findings suggest that curriculum, along with student ability and teachers' preservice experiences, may not be as important of a factor in teachers use of inquiry as previously thought. Therefore, simply modifying the curriculum or providing additional preservice professional development will likely not result in changes in teaching with inquiry. The underlying structure of the discipline appears to be the driving factor in teachers' conception and enactment of inquiry in this study.

An important implication of our study is that presenting a broad vision of inquiry to preservice and practicing secondary science teachers may have a limited impact on their use of inquiry. For example, presenting inquiry as *SCSI*, as is often done in both preservice and inservice science teacher education programs, will likely be of limited use to chemistry and physics teachers. Based on the findings in this study it may be more effective to offer more discipline-specific examples of inquiry.

An encouraging finding is that teachers' conceptions of inquiry are flexible and often adapt to disciplinary contexts. In particular, what we learned from the hybrid teachers in our study suggest this flexibility may be a reason for optimism. If curriculum and preservice/inservice experiences take into account and address issues related to the structure of the discipline, science teachers may be able to modify their conceptions to include more varied forms of inquiry. Learners in science would benefit from experiencing inquiry in a more varied, and thus authentic representation of scientific practices.

It is important to note that the *frequency* of teaching with inquiry was not a focus of our study. Nevertheless, one implication may be that curriculum and preservice/inservice experiences more suited to specific disciplines may result in more frequent use of inquiry if teachers find it aligns with their conceptions and enactment of inquiry.

A final implication and area for future study involves whether disciplinary trends are a common feature for other instructional strategies. For example, do significant disciplinary differences exist in how teachers conduct demonstrations, teach with socioscientific issues, or use technology in the classroom? The current study suggested that the context of discipline may be influential in these cases and have consequences for curriculum design and professional development.

Limitations

We recognize that science teachers, exemplary or otherwise, are individuals, and our findings suggest trends and not absolutes. Further, this study does not advocate any one approach towards inquiry in science; quite the opposite. It does, however, encourage the science education research community to consider further the importance of the context of discipline in how teachers actually think about and use inquiry in their classrooms.

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Footnotes

[1] The first author achieved National Board certification in Adolescent and Young Adult Science: Chemistry in 2007 and has mentored numerous teachers seeking National Board certification. As a result, he has an in-depth knowledge of the AYA Science certification structure and process.

Appendix A: Interview Questions

I. Teachers' Conceptions and Enactment of Inquiry

a. General Conception of Inquiry

   i. Could you describe to me what you think of when you hear the word inquiry in science teaching?

b. Enactment of an Inquiry Lesson

   i. Now I'd like to talk about how you would teach an inquiry-based lesson of your choice. Please describe the lesson plan in as much detail as possible.
   ii. What were your goals for the lesson plan?
   iii. What is your primary goal or reason for using and inquiry lesson like this?
   iv. How much choice did students have in the question(s) they researched?
   v. How did you support the development of their question?
   vi. Please describe how students used mathematics in the lesson.
   vii. How did students communicate their results?
   viii. You mentioned (technology, hypotheses, modeling, alternative explanations, defending an argument, etc.). Could you describe why that is important?
   ix. Is this inquiry lesson appropriate for lower ability students? How would you modify it for lower ability students?

   * This section is repeated when teachers have classes in more than one discipline.

c. Inquiry and Curriculum
   i. Where would you go to find inquiry-based curriculum?
   ii. What are three characteristics that you would look for in inquiry-based curriculum?

Appendix A: ANOVA for *PII* Data

Table 13

ANOVA Summary for Portfolio Inventory Items across Disciplines

Item	Biology	Chemistry	Earth Science	Physics	F	p
Item 1A	3.00 (1.28)	1.69 (1.03)	2.00 (1.70)	1.38 (1.65)	4.31	.010
Item 1B	3.00 (1.13)	1.69 (0.86)	1.70 (0.95)	1.38 (0.65)	7.70	< .001
Item 2A	4.50 (0.80)	3.69 (1.11)	3.80 (1.55)	3.77 (1.17)	1.26	.299
Item 2B	4.83 (0.58)	4.15 (0.80)	4.80 (0.42)	4.62 (0.65)	2.95	.043
Item 3A	1.92 (1.38)	2.46 (1.71)	1.80 (1.32)	2.92 (1.80)	1.28	.294
Item 3B	1.75 (1.29)	2.54 (1.81)	2.40 (1.27)	4.23 (1.30)	6.73	.001
Item 4A	3.25 (0.62)	3.15 (0.90)	3.20 (1.23)	4.23 (0.73)	4.39	.009
Item 4B	3.17 (0.58)	3.15 (0.56)	3.30 (0.68)	3.69 (0.63)	2.20	.101
Item 5A	1.67 (1.37)	1.08 (0.28)	1.10 (0.32)	1.31 (0.63)	1.43	.247
Item 6A	4.17 (1.53)	2.46 (1.20)	2.60 (1.65)	2.92 (2.02)	2.74	.055
Item 6B	2.58 (1.62)	2.16 (1.07)	1.50 (0.71)	2.31 (1.65)	1.25	.304
Item 6C	3.25 (1.71)	3.15 (1.28)	2.70 (1.34)	2.38 (1.76)	0.86	.471
Item 7A	4.58 (0.74)	2.62 (1.61)	3.10 (2.03)	1.77 (1.24)	8.15	< .001

Note: standard deviations appear in parentheses below means.