

An Investigation of the Practice of Scientific Inquiry
in Secondary Science and Agriculture Courses

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Dissertation submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Curriculum and Instruction

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April 30, 2007

Blacksburg, Virginia

Keywords: Scientific Inquiry, Nature of Science, Voices,
Science Education, Agriculture Education

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ABSTRACT

The purpose of this exploratory qualitative study was to investigate the practice of scientific inquiry in two secondary biology classes and one agriculture class from different schools in different communities. The focus was on teachers' interests and intentions for the students' participation in inquiry, the voices contributing to the inquiry, and students' opportunities to confront their conceptions of the nature of science (NOS). The Partnership for Research and Education in Plants (PREP) served as the context by providing students with opportunities to design and conduct original experiments to help elucidate the function(s) of a disabled gene in *Arabidopsis thaliana*.

Transcripts of teacher and student semi-structured interviews, field notes of classroom observations and classroom conversations, and documents (e.g., student work, teacher handouts, school websites, PREP materials) were analyzed for evidence of the practice of scientific inquiry.

Teachers were interested in implementing inquiry because of potential student learning about scientific research and because PREP supports course content and is connected to a larger scientific project outside of the school. Teachers' intentions regarding the implementation of inquiry reflected the complexity of their courses and the students' previous experiences. All inquiries were student-directed. The biology students' participation more closely mirrored the practice of scientists, while the agriculture students were more involved with the procedural display of scientific inquiry. All experiences could have been enhanced from additional knowledge-centered activities regarding scientific reasoning.

No activities brought explicit attention to NOS. Biology activities tended to implicitly support NOS while the agriculture class activities tended to implicitly contradict NOS. Scientists' interactions contributed to implied support of the NOS. There were missed opportunities for explicit attention to NOS in all classes.

The major voices contributing to the inquiry in all classrooms included those of teachers, students, technology, scientists, textbooks, and mandated standards; however, they were more prevalent in the biology classrooms than the agriculture classroom. The powers influencing the voice frequency may be related to the teachers' own teaching and research experiences, as well as the alignment of the expectations and values of students' participation in scientific inquiry and those associated with the school-classroom communities and the students' identities.

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INTRODUCTION

Fifteen years ago, the American Association for the Advancement of Science (AAAS) published *Science for All Americans* (Rutherford & Ahlgren, 1990), which called for science education reform to include an increased emphasis on educating scientifically literate citizens who have a basic understanding of the principles of science and could use these principles and scientific ways of thinking in their everyday lives. The *Benchmarks for Scientific Literacy* (AAAS, 1993) reinforced the importance of students learning scientific concepts and recommended that students be involved with the processes of scientific inquiry during their science courses in school. The National Research Council (1996) followed these two science education reform documents with the *National Science Education Standards*, which further emphasized the importance of the studies of science, the scientific processes, nature of science, and science as inquiry.

Published educational research during the past fifteen years has included a wealth of information about incorporating the nature of science in science lessons, as well as promoting scientific inquiry as a valuable teaching strategy for grades K-12. Additionally, science educator practitioner journals have contained an abundance of articles promoting the use of scientific inquiry as an instructional strategy, as well as supporting different aspects of the nature of science during class lessons. This interest in increasing the focus on the nature of science and the use of scientific inquiry in science classes stems from research in cognitive and cultural studies that indicates that students will grow in their interest, knowledge, and understanding of science if they are involved in socially-situated, content-rich classroom experiences that are grounded in activities typical of practicing scientists (for example, see AAAS, 1993; Carey & Smith, 1993; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Kuhn, 1993; NRC, 1996). Curricula built around scientific inquiry potentially provide valuable opportunities for students to further develop their conceptions of nature of science and their understanding of the processes of scientific inquiry.

However, there is evidence that students still hold naïve views of the nature of science and are involved in activities that fail to challenge them to reason scientifically during their science classes (for example, see Chinn & Malhotra, 2002; Ryder, Leach, & Driver, 1999). Teachers report that their reluctance to incorporate these kinds of activities is based on the many

factors that interfere with implementing inquiry-based instruction in their science classes (for example, see Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naaman, Hofstein et al., 2004; Hofstein & Lunetta, 2004; Lewellyn, 2005). These impediments include factors that are part of the school environment such as limitations on class time, large classes, classroom management issues, lack of support from colleagues and other professionals, and pressure to cover specific content before students take their high-stakes tests at the end of their science courses. Other reported obstacles include lack of materials and resources, and teacher inexperience and lack of training with non-didactic teaching strategies.

There is interest among science educators in conducting additional research that investigates the practice of scientific inquiry in high school science classrooms because of the scarcity of published literature in this area. Further research “is needed to inform the science education community, teachers, administrators, teacher educators, and the public as a whole about what kinds of inquiry-based science may be reasonably carried out in ordinary classrooms...” (Keys & Bryan, 2001, p. 642). Hofstein and Lunetta (2004) called for additional studies that examine teachers’ perceptions of the purposes of implementing problem-based instruction, as well as their implementation of the instruction. Furthermore, additional research needs to examine various aspects of inquiry including the student discussions about the data they have collected, the interpretations of their data, relating their data to their research questions, generating claims based on their data, and then supporting and justifying their findings (Duschl, Ellenbogen, & Erduran, 1999; Hofstein & Lunetta, 2004; Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl, 2000).

Currently, high school students across Virginia are conducting original experiments within the context of the Partnership for Research and Education in Plants (PREP), to elucidate the function of a gene that has been disabled in the *Arabidopsis thaliana* plant. Through support from a university outreach program, these students participate in scientific inquiry by designing their own experiments; observing, collecting, and analyzing original data; formulating and evaluating explanations based on evidence; drawing conclusions; and communicating their findings. These student experiences with scientific inquiry potentially provide optimal settings for research regarding the practice of inquiry in secondary agriculture and science classes.

The goal of this descriptive research study of scientific inquiry lessons as carried out by high school science and agriculture teachers and students is to contribute to the science education literature concerning how scientific inquiry is practiced in secondary classes. With more clarity and depth of understanding concerning how scientific inquiry is actually conducted in real classes, science educators may be better equipped to support future and practicing teachers in their efforts to implement scientific inquiry with their own students. In addition, it is hoped that the findings will inform those science educators who create inquiry-based curriculum so that their support materials may better address the needs of teachers who incorporate scientific inquiry into their courses.

CHAPTER ONE

A REVIEW OF THE LITERATURE

Scientific Literacy

Inspired by the noncompetitive national science test scores of American youth in spite of substantial financial support for science education that had been motivated by the Russian-US race to space, the U.S. Department of Education (1983) published the *A Nation at Risk* report which posed recommendations for new directions for science education. Included among the many concerns that motivated discussions about the future of science education was an interest in promoting the national economy and global economic competition, sustaining local and global environmental conditions, and improving the quality of human health. Recognizing these national concerns, the members of the American Association for the Advancement of Science established *Project 2061* in 1985. *Project 2061* presented a document, *Science for All Americans* (Rutherford & Ahlgren, 1990), to the science education community, the contents of which recommended “what students should know and be able to do in science, mathematics, and technology at various grade levels” (p. x). Their recommendations included a description of the science-literate person as one whom

1. is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations;
2. understands key concepts and principles of science;
3. is familiar with the natural world and recognizes both its diversity and unity; and
4. uses scientific knowledge and scientific ways of thinking for individual and social purposes (p. xvii).

Following their initial document that advocated high standards of scientific literacy for all Americans, AAAS presented a supplemental report, *Benchmarks for Scientific Literacy* (AAAS, 1993), for educators involved with the teaching and learning of science, mathematics, and technology. The *Benchmarks* (AAAS, 1993) provides educators with the supporting information needed as they design the content of their own curricula so that they promote the development of scientifically literate students. In addition to summarizing the desirable levels of understanding and abilities associated with what AAAS (1993) considered the common content core of science,

mathematics, and technology, this document includes a description of the philosophical and sociological aspects of scientific knowledge and scientific practice that are worthwhile for students to consider as they develop their scientific literacy. AAAS (1993) recommended that science students take time to consider the scientific enterprise, the scientific world-view, and the scientific process of inquiry, in addition to their study of science content knowledge.

With the groundwork laid by the AAAS, the National Research Council (NRC) published the *National Science Education Standards (NSES)* (NRC, 1996), a text that contains teaching, content, program, and assessment standards recommended for educators when designing instruction that provides opportunities for students to learn science and science process skills. The *NSES* (NRC, 1996) also includes the following additional details about the specific abilities that are characteristic of scientifically literate students. Scientifically literate students can

1. ask, find, or determine answers to questions derived from curiosity about everyday experiences;
2. describe, explain, and predict natural phenomena;
3. read with understanding articles about science in the popular press and ... engage in social conversation about the validity underlying national and local decisions and express positions that are scientifically and technologically informed;
4. evaluate the quality of scientific information on the basis of its source and methods used to generate it; and
5. pose and evaluate arguments based on evidence and apply conclusions from arguments appropriately (p. 22).

During the 1990s, these three national reform documents brought science education's goal of scientific literacy for all students to the forefront of national and international conversations. Together the three documents advocate for science, mathematics, and technology curricula to present opportunities for students to gain a strong science content knowledge, as well as to develop an understanding of the nature of science (NOS), the scientific world-view, and science as a process. It was the general consensus of science educators who prepared the national documents that this content knowledge and related abilities would better prepare students to meet the future challenges of making individual and collective, respectful, responsible and just

decisions about the health and welfare of the planet's inhabitants and their environments, and then follow up these decisions with responsible actions. Additionally, from the economic perspective, this new emphasis on science content and process would better prepare students for future employment, thus increasing the country's competitive edge in the global economic markets.

The Nature of Science, the Processes of Scientific Inquiry, and Student Voice

Perspectives of the nature of science, scientific inquiry, and student voice as presented by the national science education reform documents. The perspectives of the nature of science, which Lederman and Zeidler (1987) define as “the values and assumptions inherent to the development of scientific knowledge” (p. 721), and the processes of science presented in the national reform documents were generally agreed on by scientists and educators. In summary, scientists believe that, through investigations, they can figure out a great deal about how the world and universe work because matter and actions occur in regular patterns. This knowledge, which scientists do not consider to be the absolute truth about nature, is exceedingly stable and may be useful in explaining other events and may, as well, lead to further questions about the world and universe. Because practices of science are human endeavors, scientific knowledge is inherently theory-laden and influenced by social and cultural norms. Scientific knowledge, which is gained through systematic investigations, is somewhat tentative and may be modified as scientists become engaged in investigating new questions or using new equipment or methods (AAAS, 1993; Rutherford & Ahlgren, 1990).

Scientific inquiry, or the processes of doing science involve scientists in imaginative and creative inquiry into how the world works. The structure of the inquiry varies somewhat depending on the investigation but the inquiry will most likely involve the scientist in posing questions, formulating hypotheses about the phenomena of interest, designing and implementing procedures for collecting empirical data, and using their senses and equipment to test the hypotheses. The evidence is interpreted, explained at a theoretical level, and potentially useful in making future predictions. Scientists are skeptical and therefore they depend on evidence and the use of logic to support their hypotheses and theories but they are aware that the same evidence may be justifiably explained in different ways. Even though scientists realize that complete objectivity is not possible, they incorporate strategies during their research to minimize personal,

method, and instrument biases (AAAS, 1993; NSES, 1996; Rutherford & Ahlgren, 1990). Because inquiry and the nature of science are inextricable, scientific inquiry and NOS are frequently mistakenly treated as being one and the same (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). To clarify the distinction between the two, nature of science refers to the epistemology of science, or the values and assumptions of scientists during their practice concerning what counts as scientific knowledge, how that knowledge is constructed, and even how it may be discounted in the future. On the other hand, scientific inquiry is that practice by which scientists conduct their work. To further explicate the distinction, consider the investigations conducted by some primatologists to gain insight into the social organization of apes (Haraway, 1991). These scientists were involved in the processes of scientific inquiry – designing their studies, making and recording their observations, interpreting data to formulate conclusions; however, since the findings of the research were based on scientists’ decisions that were intrinsically influenced by the society within which science is practiced, the scientific knowledge concerning the social organization of apes was influenced by social and cultural norms.

The National Research Council (1996) emphasized the importance of students’ voices in science classroom conversations in Standard B of *the National Science Education Standards*. This standard recommends that teachers “guide and facilitate learning by orchestrat[ing] discourse among students about scientific ideas” (p. 32). This coordination by the teacher of the inquiry activities should include opportunities for both written and oral discussions. Written discourse may take the form of recording data, representing data graphically or pictorially, or writing lab reports, for a few examples. Student presentations, as well as small group and whole-class discussions, provide a platform from which students can talk about their experimental designs and research findings, as well as explain their findings and justify their conclusions.

The *NSES* (NRC, 1996), Standard E emphasizes the teacher’s role in developing “communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning” (p. 45). Teachers can promote this intellectual rigor and these social values and attitudes that are characteristic of scientific work by supporting collaborative learning and giving each student a major responsibility during the inquiry, and thus a voice in making their decisions related to their inquiry. As was emphasized in Standard B, Standard D recommends that teachers encourage and assist their students in talking

about their work in the ways that scientists communicate about their work. This talking can include informal discussions or formal presentations, and may include, but is not limited to students summarizing their data, explaining their findings, using their data to defend their conclusions, and challenging their peers' explanations.

Additional emphasis was given to students' voices, science-talking, and communication as essential features of science classroom inquiry by the National Research Council (2000b) in *Inquiry in the National Science Education Standards*. The NRC (2000b) highlighted the need for students to be involved in discussions about the different aspects of their experiments, as well as having opportunities to present information about their experiments, including defending their arguments, logically and clearly.

Concerns about the nature of science, scientific inquiry, and student voice as presented in national reform documents. Even though very diverse committees composed of thousands of educators, scientists, philosophers, mathematicians, historians, engineers, and physicians affirmed the tenets of the nature of science and the processes of science as stated in the reform documents, the tenets drew criticisms from various sources (Alters, 1997; Donmoyer, 1995; Eisenhart, Finkel, & Marion, 1996; Lee, 1997, 1999; Rodriguez, 1997). Donmoyer (1995) expressed concern about the reality of meeting the goals of the *NSES* (1996) at more than a rhetorical level as educators turned their attention to how they would go about reaching those goals. In his study of academic science philosophers' views of a compilation of tenets of the nature of science from a number of different sources including the *Benchmarks* (1993), Alters (1997) concluded that there was no one set of tenets of the nature of science in which science education could be grounded. This may partially be due to the belief that "Beyond these general characteristics [of the nature of science], no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS" (Abd-El-Khalick, 2000, p. 666; see also Rudolph, 2000; Schwartz & Lederman, 2002).

Eisenhart et al. (1996) questioned the implicit assumptions of the national documents that students will become scientifically literate if they participate in science activities that reflect the processes of science and support the tenets of the nature of science. They expressed concern that "no clear conceptual connections, strategies to achieve, or empirical support are offered to suggest how knowledge of science content and methods might lead to its use in socially

responsible ways” (p. 269). Adding to these concerns, Rodriguez (1997) criticized the *NSES* for lacking the explicit pedagogical information teachers need if they are going to design activities that promote learning about the processes of science and the nature of science for *all* students including those from diverse linguistic, racial, cultural, and socio-economic backgrounds.

Proponents of scientific literacy for *all* students expressed concern that the science processes presented in the reform documents were based on only one tradition of science, that of the Western view, which may be incompatible with practices of students from different cultures (Lee, 1997, 1999). Cobern and Loving (p. 58, 2001) provided the following concise summary of the Western, or Standard Account of science:

1. *Science is a naturalistic, material explanatory system used to account for natural phenomena that ideally must be objectively and empirically testable.*
2. Science is about *natural phenomena*.
3. The explanations that science offers are *naturalistic* and *material*.
4. Scientific explanations are *empirically testable* (at least in principle) against natural phenomena (the test for empirical consistency) or against other scientific explanations of natural phenomena (the test for theoretical consistency).
5. Science is an explanatory *system* – it is more than a descriptive *ad hoc* accounting of natural phenomena.
6. *The Standard Account of science is grounded in metaphysical commitments about the way the world “really is”* (e.g., see Burt, 1967; Cobern, 1991, 1995).
7. Science presupposes the possibility of knowledge about nature.
8. Science presupposes that there is *order* in nature.
9. Science presupposes *causation* in nature (Collingwood, 1940)
10. *What ultimately qualifies as science is determined by consensus within the scientific community.*

There is concern among science educators that “scientific practices to encourage empirical standards, logical arguments, skepticism, questioning, criticism, and rules of evidence may be incongruent with cultural interactions that favor cooperation, social and emotional

support, and consensus building” (Lee, 1997, p. 221). The emphasis on science from a Western-view may influence the degree of accessibility, meaningfulness, and interest, and therefore the achievement by students whose backgrounds are centered in other ways of knowing science. Science educators who believe that presenting science solely from the Western view may create barriers to students because of their culture, gender, class, and language, fervently recommend that the presentation of the nature of science and science as a process should include Western *and* other ways of knowing the natural world (Cobern & Loving, 2001; Lee and Fradd, 1998; Loving, 1997; Smith & Scharmann, 1999; Snively & Corsiglia, 2001; Stanley & Brickhouse, 1994).

For example, Ogawa (1995) argued that both personal science and indigenous science need to be recognized as acceptable views of science. Inclusion of other views of science, such as indigenous science and traditional ecological knowledge, need to be taught alongside Western modern science so that students have opportunities to learn about the intrinsic worth of each as well as the related controversies surrounding each with regard to the school science curriculum (Sniveley & Corsiglia, 2001; Stanley & Brickhouse, 2001).

For a majority of the students, neither the social languages of science talk nor classroom talk are their everyday ways of talking. At best, the language of science is a register of the student’s native language; however, many students must learn the language of science concomitant to learning colloquial English (Lemke, 1990). These students, as well as many native English speakers who have not mastered science-talk, do not have the same advantages in science classes as those students whose social language already shares many aspects of language with science-talk (Lemke, 1990). Thus science educators need to consider the language and cultural borders that these students may need to cross when moving into the world of school science (Aikenhead, 2001; Lemke, 1990). While some students easily move back and forth between the world of science and that of their family and friends, others find the border crossing difficult, or even impossible because of the incompatibility of the two distinct cultures.

Perspectives on Learning

Because “effective teaching is at the heart of science education” (NRC, 1996, p. 4) there has been considerable interest in the subject of teaching science so that the curricula and instruction are compatible with current views about student learning. These beliefs concerning

how children build their knowledge of the natural world are credited with being the major influence in the philosophical grounding of the science education reform of the last two decades (Eisenhart et al., 1996).

Each child enters the science classroom with a unique, personal knowledge of how the world around them works based on their many years of inimitable interactions with their environment inside and outside of the science classrooms. These children continuously and actively construct and re-construct the many mental frameworks that they use to make sense of their world (Piaget & Inhelder, 1969). This sense-making involves children in assimilating, or fitting new information into their existing knowledge structures. However, new information often requires adjustments within existing knowledge structures in order to accommodate the new information.

Children make sense of their worlds at different cognitive levels, which Piaget and Inhelder (1969) referred to as stages. While there has been some serious criticism of Piaget's ideas about intellectual development (Fetsco & McClure, 2005; O'Loughlin, 1992; Santrock, 2001), his understanding and description of the formal operation stage of children's cognitive development offers middle and secondary science teachers a partial basis for making some of their decisions about science instruction. This last of Piaget's four stages, usually evident in children between the age of eleven and fifteen, is characterized by the children's ability to move their reasoning beyond thinking about real objects to logical, imaginative, and abstract thinking. "The great novelty of this stage is that by means of a differentiation of form and content the subject becomes capable of reasoning correctly about propositions he does not believe, or at least not yet; that is propositions that he considers part hypotheses. He becomes capable of drawing the necessary conclusions from truths which are merely possible, which constitutes the beginning of hypothetico-deductive or formal thought" (Piaget & Inhelder, 1969, p. 132).

Piaget identified three varieties of intelligence that emerge during the students' formal-operational stage: reflective abstraction, scientific reasoning (induction), and hypothetical-deductive reasoning (Brainerd, 1978). The deductive and inductive forms of reasoning can be distinguished by the kinds of inferences made: whether the reasoning is moving from general to specific (deductive) or from specific to general (inductive or scientific). To clarify further with examples, deductive reasoning is modeled when students use established geometry rules about

triangles to draw conclusions about new geometric problems. Scientists are involved with inductive reasoning when they pose relationships about the variables under study based on a compilation of experimental findings. For example, science students may generate statements about the relationship between the pressure of a gas and its volume after collecting sufficient data in the laboratory.

Regardless of the age or learning stage, learning is influenced by the children's social situations, and their culture and language, as well as the language and culture of those people with whom they interact (Fosnot, 1996; Vygotsky, 1978). Students' understandings of concepts "develop...through enculturation into practices of society; through the acquisition of society's technology, its signs and tools through education in all its forms" (Moll, 1990, p. 1) and are inextricably bound to and reciprocally dependent on experiences in their everyday lives (Vygotsky, 1986).

Making meaning is not limited to the internal workings of students' minds. Instead, the process of meaning-making is facilitated by the back and forth process of putting thoughts into spoken words and then words back to thoughts (Vygotsky, 1986). It is through the meaning-making that thoughts become spoken words. Vygotsky (1978) also emphasized the importance of the transition of higher mental functions from the student's social level to the individual level through an extended development process. The complex process of personal interpretation involves students making connections between their prior knowledge and the conversations they are a part of in the social plane in the classroom (Leach & Scott, 2003, interpreting Leontiev, 1981).

In attempting to understand how meaning is constructed by students, the attention needs to be expanded beyond what goes on in their minds to also include considering the "dialectic interaction" between the student, the activity the student is involved in, and the setting, all within a specific context (Lave, 1988). O'Loughlin (1992, p. 810) summarized Lave's perspective which supports the unit of educational research analysis as person-acting-in-setting:

Although the activity and the setting are important factors, they are bound together by the acting person, [an embodied] self that is historically and socially constituted and that is engaged in relational activities with others and becomes a self precisely through action in and on the world....that practice must be studied within the context of the

larger constitutive order provided by the larger social, historical, political, and economic order.

In addition, cognition is not the private property of individual students. Instead it is “distributed – stretched over, not divided among – mind, body, activity and culturally organized settings (which include other actors)” (Lave, 1988, p. 1). Salomon (1993) clarified the meaning of *distributed* as the “...absence of a clear, single locus....sharing authority, language, experiences, tasks, and a cultural heritage” (p. 111) and emphasized the need to include the roles played by individual cognitions in distributed cognitions. Intelligence, which is often thought of as being an entity which is held in each individual’s mind and something that is crafted through activity, is also “distributed – across minds, persons and the symbolic and physical environments, both natural and artificial” (Pea, 1993, p. 47). Because students’ crafted intelligence (or cognition) is “distributed,” it is concomitantly *situated*, or inextricably linked, to the activity, the context of the activity, and the historical, social, political, and economic context within which the activity was designed and implemented (Brown, Collins, & Duguid, 1989).

Wertsch (1991) drew from the works of both Vygotsky and Bakhtin for the assumptions on which he based his framework for the study of mental actions that emerge from human actions. (Instead of using the term “cognition,” he preferred the terms “mind” and “mental action” to emphasize the social distribution and meditative dependence of these activities.) Vygotsky’s influence is evident in Wertsch’s (1991) assumptions that “[understanding] mental actions relies on genetic, or developmental, analysis; higher mental functioning in the individual derives from social life; and human action, on both the social and individual planes, is mediated by tools and signs” (p. 19). Wertsch (1991) expanded Vygotsky’s ideas about the forces that shape and are shaped by mediational means, such as tools and language (that influence and are influenced by human action) to include historical, institutional, and cultural forces. He contended that the mediational toolkits of the students and the teachers do not include the means for successful interactions during inquiry-based instruction.

For a basis of understanding the relationships between oral and written communicative processes and human mental functioning, Wertsch (1991) depended on Bakhtin’s concepts of voice and dialogicality. Bakhtin (1986) included additional dimensions to voice beyond the collection of written, spoken, and heard sounds or words. For example, the dynamic processes of making meaning include considering who is doing the talking, who is doing the listening, and the

participants' perspectives and intentions. In addition, the participants' voices that create the speech event, of which there will be at least two, may or may not be involved in the immediate conversation: instead they may be separated by space and time.

Wertsch (1991) described Bakhtin's concept of language as a collection of "categories or *types* of speech events (types of utterances produced by types of voices)" (p. 56) which still embrace the properties of voice and dialogicality. One kind of language, the social language (e.g., professional jargon, social dialects, language used by a particular age group) is "a discourse peculiar to a specific stratum of society within a given social system at a given time" (Holquist & Emerson, 1981, p. 430) that invariably influences voices. Gee (2004) defined social language as "a way of using language so as to enact a particular socially situated identity and carry out a particular socially situated activity" (p. 20) that is recognizable by the patterns of the grammatical elements.

Also relevant to educational studies are the socially agreed upon speech genres which "correspond to typical situations of speech communication, typical themes, and consequently also to particular contexts between *meanings* of words and actual concrete reality under certain typical circumstances" (Bakhtin, 1986, p. 87). Two examples provided by Wertsch (1991), the speech genre of 'formal instruction,' [which is the traditional genre used by teachers in school classrooms and well known to all participants (Wittgenstein, 1967, as cited in Polman & Pea, 2001)], and the speech genre of "official science," reflect the authoritative nature, power, and status inherent in some genres. It is speech genres and social languages that Bakhtin believed organize communication and mental action establishing "a centrality of the relationship between psychological process and sociocultural setting" (Wertsch, 1991, p. 122). Successful learning about science requires the "internalizing the social language and genres of science and becoming able to use them appropriately in various situations" (Leach & Scott, 2003, p. 100).

In his summary of knowledge construction, Staver (1998) declared that knowledge is actively built up from within by each member of a community and by a community itself;

1. social interactions between and among individuals in a variety of community, societal, and cultural settings are central to the building of knowledge by individuals as well as the building of knowledge by communities, societies, and cultures;

2. the character of cognition and language which is employed to express cognition is functional and adaptive; and
3. the purpose of cognition and language is to bring coherency to an individual's world of experience and a community's knowledge base (p. 504).

To summarize, students bring with them to the classroom their unique experiences and prior knowledge about the natural world and science, which have been socially, politically, economically, and culturally influenced throughout their entire lives. Learning science requires students to confront their prior knowledge and assimilate new understandings with the prior understandings. Learning is inextricably connected to the activity and the context of the activity and is shared across time and space by all who participated in and contributed to the learning activity. Learning is a social process and, as such, is mediated by tools and signs, including written and spoken language. Part of what students come to know about science, the nature of science and the scientific processes, is through their dialectical interactions with the activities, the equipment and supplies, their textbooks, the other participants, and the settings of the activities. Finally, teachers play a very important role in providing activities and discussion opportunities during which students may reconstruct their personal views of science to accommodate scientific views of the natural world.

Recommendations for Instruction

The quote, "...amid all uncertainties there is one permanent frame of reference: namely, the organic connection between education and personal experience," clearly communicates Dewey's (1938, p. 25) thoughts about the relationship between learning and a child's experiences within and outside of the classroom. However, because those experiences may have both adverse and favorable influences on a child's education, Dewey (1938) challenged educators to reflect on the nature of those activities – the social structure, the materials used, and the methods implemented – and make certain that they are grounded in experiences that are not themselves the goal, but instead challenge the children's intellects.

Dewey's (1938) challenge to the science education community, buttressed by cognitive science research done during the last half of the 20th century, advocated moving instruction away from traditional, teacher-directed curricula towards a variety of instructional situations to include greater emphases on those that require students to be more mentally and physically active and

gives them more control of their learning (NRC, 2000b). Cobb (1994) underscored the important role that activity plays in student learning whether the focus of the activity is attributed to involving students in participation at a sensory-motor and conceptual level or activity that is considered to be culturally dependent. Instructional strategies that involve students in addressing real-life problems in collaboration with other students and adults facilitate learning because the learning process is socially situated (Fetsco & McClure, 2005). The socially situated collaboration promotes learning that is not possible when students work independently. For example, when a group of students works together using their collective knowledge they are more likely to be able to process challenging problems that could have been cognitively out of reach for the individual members of the group.

Pea (1993) challenged educators to mediate dynamic and imaginative activities in the classroom that promote students creating distributed intelligences through individual and collaborative activities that evoke students' cultures and involve the use of tools, symbols, and artifacts. Moving the focus of the activities from being the means-to-an-end, Salomon (1993), recommended that educators aspire to challenge their students with collaborative activities so that they have opportunities to "reciprocally scaffold" (p. 133), thereby distributing cognition. These activities should be grounded in experiences that reflect authentic and meaningful contexts outside of the classroom for learning to maximize the student's transfer of skills and knowledge (Brown, et al., 1989).

Based on the remarkable influence of prior conceptions on learning, the National Research Council (2000a, 2005b) recommended learning environments within which instruction incorporates opportunities for students to confront and activate their preexisting beliefs and knowledge. Throughout their entire lives, students have had experiences with scientific concepts, through observation, play, and formal study that guide them in formulating their own ideas about scientific concepts, what science is, and how science is "done." Teachers, as well, must be aware of these conceptions so that instruction can be planned to address the conceptions and provide opportunities for the students to build from them. These opportunities need to include the in-depth study of subject content so that students will have a rich background in factual knowledge and the conceptual frameworks holding the subject related facts and ideas. Explicit support needs to be built into instruction to guide students in reflecting on how they learn and their learning progress.

Lemke (1990) cited potential tension between students' social languages and speech genres and those typically used in the classroom – “science talk” (not to be confused with “official science”) and “formal instruction.” Those students whose social languages and speech genres most closely resemble those used by the teacher in the science classroom may have an advantage during classroom discussions. By situating their lessons in scientific activities to include scientific materials and both science and everyday discourses, teachers can assist all students, and especially those whose social languages most diverge from science social language, with practicing their “science talk” (Gee, 2004; NRC, 2000a). Incorporated into these lessons should be explicit attention to the semantics of “science talk” (Leach & Scott, 2003). The goal of these opportunities is not to replace the students' social languages with “science talk” but to expand the students' repertoires to include additional tools or ways to think and communicate about the world around them (Leach & Scott, 2003; Lemke, 1990). By supporting students with learning to “talk science,” they may strengthen their abilities to “work with, the conceptual tools, the epistemological framing, ontological perspectives and forms of reasoning of the scientific community” (Scott, 1998). Ultimately this is the goal of teaching – “to introduce new ways of thinking and talking to students, illustrating and modeling, how ideas are used appropriately in particular situations” (Leach & Scott, 2003, p. 101).

To support students in their learning about new science concepts, Leach and Scott (2003, p. 105) recommended that teachers involve students in practical activities on the social plane and at the same time

1. develop key ideas relating to the new concepts being introduced;
2. introduce points relating to epistemological features of the new way of knowing;
3. promote shared meaning amongst all of the students in the class, making key ideas available to all; check student understanding of newly introduced concepts.

While the meaning-making involves students reworking their understanding of science concepts from the social to the internal plane, the teacher plays a critical role in how these concepts are presented and incorporated into class discussions (Mortimer & Scott, 2003). Learning science and the ways of thinking characteristic of science requires students to internalize and make their own personal knowledge, or reconstruct, that scientific knowledge that has been presented on the social plane in the classroom (Leach & Scott, 2003). Individual and

collective understandings of science can be enhanced by students sharing scientific activities and discussions about science (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Opportunities for students to use the language of science by writing and talking about science concepts, including descriptions and comparisons, need to be included in class lessons (Lemke, 1990). These opportunities should include less teacher-talk and more occasions for students to pose questions to the teacher and each other, talk in small groups, present oral individual and small group reports, and write individual and small group reports (Lemke, 1990). Student discussions give students the chance to become familiar with the discourse of science: “a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaning group or ‘social network’ ” (Gee, 1989, p. 18). However, these discussions need some facilitation by the teacher so that all of the students are benefiting from the experience to scaffold their understanding of how to use the scientific social language and how it compares with everyday languages (Gee, 2004). In addition, it is vital for students to talk with and listen to their teachers and scientists talk about science because they model the use of scientific language. This modeling is particularly valuable when the teachers and scientists use metadiscourse, or discuss with the students how they are using scientific language.

Teaching students how to think scientifically “...may be the most significant, far-reaching, and long-lasting benefit that students take away from their learning in science” (Kuhn, 1993). This scientific thinking, developing theories to explain evidence, not the experimental portion of the scientific process, is the “essence” of scientific inquiry (Watson, Swain, & McRobbie, 2004). Students talking with each other about their scientific ideas, explaining support for their experimental evidence, defending their experimental conclusions, and considering rebuttals from other students can grow in their reasoning and arguing skills (Kuhn, 1992). Driver et al. (1994) consider it the science educator’s responsibility to “mediate scientific knowledge for learners, to help them to make personal sense of the ways in which knowledge claims are generated and validated” (p. 6). This is most effective when students are sharing their problem-solving experiences with each other and those who are already members of the scientific community. The experiences help to move the students beyond the relevant classroom activities to include discourse that may help to shape a deeper understanding of scientific

conventions and cultural tools associated with science knowledge – those scientific concepts, models and symbols that students are unlikely to build on their own.

The teacher's instructional roles as curriculum designer and implementer change depending on the borders the students must negotiate to be successful in science (Aikenhead, 2001; Costa, 1995). Non-mainstream students in particular, benefit from participating in arenas within which they can practice a secondary discourse (Gee, 1989) such as would be used in a science classroom while discussing scientific work. These skills, which are not natural, support thinking about science during their science courses, and as well, will benefit the students in their thinking outside of class.

Based on current cognitive, social, and cultural theories about learning and knowing, O'Loughlin (1992) described the following overarching challenges for science teachers

Science teachers...face the simultaneous challenges of validating their students' ways of knowing, introducing them to the powerful speech genres of conventional science, and equipping them with an understanding of the fundamentally socioculturally constituted ways of knowing that underlie science so that the process of science is demystified and they do not feel compelled to defer to the intrinsically authoritative power of the received view (p. 816).

The Processes of Inquiry as Instructional Strategies

Definitions of inquiry. The National Research Council (2000a) identified five techniques that teachers can use to promote student learning: inquiry, individual versus group, technology-based, lecture based, and skills based. "There is no universal best teaching practice" (NRC, 2000a, p. 22) and all five instructional strategies can be quite potent for supporting student learning if careful thought is given to the learner, the learning environment, and the subject. The *NSES* (1996) primarily promotes inquiry-based instruction (Lee & Fradd, 1998) but does acknowledge that other instructional strategies, such as direct instruction, hold a legitimate place in a teacher's collection of teaching methods (Fetsco & McClure, 2005).

Rudolph (2005) credited the national documents with bringing attention to inquiry-based instruction to the forefront of science education conversations. According to the National Research Council (1996), inquiry-based instruction provides a context for learning about the

nature of science and scientific inquiry. DeBoer (2006, p. 17) described scientific inquiry as “the general processes of investigation that scientists use as they attempt to answer questions about the natural world.” The NRC (1996, 2000b) more descriptively described scientific inquiry as both the cognitive and procedural processes that involve students in

making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, the use of critical and logical thinking, and consideration of alternative explanations (p. 23).

Science educators do not advocate for schools to attempt to involve students in scientific inquiry at the intellectual and methodological levels of practicing scientists; instead, educators are asked to consider “scientific inquiry...a metaphor for what goes on in an inquiry-based classroom” (DeBoer, 2006, p. 17) and attempt to involve learners in classroom activities that include different intensities of inquiry depending on the goals of the lessons (NRC, 2000b). Rather than expecting high school students to engage in scientific inquiry as scientists do in their communities of science, concomitant to students’ cognitive and methodological involvement with school scientific inquiry, students may benefit from considering how their own classroom inquiry practices reflect NOS and the authentic inquiry practice of scientists (Schwartz & Crawford, 2006).

While the definition and practice of inquiry-based instruction may appear to be clear in the National Research Council documents (1996, 2000a, 2000b, 2005b), individual science educators have different interpretations of the meaning of “inquiry” and “scientific inquiry,” the characteristics of inquiry-based activities, and how these activities are employed in the science classroom (Hofstein & Lunetta, 2004). Described at the simplest level, inquiry-based instruction is defined as “a systematic process for answering questions based on facts and observations” (Eggen & Kauchak, 2001). Lewellyn (2005) included activity, critical thinking, and creativity in the definition: “...inquiry is the scientific process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interest” (p. 24). Schwartz, Lederman and Crawford (2004) incorporated the same basic ideas in their definition

about how science is done but added the ethical dimension of scientific processes: Scientific inquiry is “the scientific enterprise and processes through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge” (p. 611). Hofstein and Lunetta (2004) expanded the discussion of inquiry in action to include “the authentic ways in which *learners* can investigate the natural world, propose ideas, and explain and justify assertions based on evidence and, in the process, sense the spirit of science” (p. 30).

One way to distinguish different forms of inquiry-based instruction is by the roles played by both the student and teacher during the inquiry process. The National Research Council (2000b) identified five different levels in inquiry as “true,” “full,” “partial,” “guided,” and “open.” Full- and open-inquiry typically refer to instruction during which the learner has the most control over the process of making decisions about which scientific questions to pursue, collecting and analyzing data, formulating explanations about the collected data, investigating support for the explanations from scientific resources, and communicating the findings to others. Guided- and partial-inquiry describe instruction during which the teacher structures a higher degree of the process such that the student is in control of less of the process. In addition to the student and teacher roles, Llewellyn (2002) incorporated a curriculum dimension to his levels of increasing degrees of inquiry. For instruction that is the least inquiry-based, curricula are determined by textbook content, focused on a single topic, and influenced minimally by the *NSES* (1996). In comparison, curricula that promote inquiry involve students with multiple primary sources, interdisciplinary themes, and are supported by the *NSES* (1996).

Models of classroom inquiry-based instruction. There are likely as many models of inquiry-based instruction as there are definitions and kinds of inquiry because teachers make their own meanings of inquiry as they mediate the role and use of inquiry based on their personal knowledge and experiences, and the students’ classroom and school cultures (Keys & Bryan, 2001). The National Research Council (1996, p. 25) outlined the following five recommended components of inquiry-based instruction used in classrooms:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.

3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

One example of an inquiry instructional model (Eggen & Kauchak, 2001, p. 242) includes the following six steps in the student inquiry process: (a) identifying a question, (b) making hypotheses, (c) gathering data, (d) assessing hypotheses, (e) generalizing, and (f) analyzing the inquiry process itself. For incorporating inquiry into high school science classrooms, Llewellyn (2002) recommended the “inquiry cycle” presented in Figure 1.

Bransford and Donovan (2005) expanded the model of inquiry-based instruction to include consideration of the students’ prior knowledge and their metacognition. They recommended that students have opportunities to participate in rigorous, guided scientific inquiry at three levels: (1) addressing their preconceptions about science content and the process of doing science; (2) doing science by being involved with observing, hypothesizing, reasoning, imagining, collecting, and interpreting data, developing theories, and communicating with others about their science; and (3) attending to and reflecting on their own processes of inquiry and considering their learning from a metacognitive perspective.

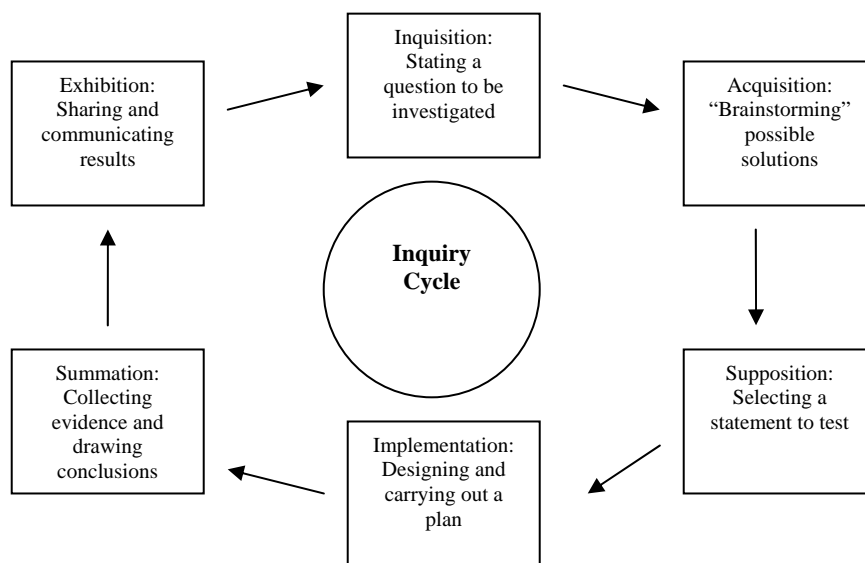


Figure 1. The inquiry cycle (Llewellyn, 2002).

Voices in the science classroom. The processes that typify scientific inquiry experiences, regardless of the preferred definition of inquiry, naturally lend themselves to conversations among students and their teachers, and possibly even scientists. Explicit in the essential features of inquiry as described by the National Research Council (2000a), is that students participating in inquiry-based activities will be involved with discussions during their inquiry. It is expected that during these discussions, students will plan their investigations, appraise their data, come to consensus about which data represents evidence, and create, communicate, and justify explanations based on their investigations. These discussions, which provide a platform for student voice, occur in the social plane and thus facilitate the students' reconstruction of their science knowledge through internalized meaning-making of science and the ways of thinking about science (Leach & Scott, 2003). These conversations in science classrooms also provide valuable opportunities for students to appropriate the social language of science (Bakhtin, 1986) provided it is modeled for them.

Leach and Scott (2003) discussed three essential aspects of a lesson on air pressure that may promote this reconstruction process by guiding students as they compare their own personal ways of knowing about air pressure to the scientific way of knowing about air pressure. Leach and Scott (2003) recommended that students need to

1. become familiar with and use alternate concepts of air pressure than those they may use in their everyday conversations
2. be involved in discussions about air pressure from the ontological perspective of science
3. understand that explanations used in science and thus related to air pressure need to be generalizable and consistent with empirical findings.

After observing guided inquiry lessons that successfully enhanced high school students' understandings of chemical reactions, Mortimer and Scott (2003) described a rhythm to the classroom discourse established by the teacher as she moved through the nine lessons supporting the students' efforts at recontextualizing their thinking from that which was familiar to that which was scientific. This rhythm included an interactive and dialogic initial phase during which many ideas were explored as students made contributions of their own ideas to the discussion. The phase that followed this exploration phase was also interactive (many students and the

teacher made contributions), but the focus was on the authoritative voice of the teacher as she moved the discussion towards a particular scientific point of view. Finally, the lesson rhythm included sessions during which the teacher was the only contributor to the discussion as she reviewed the scientific point of view (non-interactive/authoritarian). Mortimer and Scott (2003) found that the students were successful with learning new science content when the lessons were fashioned so that these phases spiraled through the process. The process of learning involved periods when many voices (students and teacher) and many ideas were posed, as well as segments where only one voice, that of the teacher, was essential to introducing the scientific point of view. When attempting to help the students move from everyday talk to science talk, the teacher must employ both interactive and non-interactive methods for including both authoritative and dialogic discourse.

Not all classroom lessons involving scientific inquiry engage students in extensive, meaningful discussions about their work. In their study of the inquiry activities of 8th graders attempting to determine what factors affect the strength of a paper chain, Watson, Swain, and McRobbie (2004) found that types of communication associated with scientific work (justifying claims and argumentation) were absent from the students' conversations about the inquiry. Students' lack of opportunities to become involved with deeper conversations, as well as interfering socio-cultural practices, were cited as probable reasons that the discussion were not more scientific. These socio-cultural practices included (a) assumptions by the students and the teacher that scientific inquiry is a routine mechanical process, (b) the teachers' lack of pedagogical skills to facilitate discussions during inquiry activities, (c) the students merging of the data and the solution, (d) the classroom climate, and (e) the students' roles during typical class lessons.

Successful efforts to include all students, particularly those identified by a teacher as having special needs, in discussions during inquiry-based activities have been reported in the literature. One such study was based on Schwab's premise (as cited in Collins, Palinscar, & Magnusson, 2004) that for students to fully understand substantive scientific knowledge, they must also understand how this knowledge was generated through the processes of inquiry (syntactic knowledge). The research study focused on activities that intentionally involved 5th grade students in using scientific language and tools of scientific problem-solving grounded within the social context of the classroom but reflect scientific practices outside of the classroom

(Collins, Palinscar, & Magnusson, 2004). Especially important to the students' successes at being part of the discourse were the teacher's explicit efforts to demonstrate how to talk science and explain what it means to talk science. Five discursive strategies on the part of the teacher were identified during the implementation of the inquiry lessons. These included

1. explicit introduction of physical tools of inquiry and their labels in the context of the inquiry
2. introduction of conceptual tools and their labels in the process of inquiry
3. drawing boundaries around the problem space
4. revoicing to extend and clarify thinking
5. assigning roles and making expectations for appropriate participation explicit (p. 321).

Yerrick (2004) found that attempting to involve students in scientific discourse during inquiry-based activities was challenging partly because of the students' established comfort level with traditional science classroom learning environments. In his study of his own students who were primarily lower track Black students attending a rural high school in the south, Yerrick (2004) uncovered other obstacles to involving students in scientific discourse such as the students' expectations that the teacher's role was to provide the correct answers, as well as the teachers' lack of understanding of and skills for facilitating and negotiating whole-class and small group discussions revolving around inquiry activities. Yerrick (2004) concluded that moving classroom discourse away from the traditional classroom discourse to promoting scientific discourse resulted in resistance because of the increased discomfort, unpredictability, and open-endedness associated with unfamiliar inquiry-based discussions.

Students: Nature of Science and Scientific Inquiry

Students bring to the classroom their own ideas about the nature of science (NOS) and scientific processes that they have constructed from their experiences within and outside of the classroom. Their formal, classroom-based activities may or may not promote an understanding of the nature of science and the scientific processes consistent with the current conceptions previously stated (Chinn & Malhotra, 2002; Hogan & Maglienti, 2001; Khishfe & Abd-El-Khalick, 2002). However, part of the predicted potential of student involvement with inquiry-

based science activities is that students will progress in their views of nature of science and scientific processes (AAAS, 1993; Carey & Smith, 1993; NRC, 1996). While inquiry-based instruction appears to have somewhat of an impact on helping students' develop their conceptions of NOS and the scientific processes, it has not been the instructional panacea science educators had anticipated. Deboer (2006) suggested that part of the reason that scientific inquiry has not produced the expected learning results is due to (a) the emphasis on the physical methods of inquiry rather than both the methods and intellectual engagement and (b) the lack of attention to matching student learning outcomes to classroom instructional practices.

An example of inquiry-based instruction falling short of its predicted impact in the classroom was demonstrated by a study conducted by Hogan and Maglienti (2001). When these researchers examined middle school science students' responses to conclusions drawn after examining evidence collected during a watershed ecology program, they determined that students frequently incorporated their own personal views when deciding if the conclusions were suitable based on the presented evidence. Middle school science students were also likely to view the processes of science as involving scientists in procedural activities, such as making observations, taking measurements, and recording data, gathering factual information to help them answer their questions, or finding and testing cures. Their views of the questions scientists study were limited to those that are procedural in nature, or concerned with concrete events and objects.

In another study, many sixth graders who participated in the study done by Smith, Maclin, Houghton, and Hennessey (2000), tended to believe that after only one experiment or observation, scientists would decide whether or not to continue supporting an idea. It was unlikely that the middle school students, who had participated in traditionally structured science classes, recognized that scientists work at trying to understand, test, and develop ideas or viewed scientists as asking questions of theoretical substance or of metacognitive focus. On the contrary, sixth grade students who had been together throughout their entire elementary school experience and with the same teacher who emphasized constructive pedagogy, demonstrated very different ideas about the nature of science and the scientific process. This group of students, who had experienced a unique elementary science program in grades 1-6, viewed scientific processes as more than fact gathering and procedures to collect facts; they understood that scientists are motivated by understanding ideas, and testing and developing those ideas. They also recognize

that scientists ask complicated questions about theoretical and unobservable entities, as well as about their own thought processes.

Contrary to what might be expected, participation in inquiry-based activities may actually discourage the development of students' conceptual understanding of nature of science and scientific processes. Chinn and Malhotra (2002) proposed that by participating in simple inquiry activities in science classrooms, students may actually develop a nonscientific epistemology "in which scientific reasoning is viewed as simple, certain, algorithmic, and focused at a surface level of observation" (p. 190) as opposed to an epistemology of authentic scientific inquiry.

More attention to NOS during instruction could make a difference in the students' progress in understanding NOS, provided the students are developmentally ready to understand the concepts. Ryder, Leach, and Driver (1999) recommended that teachers give careful thought to the views of science they want to incorporate into their lessons prior to implementing them and then follow-up with explicit attention to these views during the lesson.

Contributing to the notion that explicit attention to NOS conceptions and scientific processes during inquiry-based lessons supports students' growth in these areas was further investigated during a study conducted by Khishfe and Abd-El-Khalick (2002). Using inquiry-based instruction that *explicitly* addressed aspects of nature of science with a group of sixth grade science students resulted in considerable growth in the students' perceptions of NOS with regard to the empirical, tentative, creative, and inferential dimensions. Contrary results were found with a second group of students who participated in the same inquiry activities as the "explicit" group of students except with this second group the lessons did not have NOS understanding as a cognitive outcome and the students' attention was not intentionally drawn to related NOS ideas through reflective discussions about NOS as was included with the "explicit" group of students.

Additional evidence for the value of students explicitly focusing on nature of science and scientific inquiry was provided by Schwartz, Lederman, and Crawford (2004) during their investigation of pre-service science teachers who were involved with authentic university-level science research. While they were skeptical that participating, alone, in inquiry-based lessons would support student progress in developing current conceptions of NOS and scientific inquiry, Schwartz et al. (2004) found that students involved with purposeful, active reflection about their

research experiences during journal writing and class discussions, advanced in their conceptions of NOS and scientific inquiry.

Teachers: Nature of Science and Scientific Inquiry

Teachers' perceptions of nature of science and scientific inquiry. Science teachers enter their classrooms with their own individual views about scientific knowledge, how that knowledge is developed, and how they can most effectively inspire their students to develop their own epistemologies of science. Lederman (1992) reviewed the studies of teachers' views of NOS and the processes prior to the publication of the national reform documents of science, during the time range 1950 to 1991. To summarize his analysis of the research, experienced and prospective high school science teachers held serious misconceptions about NOS, including views that science is positivistic and idealistic. Unfortunately, much of this early research about views of nature of science is suspect because "many of the instruments pre-date significant work in the philosophy and sociology of science and so are of limited value for the 1990s" (Hodson, 1993, p. 43). Caution in placing too much value on the results of studies prior to the early 1990s is also justified because of problems with the instruments and data analysis, including conflicting interpretations by different people (students and researchers) of scientific terms and language used verbally or on paper and pencil assessments (Aikenhead, 1987; Lederman & O'Malley, 1990; Zeidler & Lederman, 1989).

Since the release of the national documents in the early 1990s, research related to *practicing* teachers' conceptions of nature of science has been scarce. The focus of the research has moved from primarily examining practicing teachers' conceptions to those of *preservice* teachers who have participated in college philosophy and history of science courses or secondary science methods courses.

In a limited study of 12 secondary science teachers in New Zealand, Hodson (1993) investigated the relationship between the teachers' philosophical views about scientific knowledge gained from their involvement in scientific experimentation. The group of teachers reported evidence of a mixture of philosophies about experiments including "inductivist (emphasizing the priority of observation), verificationist (claiming that experiments are used to verify or 'prove' theories), hypothetico-deductivist (prioritizing theory and emphasizing falsification by critical experimentation), and contextualist (assuming that scientists employ

whatever investigative strategy they deem appropriate to the circumstances – i.e., there is no one method of science.)” (p. 45). Five of the twelve teachers’ philosophies indicated enough contradictions that they could not be labeled as one of the above views.

The results of a limited study of eleven experienced United Kingdom secondary science teachers indicated that this group of teachers was generally insecure about their limited knowledge of the history and nature of science, and presented little evidence that they reflected about nature of science (Lakin & Wellington, 1994). The research study by Abd-El-Khalick and BouJaoude (1997) of seventeen practicing middle and secondary science teachers in Lebanon demonstrated similar results. These teachers had earned bachelor degrees in fields of science and had a range of years of teaching experience, held many views of nature of science that were considered naïve and “fluid and incoherent” (p. 684). For example, most of the teachers described the process of doing science as a formal, rigid procedure that lacked creativity and imagination. Many teachers did not have well-developed understandings about the relationships between hypotheses, theories, and laws, or the theory-ladenness of scientific observations. The most comprehensive study (Zoller, Donn, Wild, & Beckett, 1991) examining 183 British Columbia teachers’ beliefs on issues related to science-technology-society topics, indicated that the teachers viewed scientists as being “completely objective, unbiased, disinterested human beings” (p. 31).

Opportunities within college courses and professional development may or may not contribute to teachers’ developing their own understandings of NOS and scientific inquiry. Lederman (1999) studied five experienced science teachers, four of whom held either M.S. or M.A. degrees in education or biology and had a wide range of teaching and non-teaching work experience. After these teachers had attended professional development workshops about the nature of science facilitated by the author, they held views of “the nature of science consistent with that advocated in the current reforms” (p. 919). However, even after participation in a science methods course and additional professional development that included instruction about NOS, one experienced 4th grade science teacher still expressed naïve views about the empirical and tentative nature of scientific knowledge, as well as misunderstandings about theories and laws, the role played in scientific work by creativity and imagination, and social and cultural influences (Akerson & Abd-El-Khalick, 2003).

The nature of science represented in the science classrooms. Before science teachers can enact instruction that supports NOS in their classrooms, they need to have their own internalized views of NOS. However, just because teachers have well developed beliefs about NOS, this does not imply that they necessarily externalize these NOS conceptions in their instruction. There is limited recent research available that examines practicing science teachers' representations of nature of science in their classrooms, and that which has been published has examined the classroom practices of preservice and practicing teachers who have been enrolled in courses and professional development specifically focused on nature of science and teaching nature of science. While these studies are valuable, they only provide a narrow view of the presentation of NOS in science instruction.

In one such study, the classroom instruction of five practicing biology teachers was examined for evidence of inclusion of nature of science concepts (Lederman, 1999). Even though all five of the teachers expressed views of NOS consistent with current conceptions about NOS, none included student understanding of NOS as objectives for their lessons. The instruction of the novice teachers in the group, who were still developing content pedagogy and learning to manage a room full of high school students, included no examples that they had a well developed grasp of NOS. Two of the three experienced teachers clearly taught their courses in a manner that supported NOS by including activities that required students to use scientific processes.

Eleven preservice science teachers participating in a different study recognized the value in including nature of science in their instruction. These preservice teachers expressed an interest in nature of science as a part of their lessons because of the added authenticity it gives the study of scientific concepts, the grounding it provides for developing scientific literacy, and the framework it creates for problem-solving and critical thinking (Bell, Lederman, & Abd-El-Khalick, 2000). Of these eleven students, nine followed-through with their belief of the value of including NOS in their instruction and explicitly incorporated NOS in their lessons. However, their instructional objectives did not include references to NOS, nor did their assessments include any evaluation of students' NOS conceptions.

A study of two first year science teachers who had graduated from a Masters of Arts in Teaching program with a strong NOS and inquiry emphasis underscored the importance of

teachers having a strong background in their science content area and NOS as well as sincere intentions in including NOS in their lessons (Schwartz & Lederman, 2002). This combination of knowledge and intentions provided the needed foundation for the success of these two new teachers to explicitly include NOS in their instruction.

The importance of collegial support for teachers who desire to include NOS in their instruction was revealed in an in-depth study of a 4th grade science teacher's instruction (Akerson & Abd-El-Khalick, 2003). This year-long study illustrated the disconnect between a teacher's strong understanding of NOS and sincere interest in including NOS concepts in her instruction, with the actual NOS focus within the lessons. Regardless of the teacher's NOS understanding, interest and intention, it was not until outside support was provided that the teacher incorporated NOS into her instructional practice.

The nature of science and scientific inquiry represented in textbooks. Apparently, students may not be exposed to modern conceptions of nature of science or the processes of science from their teachers or from the textbooks that are traditionally used for a majority of science class and homework assignments (Lumpe & Beck, 1996). In a dated study during which researchers examined five popular middle school science textbooks, Chiappetta, Sethna, and Fillman (1993) found that the texts were not reliable sources for students to learn about science as a process. Even though the texts did introduce nature of science topics early in their volumes, they limited the discussions about science as a way of thinking, and instead promoted one, formal scientific method by which scientists solve problems. In a more recent study of seven popular high school biology textbooks, Lumpe and Beck (1996) concluded that the emphases of the texts were science content knowledge that was not linked to nature of science and the processes used by scientists (e.g., developing theories). Science as a way of thinking was not stressed by the books' contents.

While the simple inquiry activities typically found in textbooks tended to support an epistemological view of science that is antithetical to authentic science epistemology, the inquiry activities designed by educational researchers provided a greater number of opportunities for students to experience a more authentic process of science because of the theory building and revising associated with these activities due to the inclusion of more complex models of data.

However, even the most authentic inquiry activities designed by educational researchers still lacked a focus on the theory-ladenness of data (Chinn & Malhotra, 2002).

The Practice of Scientific Inquiry in Classrooms

In spite of strong recommendations by science educators and the national science teachers' professional organizations for support of both inquiry- and problem-based instruction for science students in grades K-12, "serious discrepancies exist between what is recommended for teaching in the laboratory-classroom and what is actually occurring in many classrooms" (Hofstein & Lunetta, 2004; see also Bybee, 2000). In their analysis of literature published between 1982 and 2002, Hofstein & Lunetta (2004) concluded that students are still primarily involved with laboratory work that involves following explicit, cookbook instructions and collecting data to confirm well-established conclusions, with little focused thought about the deeper meaning of the activities. Even when students have opportunities to design their own experiments, make predictions, generate hypothesis, collect data, and draw conclusions about their investigations, they are superficially participating in the scientific process, focused on getting the pieces of the process finished instead of thoughtfully participating in the process and practicing the skills of scientific argumentation (Driver, Newton, & Osborn, 2000; Watson et al., 2004).

A myriad of factors inside and outside of the classroom constrain the implementation of meaningful, inquiry-based experiences even by those teachers who have a wealth of practice and knowledge about teaching science. Most of the literature has examined the implementation constraints from the teachers' perspectives. To a lesser degree, the influence of students, parents, the school science culture, and other factors outside of the school have been discussed.

Teacher beliefs. Many factors influence teachers' decisions about the content to include in classroom lessons, the instructional strategies to use, and how to manage the classroom environment. One powerful influence that impacts these decisions is the set of beliefs that a teacher brings to the classroom (Richardson, 1996). These personal beliefs are constructed and stored in experiences and events (Abelson, 1979) that occur throughout the teachers' lives, during their own schooling experiences (Lortie, 1975), and their experiences as teachers. These beliefs, which are tenable constructions created from previous events and experiences, powerfully influence interpretations of events in classrooms and cognitive knowledge. Even

though systems of beliefs are not bounded by internal inconsistency or validity, they might be more influential than knowledge structures when teachers react or respond to the ubiquitous classroom “ill-structured problems” (Nespor, 1987; Pajares, 1992).

Teachers’ beliefs act as filters when they try to make sense out of their classroom events as they make decisions and take action regarding classroom instruction and other situations (Borko & Putnam, 1996; Brand & Glasson, 2004; Calderhead & Robson, 1991; Fang, 1996; Guskey, 1985; Magnusson, Krajcik, & Borko, 1999; Richardson, 1996), and as they formulate educational values, prescribe guidelines and empirical claims, and categorize concepts (Bird, Anderson, Sullivan & Swidler, 1993). Based on a thorough study of 27 science teachers working in five different schools in two different school districts, J. Gallagher (1989) summarized the following assertions about science teachers’ knowledge and beliefs:

1. Science teachers believe it is their responsibility to present information to students and that it is the students’ job to learn it.
2. Teachers generally believe that able, motivated students will learn the subject matter, whereas those who lack ability and/or motivation will not.
3. Teachers believe that the quality of their work is high and that little improvement is possible without additional resources or altered conditions.
4. Secondary science teachers appear to have limited vision about their role and future directions for their work.
5. Nearly all secondary science teachers possess a very limited conceptual framework regarding teaching and learning.
6. Many secondary science teachers feel trapped and unappreciated in their jobs.
7. Many teachers are frustrated by conditions over which they have little or no control and fail to act concerning matters which they can influence.
8. Secondary science teachers demonstrate a high level of resiliency.

In her case study of two middle school science teachers, Cronin-Jones (1991) determined that the teachers’ beliefs about teaching, student learning, and the students’ intellectual abilities did influence their curricula delivery. Contrary to these findings, Haney, Czerniak, and Lumpe

(1996) and Lederman (1999) acknowledged that teacher beliefs are not automatically translated into subsequent teaching practices. After reviewing literature about teachers' beliefs about teaching and learning, Fang (1996) determined that there was no *consistent* relationship between these beliefs and actual teaching practices.

This inconsistency may be the result of two conflicting sets of beliefs teachers have - private and public - that compete as influences in decisions about classroom teaching practice (Wallace & Kang, 2004). The individual beliefs, which are private and *not* typically part of the required curriculum, are grounded in the teacher's notions about how students learn and how they can achieve in science. The public beliefs, which tend to be more constraining, include those associated with school culture (e.g., high-stakes testing, definition of course rigor, class time needs to be used efficiently, assumptions made about student ability; Tobin & McRobbie, 1996). Science teachers who have a strong set of public beliefs may completely resist considering teaching in any other way than to support traditional, mandated instructional goals (Yerrick, Parke, & Nugent, 1997), while for science teachers who may have strong private beliefs about the educational value of inquiry-based instruction, enacting these beliefs means struggling with the tensions created by these beliefs and public beliefs (Tobin & McRobbie, 1996).

Overview of impediments to implementing inquiry-based instruction. Teachers face a multitude of challenges coming from many different sources when attempting to include inquiry at any level within their science classrooms. Among teachers' major concerns for incorporating more inquiry into their curricula is the dilemma of committing the additional class time required for enacting the scientific inquiry process compared to other, more teacher-directed instructional strategies. Compounding this concern for efficiency is the pressure of preparing students for the end-of-course tests currently required for most science courses (Abd-El-Khalick et al., 2004; Chinn & Malhotra, 2002; Hofstein & Lunetta, 2004; Layman, Ochoa, & Heikkinen, 1996; Llewellyn, 2005; Loughran, 1994; Magnusson & Palincsar, 2005; Newton, Driver, & Osborne, 1999; Tobin & McRobbie, 1996). Additionally, teachers are concerned that even during well-planned guided inquiry students may not learn the specific science content knowledge required by science programs and standards testing requirements (Hofstein & Lunetta, 2004; Magnusson & Palincsar, 2005; Tobin & McRobbie, 1996; Wallace & Kang, 2004).

The lack of meaningful and rich inquiry-based experiences available for teachers may also interfere with using these kinds of activities in the science classroom. Chinn and Malhotra (2002) analyzed 468 inquiry activities from textbooks, trade books, educational software, and websites, and 26 educational researcher-developed inquiry activities and characterized them as involving either authentic inquiry or simple inquiry. The analysis of simple inquiry tasks found in texts, software, and websites showed that they involved students with few, if any, of the cognitive processes used by scientists in authentic scientific inquiry such as creating research questions, designing experiments to investigate the questions, collecting data, explaining patterns in data, proposing theories, and relating the research to existing research. The educational researcher-designed activities involved students in more authentic inquiry, but Chinn and Molhotra (2002) acknowledged that even the innovative researcher designed activities could be revised to include more authentic scientific inquiry. If resources supplying appropriate inquiry or problem-based activities are not available, the teachers will have to design their own. Developing the activities and providing the material resources needed by students involved in inquiry-based learning can be challenging for teachers (Abd-El-Khalick et al., 2004; Crawford, 1999; Eggen & Kauchak, 2001; Llewellyn, 2005; NRC, 2000b).

Teachers, who are accustomed to traditional, didactic instruction during which they are the transmitters of science knowledge and students are the receivers of the content, may have difficulty making the transition necessary to establish a learning environment conducive to scientific inquiry. Teachers who are comfortable with having ready answers for students' questions and solutions for their problems may struggle with assuming the new roles of facilitator and resource person and allowing students to make their own mistakes (Layman, et al., 1996). In her study of inquiry-based teaching, Crawford (2000) determined that implementing collaborative inquiry necessitates new roles for teachers that may be more complicated than educators originally thought. For example, during her study of a successful inquiry-based high school ecology class, the teacher took on the roles of motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner.

Teachers attempting to implement authentic classroom inquiry so that it is "minds-on" as well as "hands-on" may find themselves facilitating new kinds of conversations they are not accustomed to having with students, adding to the teachers' challenges of facilitating classroom inquiry (Crawford, 1999). In their study of high school students participating in four different

classroom projects during a project-based Conservation Biology class, Moss, Abrahams, and Kull (1998) determined that students' involvement with the project was limited to data collection with little time spent for discussions of data analysis, generating conclusions, or sharing the research results. Even though the projects were designed by scientists to answer questions of current scientific interest and the student collected data was reported to scientists, the students felt little ownership of the problems they investigated. Without intentional, purposeful scientific discussions and arguments about the experimental data collected during the projects, the students started and finished the year with undeveloped understandings of the scientific process. Contributing to the discussions being weak or even omitted, may be the teachers' lack of the pedagogical knowledge necessary to organize and facilitate these valuable student conversations (Driver, et al., 2000; Rowell & Ebbers, 2004).

Additionally, teachers who are accustomed to traditionally structured classrooms and controlled, ordered environments may face logistical challenges such as how to manage the students in a non-didactic environment and how to facilitate small group work so that the students reap the greatest benefit from the valuable social dimension of inquiry-based instruction (Crawford, 1999; Eggen & Kauchak, 2001; Llewellyn, 2005; Roehrig & Luft, 2004). Large class sizes, as well, contribute to the difficulty in implementing these non-direct instructional strategies (Munby, Cunningham, & Lock, 2000).

Successful planning and enactment of the inquiry-based activities, whether or not the teachers themselves have designed them, will depend on the teachers' science content knowledge, understanding of nature of science, understanding of how the science and NOS concepts interrelate, and how they are most effectively taught to and learned by students (Adams & Krockover, 1997; Brickhouse, 1990; Carlsen, 1993; Crawford, 2000; Driver et al., 2000; Duschl, 1988; Gess-Newsome, 1999; Roehrig & Luft, 2004; Shulman, 1987). Prior experiences working in the scientific fields and in classrooms can influence the success of inquiry-based instruction. In her study of a preservice science teacher, Crawford (1999) noted that the teacher's experiences as a successful research technician and in a classroom where her mentor modeled inquiry-based instruction were extremely valuable in her own successful implementation of inquiry-based instruction. For both teachers and students, past experiences in the classroom with solving inquiry lessons contribute to future successes with this instructional strategy especially in the areas of student collaboration, and finding and using resources (Roehrig & Luft, 2004).

These experiences may be especially important for preservice science teachers who have weak understandings of the nature of scientific inquiry (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005).

Working with students who have little experience with scientific inquiry may add additional hurdles for a teacher. Students who are accustomed to traditional science classroom instruction need to shift in their roles if they are going to be successful with inquiry-based instruction because they need to adopt new roles atypical for students such as being planners, teachers, apprentices, leaders, and collaborators (Crawford, 2000). Students who are asked to take on more responsibility for their learning and be more self-directed in their learning may feel a sense of discomfort, which may lead to a lack of success. Student resistance to adapting to new instructional strategies can be discouraging to innovative teachers (Loughran, 1994).

Additionally, relinquishing more responsibility and control of learning to the students is difficult for some teachers (Crawford, 1999; Polman, 2000) especially if they view the students as not being motivated, or mature or intelligent enough to be successful with inquiry-based instruction (Marx et al., 1994; Roehrig & Luft, 2004). Teachers report that they need confidence in themselves as teachers in order to relinquish some of the control of the lessons to their students (Loughran, 1994).

In addition to personal experiences within the classroom, influences from outside of the classroom through professional development, and collegial support from administrators, other science teachers, mentor and veteran teachers, expert community members, parents, and content specialists from local universities can be very influential when teachers are attempting to reform instruction. Collegial pressure to maintain the instructional status quo or to support reforming the compartmentalized view of science backed by the curriculum, and traditional teaching and student assessment practices, may affect the decisions teachers make about their instruction (Brickhouse & Bodner, 1992; Crawford, 1999; Duschl, 1988; Fensham, 1993; Gruender & Tobin, 1991; Loughran, 1994; Marx et al., 1994; Munby, Cunningham, & Lock, 2000; Tobin & McRobbie, 1996; Wallace & Kang, 2004).

Summary

During the last two decades the science education literature has been replete with many discussion threads dialoguing and debating about the past condition and future directions of the

education of science students in grades K-12. Many of these discussions grew out of the convictions of science educators that students' futures would be enhanced and enriched if they matured into young adults who have substantial knowledge of scientific concepts and principles, as well as understandings and skills associated with scientific ways of knowing, thinking, and doing (AAAS, 1990, 1993). Concomitant to this appeal for a future, scientifically literate populace, a growing body of literature posed fundamental changes in educators' ideas about how students learn (for example, see Bransford & Donovan, 2005; Lave, 1988; Piaget & Inhelder, 1969; Vygotsky, 1978, 1986; Wertsch, 1991). These renovated educational philosophies which underscore the social dimension of learning and the role of language in learning, laid the foundation for a reformation of best practices for teaching science. One of these best practices, scientific inquiry, has been touted as an instructional strategy that may be the "best" of the best practices (NRC, 1996, 2000b).

The practice of scientific inquiry in science classrooms and students' and teachers' understandings of NOS and the methods of science have been well documented; however, this literature is based primarily on research conducted with elementary and middle school science students or preservice and inservice teachers (for example, see Hogan & Maglienti, 2001; Khishfe & Abd-El-Khalick, 2002; Schwartz et al., 2004; Smith et al., 2000). The many studies that have been conducted that focused on appraising both novice and experienced teachers' beliefs and assumptions concerning the nature of scientific knowledge indicated that it is common for teachers to have underdeveloped views of the nature of science. While it should not be presumed that *no* teachers have mature conceptions of NOS, rather than repeat the many studies that examined teachers' and students' conceptions of the nature of science, the emphasis of this study will be on the *practice* of scientific inquiry and representations of NOS within the scientific inquiry activities in the classrooms.

Few published documents provide insight into the practice of scientific inquiry in secondary science and agriculture classes. Likewise, the nascent literature examining students' voices in science classes is meager with regard to participation in scientific inquiry. Because of the gaps in the literature, the goal of this research is to contribute to the evolving discourse concerning the practice of scientific inquiry in high school classrooms. Specifically, the purpose of this study is to gain understandings regarding how scientific inquiry is conducted in secondary classes, with a focus on the opportunities for students to confront their views of the NOS and

how students' and other voices are incorporated into the scientific inquiry. As this picture of the practice of scientific inquiry in secondary classes develops with a clearer focus, the science education community will have a more substantial basis for the preparation of future science teachers particularly with regard to encouraging students' voices during scientific inquiry and promoting students' understandings of the nature of science and the methods of scientific practice.

CHAPTER TWO

RESEARCH METHODOLOGY

Purpose of the Study

The purpose of this research was to gain a greater understanding of the practice of scientific inquiry in high school science and agriculture classes within the context of the Partnership for Research and Education in Plants (PREP). While the general focus of this study was on the overall practice of the scientific inquiry in the classrooms, particular attention was given to (a) the teachers' interests in and intentions for the general implementation of the scientific inquiry, (b) how the nature of science was represented throughout the inquiry activities, and (c) how different ideas were given power and voice in the classrooms during the inquiry activities.

Strategy of Inquiry: A Case Study of the Practice of Scientific Inquiry in Secondary Science and Agriculture Classes

For this research, a case study was employed as a strategy of inquiry, or the “bundle of skills, assumptions, and practices that the researcher employs as he or she moves from paradigm to the empirical world” (Denzin & Lincoln, 1998a, p. 36). Case study as a strategy was particularly well suited to this investigation because of two major features of the research – *depth and boundedness*. While Leedy and Ormond (2001), Creswell (1998), Ary, Jacobs, and Razavieh (2002), and Merriam (1998) cite depth as a distinguishing characteristic of case studies, they do not agree on *what* is attended to in depth during case studies. Merriam (1998) describes case studies as “a design...employed to gain an in-depth understanding of the situation and the meaning for those involved” particularly with a focus on “process rather than outcomes...context rather than a specific variable...discovery rather than confirmation” (p. 19) chosen “because it is an instance of some concern, issue, or hypothesis” (p. 28). Her description of case studies supports the focus of this study because the research involved the thorough examination of the process by which students and teachers participated in scientific inquiry. Because this study involved a restricted number of classrooms, classrooms in which the same curriculum was being implemented during spring semester 2006, the research was bounded because it was limited “by time and place” (Creswell, 1998). This characteristic of boundedness

is cited by Merriam (1998) as the “single most defining characteristic of case study research” (p. 27). Both of these requisite characteristics of case studies, depth and boundedness, influenced the chosen strategy of inquiry.

While the presented justification for the case study strategy of this research may seem straight-forward on the surface, qualitative researchers do not necessarily agree on what a case study is. “A case may be theoretical or empirical, or both; it may be a relatively bounded object or a process; and it may be generic and universal or specific in some way” (Ragin, 1992, p.3). Qualitative researchers may not even consider a case study as a qualitative research strategy. While Stake (1994) credits case studies with both process and product dimensions, Wolcott (1992) supports a concept of case studies that “does not implicate any particular approach. [Case study] can be most appropriately regarded as an outcome or format for *reporting* qualitative/descriptive work...” (p. 36).

As well, the boundedness feature of case studies may be somewhat misleading because each case has many dimensions and contexts which contribute to its complexity (Stake, 1994). This boundedness may be a result of researchers “trying to make sense of (the empirical world) by limiting it with our ideas” (Ragin, 1992). For example, while the focus of this study is the practice of inquiry within the context of PREP, it should *not* be limited to the curriculum implementation because there are multiple dimensions that are inextricably linked to the curriculum presentation such as the students and teachers, the rest of the course curriculum, and the school schedule. In addition, this curriculum is being enacted within the potent cultural, political, economic, and social contexts of the public school classrooms; the particular schools; and the local, regional, state, national, and international communities within which the schools are located.

The Research Sites and Participants

Selection criteria. This research study focused on the practice of scientific inquiry within the classrooms of three teachers who responded to the invitation to participate in the study during the six to ten weeks they integrated PREP into their courses. A total of nine science and agriculture teachers across the state planned to use PREP during the March – June 2006 research timeframe and seven of these teachers were contacted to see if they would be interested in participating in the research study. Two were not contacted because they and their students were already involved in an extensive assessment of PREP by an external evaluator. Of the seven

teachers contacted, four agreed to the conditions of the research study, and thus, their classes were involved when the research began in January. Several weeks into the inquiry, one teacher dropped out of the study because his students' plants died and therefore their involvement with the scientific inquiry halted. The primary researcher shared no professional or personal history with the participating teachers prior to the study.

In one respect, this sampling was purposeful in that teachers and classrooms that provided information-rich and diverse sites were intentionally sought (Patton, 1987). On the other hand, the convenience aspect of the sampling cannot be ignored because these three teachers, Bonnie, Janet, and Sara, were the *only* teachers who expressed an interest in the study and followed-up on that interest by making a commitment for the entire span of the study. While it was a goal of this study to include schools and classes representing diverse student populations and different school communities, this diversity element of the research was only partially realized with the three teachers and student groups who participated in the study. The majority of the students and all of the teachers involved in the research were Caucasian; however, the schools' student populations were diverse in that one school was a small, rural school (Riverview High School); one was a small, private day and boarding school (St. Catherine's Academy); and the third was a small school specializing in meeting the academic needs for students particularly interested in attending a school with a science, math, and technology focus (Stuart Springs Governor's School for Science, Mathematics, and Technology). Table 1 summarizes key information about the three different research school sites, teachers, courses, and students.

Stuart Springs Governor's School for Science, Mathematics, and Technology, Bonnie, her biology course, and her students. Stuart Springs Governor's School specializes in offering a curriculum designed for high school students interested in attending a school with a math, science, and technology curricular focus. Students in grades 9-12 living in the city in which Stuart Springs Governor's School is located, a small city nearby, and five surrounding counties gain admissions to Stuart Springs Governor's School through an application process administered in their home schools. During the 2005-2006 school year, approximately 260 students attended Stuart Springs Governor's School. Of these 260 students, 47% were female and 53% were male; 90% were Caucasian, 3% African American, 6% Asian, and 1% Hispanic. The school *Program Overview* included with students' college applications quotes a 1324

average SAT score for the students in the class of 2005, over \$2.1 million awarded in scholarship offers, and seven National Merit Commended Scholars.

Bonnie is an experienced Biology teacher with both undergraduate and graduate level coursework in Biology, as well as experience with scientific research. In addition to the biology courses at Stuart Springs Governor's School, she teaches chemistry and the Fundamentals of Research course required of all 9th graders. Bonnie had incorporated the PREP experiments into her Biology course twice before the semester of this dissertation research study.

The biology course into which Bonnie incorporated the *Arabidopsis thaliana* experiments was the students' first high school biology course. The dual-enrollment status of this course allowed for Bonnie's 11th grade biology students to receive both high school and community college credit for the class provided they paid tuition fees at the local community college and maintain passing grades. In addition to designing a biology course that accommodated the community college's expectations, Bonnie and her students were also held accountable to the standards tested on the end-of-course Biology test required by the state.

The sixteen students in Bonnie's dual-enrollment biology class included seven male students and nine female students. Among this group, fourteen of the students were Caucasian; one male appeared to be African-American and one male appeared to be of Middle Eastern descent.

St. Catherine's Academy, Janet, her biology course, and her students. St. Catherine's Academy is a private Christian (no particular affiliation), co-educational college preparatory school that enrolls day and boarding students in grades preschool-12 from local, national, and international locales. The school buildings are situated under ancient oaks on a hilltop in a small city that is home to a large state university. St. Catherine's Academy supports rich extra-curricular and athletic programs and is recognized by the Boarding School Review (<http://www.boarding-school-review.com>) as a top-20 boarding school for high Scholastic Aptitude Test scores. St. Catherine's Academy prides itself on maintaining a rigorous curriculum designed to prepare students for admissions to competitive universities. The Boarding School Review

Table 1

Teacher, Student, and School Profiles

Teachers' names ^a ; Backgrounds	Courses; Students	Schools ^a ; School descriptions
Sara Novice teacher BS Animal Science, MS Agriculture Education Experience in horse training industry No science research experience Implemented PREP once before semester of study	One class Agricultural Mechanics and Basic Plant Science I Fifteen 8 th , 9 th and 10 th graders 12 males, 3 females One African American male, 14 students Caucasian	Riverview High School Public high school Located in rural community Approximately 350 in grades 8-12; 50% male, 50% female 27% of students qualify for free or reduced lunch 99% of students Caucasian, 1% Hispanic and Asian
Janet Experienced science teacher BS and MS Education, MS Environmental Science Experiences with research while working with US Army Corps of Engineers and US Geological Survey No prior experience with PREP	Two Biology classes Twenty 11 th and 12 th graders (a few) Fourteen female, six male One Korean male, one Nigerian male, and one African American male, 17 students Caucasian	St. Catherine's Academy Private Christian co-educational day/boarding school Located in small city; home to a nationally ranked university Approximately 330 students in grades 9-12, 15% boarding, 11% international; 9% "students of color" School goals include preparing students for entry into competitive universities
Bonnie Experienced biology teacher and student research project mentor BS Biology, MA Liberal Studies Biology research experience Implemented PREP twice before semester of research study	One dual-enrollment Biology class Sixteen 11 th graders Nine female, seven male One African American male, one Middle Eastern male, 14 students Caucasian	Stuart Springs School for Science, Mathematics, and Technology Public specialty school Approximately 260 students in grades 9-12; 47% female, 53% male; 90% Caucasian, 3% African American, 6% Asian, 1% Hispanic Students from seven rural and city school systems apply for admission School goals include meeting students' interests in advanced science, math, and technology courses and preparing for entrance to competitive universities

^a Pseudonym.

reports that 9% of these students are “students of color,” 11% are international students, and 15% are boarding students. School statistics regarding the student male-female ratio are not available. Approximately 330 of these students were enrolled in the upper school program (grades 9-12) in 2005-2006, the year the study was conducted.

Janet, an experienced science teacher at St. Catherine’s Academy, incorporated the *Arabidopsis thaliana* research for the first time with her biology class during the semester of the research study. Prior to joining the science teaching profession late in her career, Janet worked with the US Army Corps of Engineers and the US Geological Survey on different projects including research and writing various materials. Her educational experiences include graduate level coursework and research experiences in Environmental Science and geology.

Two of Janet’s first-year Biology classes were involved in the research. The Biology course is the students’ first biology course in high school, and because St. Catherine’s Academy is a private school, students are not required to take the end-of-course Biology test required of students enrolled in the state’s public schools. Twenty students, mostly 11th graders, were enrolled in these two courses with female students totaling 70%. One male student was African American, one male student was Korea, and a third male student was from Nigeria. The remaining students appeared to be Caucasian.

Riverview High School, Sara, her agriculture course, and her students. Riverview High School is a red-brick structure characteristic of schools built in the early 1960s. In 2005-2006, the small, rural public high school enrolled approximately 350 students in grades 8-12, with 27% of the student body qualifying for free or reduced lunches. The student body is 50% female and 50% male, with 99% of the student body identified as “White,” and 1% Asian and Hispanic (<http://www.publicschoolreview.com>).

During the semester of the research study fieldwork, Sara was completing her first year teaching agriculture courses at Riverview High School. Prior to that school year, Sara had worked in the horse training industry for a year after completing a bachelor’s degree in Animal Science and an advanced degree in Agricultural Education. Her return to education was partially inspired by the politics of the horse-training industry. Sara had no experience with scientific research. Sara had implemented the PREP experiments with her agriculture classes once prior to the semester of the dissertation research.

Sara's 1st period Agricultural Mechanics & Basic Plant Science I class participated in the research. This class included 15 8th, 9th, and 10th graders, 12 males and three females. Of these 15 students, all appeared to be Caucasian with the exception of one African American male. The state-wide Career and Technical Education tasks and competencies guided Sara's lesson planning for the Agricultural Mechanics & Basic Plant Science I course.

Data Collection

Because "understanding the case in its totality, as well as the intensive, *holistic* description and analysis characteristic of a case study, mandates both breadth and depth of data collection" (Merriam, 1998, p. 134), a wide variety of typical case study data sources were included in this study (Denzin & Lincoln, 1994; Merriam, 1998). Data were collected during the winter and spring of 2006 through class observations and informal class conversations, formal teacher interviews and student group interviews, students' work, and related course documents. Table 2 provides a detailed description of data sources for this study.

Class observations. Merriam (1998) identifies four different roles that a researcher may fulfill during field work: (a) complete participant, (b) participant as observer, (c) observer as participant, and (d) complete observer. The researcher's role in the classroom settings during the field studies was *observer as participant* (see also Gold, 1958) with an observation focus on the day-to-day activities and discussions during the practice of the scientific inquiry. In this stance, it was hoped that it was clear to the teachers and students that the researcher's primary purpose was to observe the inquiry process enacted in their classes. This role of being *observer as participant* did allow for some limited interactions with the teachers and students; however it was secondary to the observation focus of the role. One disadvantage of assuming this *observer as participant* role instead of a role that involved more time spent at the field sites resulting in more interactions with the teacher (e.g., complete participant or participant-observer), is that the researcher might have been more likely to misunderstand the teacher, the activities, and the discussions experienced in the field (Gold, 1958). Multiple visits to each site, instead of only one as discussed by Gold (1958), were scheduled in hopes of minimizing this potential problem.

Table 2

Summary of Data Sources Related to the Teachers and their Students and Schools

Teacher	Interviews	Class observations	Documents
Bonnie	Teacher: 7 Student group interview: 1 (four students)	9	<p>Bonnie's Handout, <i>Arabidopsis Lab Guidelines</i></p> <p>Students' final lab reports and a selection of lab notebooks</p> <p>State Standards of Learning for Biology</p> <p>School website including</p> <ul style="list-style-type: none"> • Background information about the school • Biology Course Information • Biology Competencies/Objectives • Bonnie's Semesters I and II Class Calendar <p>School flyer with limited student demographics provided by guidance counselor</p> <p>School Program Overview provided by guidance counselor</p>
Janet	Teacher: 6 Student group interviews: 3 (seven students)	7	<p>Janet's student handouts</p> <ul style="list-style-type: none"> • <i>How to Write a Scientific Lab Report for Biology</i> • Botany Vocabulary and Labeling Test (Chapters 24, 25, 26) • <i>Guidelines for Arabidopsis Independent Research Project</i> • Phenotypes from PREP website • Methodology Rubric Peer Review • Quickie Quiz Chapter 26, Nutrition and Transport in Plants • Discussion Section of <i>Arabidopsis</i> Paper • Student Evaluation Sheet for class discussions about genetically engineered plants • The Final Report on <i>Arabidopsis thaliana</i>, <i>Writing an Abstract</i>

(table continued)

Table 2 (continued)

			<ul style="list-style-type: none"> • Presentations and the Final Report on <i>Arabidopsis</i> • Sections of final exam related to <i>Arabidopsis</i> investigations <p>Students' final group lab reports</p> <p>School information from the school website and the www.boardingschoolreview.com and www.greatschools.net websites</p>
Sara	Teacher: 6	10	<p>Students' papers describing their treatments and materials needed</p> <p>Students' final papers</p> <p>Competency-Based Tasks/Competencies for Agricultural Mechanics and Basic Plant Science I from state Career and Technical Education website</p> <p>School information from www.publicschoolreview.com and www.greatschools.net websites</p>
	Student group interview: 0		

Throughout the duration of the study, all three teachers stayed in frequent contact with the researcher concerning their weekly plans so class observations could be scheduled when the students were most actively involved with their *Arabidopsis thaliana* inquiries. Ultimately, the teachers made the decisions concerning when the researcher would be present in the classroom to observe. The researcher observed classes at least once a week, on those days when the students spent the most time on their experiments. Janet’s classes were observed seven times, Bonnie’s class was observed nine times, and Sara’s class was observed ten times. Table 3 provides a summary of frequency and timeline of the interviews and observations.

All three teachers used a very small portion of class time one or two other days during the week for students to water their plants, give their plants the experimental treatment, and record observations. Since the researcher’s observations of the classes were usually limited to one day a week, the teachers were asked during interviews to talk about the students’ activities on the days the researcher was not present.

Table 3
Chronology for Interviews and Classroom Observations During the Practice of Scientific Inquiry

Teacher	January		February				March				April				May				June	
	23	30	6	13	20	27	6	13	20	27	3	10	17	24	1	8	15	22	29	5
Sara							CO	CO	CO		CO	CO	CO		CO	CO	CO	CO		
	TI						TI		TI				TI		TI					TI
Janet									CO	CO	CO	CO	CO		CO	CO				
							TI		TI	TI	TI	TI				TI				
															SGI	SGI				
															SGI					
Bonnie								CO			CO	CO		CO	CO	CO				
										CO						CO				
		TI						TI		TI	TI			TI		TI				TI
																		SGI		

Note. CO = Classroom observation; TI = Teacher interview; SGI = Student group interview.

Because one of the goals of the study was to explore the practice of inquiry in a variety of settings, working with three different teachers, each one day during the week when the students did the most work was preferred over being in one teacher’s classroom three or more times a

week. In addition, the travel time between the school locations and the university (Riverview High School = 45 minutes, Stuart Springs Governor's School = 1 hour and 15 minutes, St. Catherine's Academy = 3 hours) and the distances between the schools interfered with arranging more frequent visits.

The numerous observations in each classroom allowed for the researcher to get to know the setting within which the scientific inquiries were being implemented, as well as how the teachers and students participated in the inquiry. (Emerson, Fretz, & Shaw, 1995; Walker & Alderman, 1975). Noted in the documentations of the physical settings were observations about the arrangements of classroom furniture, science equipment, posters hanging on walls, available technology and audio-visual equipment, student seating, and spaces used by students and teachers. The comprehensive field notes about the activities in the classroom include details about the general activities in the classroom during the observation period. The researcher attempted to document the interactions among the students and teachers, as well as teachers' directions and comments during whole-class discussions. Notes were also recorded about intercom announcements and class visits by other teachers, students, administrators, and scientists. When possible, notes were recorded while the teachers and scientists worked with the students both individually and when they were active in their small groups. Informal interactions between the researcher and teachers and students were also recorded in the field notes.

Interviews. In order to “[understand] the experiences of other people and the meaning they make of their experience” (Seidman, 1998), interviews were conducted with both teachers and students. In the classroom, in addition to observing and writing field notes, the researcher often moved around the classrooms and informally talked with teachers and students about the work that was being done on the experiments. The three participating teachers were also formally interviewed using a semi-structured format before, during, and after the students worked on their experiments. The semi-structured nature of the interviews involved asking open-ended questions that provided some structure to the process and guided the direction of the interview. However, this questioning strategy gave the teachers some flexibility in introducing their own views about implementing scientific inquiry in secondary classrooms, in hopes that their comments would shed light on the meanings they have made of their experiences in the classroom (Seidman, 1998). (See Appendix A1 for interview question guide for teachers' interviews.) The teachers were always asked to choose a place for their interviews which were

held in a variety of locations including teachers' offices, empty classrooms, a shop area, an outdoor patio, and a school library. Sara and Bonnie were each interviewed seven times and Janet was interviewed six times. While the original research plan was to talk with the teachers after each class observation, this proved to be impossible primarily because of the teachers' schedules of prior commitments.

After some rapport had been established between the students and the researcher through her presence in the classroom and the opportunities they had to interact informally during class sessions, she spoke with the classes about the students' involvement in group interviews. All students were given the student assent and parent consent forms necessary for their participation in an audio-taped interview. The students were also assured that their decisions to participate, or not, in the interviews would have no bearing on their grades. While none of Sara's students assented to participate in a group student interview, four (25%) of Bonnie's students and seven (35%) of Janet's students agreed to talk with the researcher about their experiments attempting to shed light on the function of the gene removed from the plants. (See Appendix A2 for the interview question guide for the semi-structured student group interviews.) The group student interviews were held in locations set aside ahead of time by the teachers. These locations included a hallway, a lab preparation room, and an empty teacher's office. All formal individual and group interviews were audio-taped and transcribed by the researcher during the week following the interview.

"Asking questions and getting answers is a much harder task than it may seem at first" (Fontana & Frey, 1994) and the answers provided by the interviewees were likely to be the ones that they thought the interviewer wanted to hear (Wolcott, 1992). In addition, bringing a tape-recorder into the interview environment may have influenced teachers' and students' contributions to the interview (Flick, 2002). Very careful prior thought, on many different dimensions, was given to designing and participating in the interview process. Care was taken when designing the interview questions to use language familiar to the interviewees and to avoid using jargon or expressions of which they may be unfamiliar (Merriam, 1998). Through careful listening during the interview, follow-up questions were used to clarify and expand on previous participant's comments. Attempts were made to not assume that the participant and researcher shared common knowledge academic concepts (such as the meaning of "inquiry"). Rather than presuming that there was a shared understanding of participant's comments, the researcher

attempted to delve deeper into the meaning of the comments to hear about the participant's understandings of their spoken words. In addition, the researcher tried to be conscious of refraining from offering judgmental or reinforcing responses, posing questions that led the participant toward specific responses, delving deeper into responses for concrete examples, seeking clarifications of participants' comments when necessary, minimizing interruptions of the participant, being aware of issues initiated by the participant so that these could be addressed, staying focused on the purposes of the interview and not detouring into side conversations, and asking the participant to share information of which they had first hand knowledge rather than asking them to give information about matters with which they have no direct experience (J. Nespor, personal communication, 2004; Partington, 2001; Seidman, 1998).

As recommended by Briggs (1986) attention was also focused on the indexical meanings of the participant's gestures, choice of words, sentence structure, and acoustic aspects speech such as voice pitch, tone, loudness, and length of responses. Seidman (1998) recommended listening to a participant on three different levels: (a) the level of concrete content provided by the participants – the public voice, (b) the level of the guarded, more private voice, and (c) the level of the overall structure of the interview (e.g., nonverbal cues). An example of the guarded, private voice to which Seidman (1998) was referring could be a teacher responding that teaching in any other way but using direct instruction in her class would be a *challenge*. This may be an indication that she is “grappling with a difficult experience but not the struggle” (Seidman, 1998, p. 64). Delving deeper into why using alternate teaching strategies is a challenge may shed light on the struggle that is felt by the teacher.

Because of the potentially hierarchical nature of interviews and because the differences in real and perceived power of the interviewee and the researcher may influence the interview outcomes (Oakley, 2001; Fontana & Frey, 1994), the researcher attempted to minimize the power differential. The teacher's knowledge of the researcher's 30-year teaching history invariably impacted the research relationship which could have been both beneficial and counterproductive because the researcher may have been viewed as someone who considers herself sympathetic to teachers' concerns or an “expert.” It was extremely important from the first contact with the teacher that the researcher made it clear that just she does not consider herself an educational expert.

Related documents. In addition to interviewing the teachers and students and observing in classrooms, teachers were asked to provide copies of their lesson plans, student handouts, supplemental materials, and evaluation tasks that related to their lessons. The purpose of examining these documents was to see how the teachers incorporated science content, nature of science, and the essential features of scientific inquiry into the documents. Student culminating work, such as lab reports and final experiment papers, were examined for evidence of the connections to the scientific inquiry activities.

Other related documents were retrieved from school or commercial web-based sites. Online documents posted on the Partnership for Research and Education in Plants website were also relevant to this study because the teachers and students accessed the website for support during their experiments.

Data Analysis

In order to address the research questions, data were collected and analyzed regarding the following themes: (a) the teachers' interests in and motivations for implementing scientific inquiry in their courses, (b) teachers' plans for the implementation of scientific inquiry, (c) instructional strategies employed during the inquiry experiences, (d) the tenets of the nature of science incorporated into the inquiry lessons, and (e) the voices participating in the scientific inquiry. The analysis of interviews, field notes, and artifacts collected during this qualitative research began with the first interviews and observations and continued throughout the data collection and beyond. The advantage of analyzing data simultaneous to the data collection process was that it provided opportunities for the research to be shaped as the research study proceeded (Merriam, 1998).

The analysis continued with the reading and re-reading of the interviews, class observation transcripts, and other documents, and it was during this analysis that several of the categories and subcategories were drawn from the major themes of interest. These categories and subcategories, as well as others, evolved from various sources: (a) the research questions, (b) related literature, (c) the meanings the participants gave to the study, and (d) from the research (rather than having been formalized prior to the start of the research) (Janesick, 1998; Merriam, 1998). Table 4 summarizes the five themes and their resulting categories and subcategories. Through comparisons within these categories and subcategories and attention paid to negative

examples, a working model of the practice of scientific inquiry in secondary science and agriculture classes was developed (Flick, 2002; Janesick, 1998; Merriam, 1998).

Teachers' interests and motivations for incorporating PREP into their courses.

During the teacher interviews throughout the study, teachers were asked to reflect, in general, on their interests in and reasons for incorporating PREP into their biology or agriculture courses. In addition, teachers' verbal and written goals or objectives for their students were also examined for evidence of their reasons for including the inquiry in their courses. During the repeated reading and reviewing of the collected data, these interests were thematically coded into three categories (Flick, 2002; Merriam, 1998). The categories included (a) the administratively mandated implementation of scientific inquiry, (b) the perceived value of their students participating in a research experience, and (c) the features of the inquiry specific to PREP.

Teachers' plans and intentions for implementing the inquiry activities. During the initial semi-structured interviews and prior to the students starting their work on the experiments, the teachers described their plans for the inquiry work in their classrooms. Teachers' self-described (as opposed to administratively mandated which the teachers did not include in their discussion) plans for the inquiry fell into one of two categories: (a) the structural aspects of the inquiry such as how they would group the students into teams and the kinds of student work they would collect, and (b) their students' cognitive engagement in the inquiry process. Subcategories for this theme can be found in Table 4. Despite the plans to collect and analyze teachers' written plans for the inquiry activities, none of the teachers had any written plans, goals, or objectives for the scientific inquiry activities.

Instructional activities that supported the scientific inquiry. In order to gain an understanding of the general practice of scientific inquiry in the three different classrooms, a closer examination of the classroom activities within which the inquiry was embedded was important. Field notes of the classroom observations and interviews were analyzed for evidence of the activities that supported the scientific inquiry experiences in each classroom. These strategies primarily included interactions (a) among the students themselves and (b) students and adults who could be considered to have a greater expertise with scientific research than the students themselves. These interactions included both formal and informal discussions, peer review exercises, and assignments turned in progressively during the inquiry. Table 4 summarizes the different sub-categories of these activities.

Tenets of the nature of science made explicit or implied during the scientific inquiry. The categories for the tenets of the nature of science of interest for this research were taken from the science education literature regarding scientific inquiry (AAAS, 1993; Abd-El-Khalick & Lederman, 2000; Lederman, 2006; NRC, 1996; Rutherford & Ahlgren, 1990; Schwartz & Lederman, 2002). Instead of the categories emerging from the analysis of the research evidence as was the case with the previous themes, the tenets of the NOS of interest were those that were determined to be relevant and within intellectual reach for school students (Lederman, 2006) as well as those most likely supported by the context of the *Arabidopsis thaliana* experiments in high school classrooms. These three categories, or tenets, of the nature of science included: scientific knowledge is (a) usually generated through empirical practice, (b) socially and culturally embedded, and (c) theory-laden. Subcategories for these three categories, also defined by the literature, are summarized in Table 4.

In order to distinguish between explicit and implicit instruction concerning the nature of science, those activities that involved students in intentional discussions and reflections about the nature of science were considered to be *explicit* (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-

Table 4

Summary of Analysis Themes, Categories, and Subcategories

Theme	Category	Subcategory
1. Interests in and motivation for implementing scientific inquiry	A. Administrative mandate	<ol style="list-style-type: none"> 1. State-level standards or competencies 2. School-level expectations 3. Departmental expectations
	B. Student involvement in research process	<ol style="list-style-type: none"> 1. Students have to think critically 2. Students will learn more about designing and doing experiments 3. Students will learn more about communicating scientific research results 4. Teachers anxious for students to experience the thrill of scientific research before they did as students 5. Experience may be useful when making future decisions about careers
	C. Research context- PREP	<ol style="list-style-type: none"> 1. Supports course content 2. Exposes students to biotechnology issues 3. Involves students in authentic, relevant research 4. Students interact with people (scientists) outside of the classroom 5. PREP has a history of success 6. PREP experiments are age-appropriate 7. Meets state standards for courses 8. Experiments useful for future science fair and projects
2. Plans and intentions for scientific inquiry activities (There were no written lesson plans for the inquiry; all plans and intentions were verbally described by teachers.)	A. Structural aspects	<ol style="list-style-type: none"> 1. Time committed to inquiry each week 2. Order of activities during the inquiry 3. Students to work in groups 4. Assignments that students would turn in 5. Integrating the inquiry activities with other class work
	B. Students' cognitive processes	<ol style="list-style-type: none"> 1. Students involved in class and group discussions about research 2. Plans to help students think about and make decisions about their experimental designs, how to analyze data, how to communicate data 3. Scientist visit will give students chance to think about their experiments

(table continued)

Table 4 (continued)

3. Activities during scientific inquiry experiences	A. Student-Student Interactions	<ol style="list-style-type: none"> 1. Students' discussions within groups 2. Students' discussions across groups 3. Peer review of students' work 4. Whole class discussions about inquiry 5. Optional PowerPoint or poster presentation of research
	B. Student-"Expert" Interactions	<ol style="list-style-type: none"> 1. Online scientific resources 2. Whole class discussions led by teacher 3. Whole class discussions led by PREP staff-scientist 4. Students' informal discussions with teachers during their classroom visits 5. Students' informal discussions with scientist and PREP staff-scientist 6. Optional PowerPoint or poster presentation of research 7. Progressive assignments due during inquiry work-introductions, methodologies, analyses; final research papers and lab reports 8. Textbook assignments concerning plants 9. Quiz, tests, and final exam questions about experiments or context
4. Features of the Nature of Science Implied during Inquiry Activities	A. Tenet 1: Scientific knowledge is usually generated through empirical practices.	<ol style="list-style-type: none"> 1. The nature of the empirical investigation 2. Equipment use
	B. Tenet 2: Scientific knowledge is socially and culturally embedded.	<ol style="list-style-type: none"> 1. Basing inquiry on norms of scientific practice with regard to collaboration, collecting, analyzing, representing communicating findings; basing work on previous work of scientists 2. Connections between students' work and politics, economics, social, and philosophical influences
	C. Tenet 3: Scientific knowledge is theory-laden (or subjective).	<ol style="list-style-type: none"> 1. Basing decisions about their work on their experiences, education, interests, values, knowledge

(table continued)

Table 4 (continued)

5. Voices	A. Students' voices	<p>Spoken</p> <ol style="list-style-type: none"> 1. Team discussions 2. Team members seeking help from teachers 3. Whole-class discussions led by teacher 4. Team conversations with scientists <p>Written</p> <ol style="list-style-type: none"> 5. Observations/data 6. Progressive assignments 7. Final research reports 8. Questions on quizzes, tests, exams 9. Student created PowerPoint slides and posters 10. Peer review of methodologies
	B. Teachers' voices	<p>Spoken</p> <ol style="list-style-type: none"> 1. Answering teams' questions, giving advice to teams 2. Whole-class discussions <p>Written</p> <ol style="list-style-type: none"> 3. Providing feedback on progressive written assignments
	C. Scientists' voices	<p>Spoken</p> <ol style="list-style-type: none"> 1. Scientists' participation in student team discussions 2. Scientists' whole-class discussions 3. Teachers' experiences with science research in graduate school <p>Written</p> <ol style="list-style-type: none"> 4. PREP materials 5. Online science resources 6. Virginia Junior Academy of Science and Intel Science and Engineering Fair Paper Guidelines
	D. Other voices	<ol style="list-style-type: none"> 1. Textbooks 2. State-wide, community college standards 3. Technology 4. School community expectations 5. Teachers' teaching experiences and with scientific research

Khalick, 2002; Schwartz, Lederman, & Crawford, 2004). Those discussions and reflections that accidentally involved students in engaging in work that reflected the values and assumptions basic to the production of scientific knowledge were considered *implicit* to the practice of scientific inquiry. The analysis of the three scientific inquiry experiences revealed that the tenets of the nature of science were not explicitly addressed in the lessons. Thus, Table 4 represents the categories and subcategories of the tenets of the nature of science implicit in the students' work during the scientific inquiry.

Voices contributing to the scientific inquiry experiences. Students' constructions of the understandings of science content, the nature of science, and the processes of science are mediated by language; thus, it was important to examine both spoken and written voices that were incorporated into the scientific inquiry activities (Leach & Scott, 2003; Staver, 1998; Wertsch, 1991). During the analysis of the contributing voices during the inquiry, four distinct categories based on educational literature emerged: (a) students' voices (b) teachers' voices, (c) scientists' voices, and (d) other more subtle voices such as the state biology standards and the voice of technology. Table 4 summarizes the categories and subcategories of this theme of voice.

Preserving Confidentiality

The identities of all participants, both teachers and students, and the identities of their respective schools, have been kept confidential. Pseudonyms have been used in place of all names, and attempts have been made to avoid using identifying information in any verbal discussions or written documents. All audio-taped interviews were transcribed by the researcher and, along with all the collected documents, are being stored in a secure location.

Before making contact with possible teacher participants, this research study received Expedited Approval from the Virginia Tech Institutional Review Board. The required Institutional Review Board approval documents are compiled in Appendix B. Before conducting the preliminary teacher interviews, the three teacher participants signed Informed Consent Forms granting their consent to the conditions of their involvement in the study. Letters were signed and submitted by each school's administrator acknowledging an understanding of the terms of the research study. Students under the age of 18 who volunteered for the group student interviews returned signed parent consent and student assent forms prior to the group interviews. Appendix C contains samples of all of the consent and assent forms.

Credibility, Transferability, Dependability, and Confirmability

There are methodology strategies that can be implemented during research that inspire faith in the results so that others may feel confident when making use of the study. For the purposes of this research, instead of discussing the integrity of the research using terms typically associated with quantitative research, such as “validity” and “reliability,” trustworthiness criteria recommended by Guba & Lincoln (1994) for research studies based on the constructivist paradigm were employed. Within the trustworthiness criteria they included credibility, transferability, dependability, and confirmability (See also Denzin & Lincoln, 1994).

Credibility. Eventually the readers of this research study will evaluate its credibility by examining the degree of compatibility between the explanations and their supporting descriptions (Janesick, 1998). The possibilities of strong compatibility are more likely if the researcher is positioned in the classrooms as much as is feasible and seeks out second readers of the writing who are experienced with qualitative research (Huberman & Miles, 1994). In addition, triangulation of methods and negative case analysis strengthen the credibility of the analysis (Denzin, 1994). Triangulation of methods contributes to credibility because the analysis is supported by data that are collected in a variety of different ways from different sources (Pittman & Maxwell, 1992). To these suggestions to improve credibility, Merriam (1998) added that researchers should address their biases in their written work so that readers understand the researcher’s subjectivity. And thus, to contribute to the credibility of this research, the researcher (a) was in the classrooms as often as was possible, and particularly when the students completed the majority of their work on their experiments; (b) received guidance from experienced qualitative researchers while writing the research study document; (c) collected evidence from a variety of different data sources; and (d) has included a discussion of her own biases or limitations that may have influenced the study.

Transferability. The purpose of this case study research was to investigate how scientific inquiry was shaped by these three teachers in secondary science and agriculture classrooms. Stake (1998) expressed it well: “The purpose of case study is not to represent the world, but to represent the case” (p. 104). Hence, the goal was not to examine a small, nonrandom sample so a generalization could be mapped to much larger populations of high school teachers and their students for predictive purposes. Instead, the goal was to present the study to those interested in such as way that they can take it and relate it to their own experiences and apply it to their own

situations. This transferability, or “degree to which the findings...can be applied or generalized to other contexts or to other groups” (Ary, Jacobs, & Razavieh, 2002, p. 454) have been promoted by including three different sites and populations in the research study. In addition, transferability has been encouraged by including vibrant and clear descriptions of the research participants, their classrooms, courses, students, and schools, in the final product so interested readers are more likely identify with features in common with their own situations.

Dependability. While the purpose of this qualitative research study was not to produce findings that would have a high degree of replicability, attempts have been made in this document to be thorough and descriptive in order to contribute to consistency if the study is repeated elsewhere. In addition, the triangulation of methods supported the dependability of this research (Ary, Jacobs, & Razavieh, 2002).

Confirmability. While objectivity, or neutrality, is of concern with quantitative researchers, achieving this feature of research was not a goal of this qualitative research study. Instead, more appropriate for this qualitative research study was whether or not other researchers concur with the final analysis after examining the same data. Strategies that have already been described, triangulation of methods, peer review, keeping good records of process and decisions, and reflexivity contribute to the confirmability of the interpretation of research results (Denzin, 1994; Ary, Jacobs, & Razavieh, 2002).

Personal Reflections about the Research Limitations

When educational researchers are active in their research, they expect to have personal and professional frames of reference that influence their decisions before moving to the field, while in the field, and after leaving the field. During active research, the research goals, how the researcher attempts to accomplish these goals through interviews and classroom observations, how the observations are interpreted, and how the researcher composes the observations and interpretations on paper are biased by the researcher’s personal ideas brought into the research. Hammersley (1984) challenged researchers to be aware of and monitor the factors that impact their decisions, including their motives for the decisions that they make about their research. He also charged researchers with publicly confronting these factors by including them in their research reports so readers can consider them when evaluating the research.

Before ever going out into the field, Peshkin (1988) recommended that researchers attempt to raise their subconscious subjectivity to their consciousness so they can be aware of

and manage its influence during the entire process through a “formal, systematic monitoring of self” (p. 20). My own subjectivity, a “garment that cannot be removed” (Peshkin, 1988, p. 17) during research, became less powerful as a disabling influence on my research because I tried to identify it prior to my fieldwork. LeCompte (1987) located sources of subjectivity and bias in professional training and personal experiences and urged researchers to reflect on and identify their own individual sources in order to improve their research. Participating in this self-monitoring prior to and during fieldwork helped me to understand why and how I gave priority and meaning to certain events in the classroom and during the interviews, while ignoring or devaluing others.

Following Peshkin’s (1988) advice in identifying personal subjective “I’s” that had the potential to influence my research before going out in the field, the most obvious one to me was the “Experienced High School Science Teacher I,” that undoubtedly distorted the meanings I made of my observations and interviews. After observing and interpreting the activities in my own classroom for thirty years, this subjectivity is so much a part of me that I tried to be extremely attentive to its influence so that it did not control my research.

However, in spite of trying to be conscious of my subjectivities, my experiences as a secondary science teacher inevitably influenced the content of the observations that I made in the classrooms, as well as my interpretations of these observations and interviews. It is because of these experiences, in tension with what I have learned from professional educational sources, that I was initially intrigued with researching inquiry-based experiences in secondary classes. Because of my teaching experiences I readily identify with the impediments to implementing inquiry-based instruction cited by researchers such as such as class size, shortage of class time, and pressure to prepare students for content-focused high-stakes tests (Marx et al., 1994; Munby, Cunningham, & Lock, 2000; Tobin & McRobbie, 1996). Yet, because of the professional reading I have done during the past ten years (e.g., *The National Science Education Standards*, NRC, 1996, and *Inquiry and the National Science Education Standards*, NRC, 2000b), I have a great deal of respect for the educational value of inquiry-based instruction.

In addition, I felt some professional tension because the research emphasis was on the nature of science supported by scientific inquiry, both having their foundations in the Western view of science (Lee, 1997, 1999), as described in the major science education reform documents. I am unsure if it has been detrimental to emphasize scientific inquiry and the nature

of science as I have in this study because of the undue priority to the Western-view science which may create barriers to students because of their culture, gender, class, and language. I agree with the science educators who recommend that the presentation of the nature of science and science as a process should include Western *and* other ways of knowing the natural world (Cobern & Loving, 2001; Lee and Fradd, 1998; Loving, 1997; Smith & Scharmann, 1999; Snively & Corsiglia, 2001; Stanley & Brickhouse, 1994). I am sure my professional experiences and perspectives about nature of science and inquiry-based instruction influenced my research, and I tried to be constantly aware of and alert to this possibility.

Another possible source of my professional predispositions is my current position as a graduate research assistant working with PREP at the Fralin Biotechnology Center. Because at some level it is expected that my affiliation with PREP during the past year influenced my observations and interpretations during the research, I tried to be alert to this, and recognize it and the impact it had on the research.

My relationship with each teacher participant, which was influenced by social forces and social identities, undoubtedly affected the content, quality, and interpretation of the interviews and class observations. The gender, race, culture, class, age, and ethnic identities of the teachers, students, and me inevitably impacted our research relationships. Since the teachers and I shared gender (female), cultural (White, Western European), and linguistic (Standard English) norms, I tried to anticipate that differences (and similarities) in these areas could be problematic during a research relationship (Briggs, 1986; Cotterill, 1992; Partington, 2001; Seidman, 1998). As well, I attempted to heed Briggs' caution not to presume that shared culture, class, gender, language, and ethnicity eliminated the need to attend to both the referential and indexical aspects of the participant's contributions to the interview. During the research, I tried to be attentive to the possibility that the aspects of my professional and personal experiences that I shared with the teachers and their classroom environments would blind me to the cultural, institutional, and social dimensions of the experiences in the classrooms.

It is inevitable that my presence in the classrooms had some impact on the inquiry process in the classroom, although I was not able to predict the impact of this "consequential presence" (Emerson, Fretz, & Shaw, 1995, p. 3; see also Merriam, 1998). Concomitantly, my presence in the classroom likely influenced my observations and my interpretations of what I observed (Merriam, 1998). Throughout my notes, I included my own activities, reactions,

emotions, impressions, and questions about what I observed because “substance cannot be considered independently of method (Emerson, Fetz, & Shaw, 1995, p. 11; see also Merriam, 1998). Even though I attempted to understand and reflect the teachers’ and students’ points of view when making my observations, I tried to be constantly aware that my own life’s experiences, which are inextricably bound to my gender, age, language, class, ethnicity, and race, created a quite thick lens through which I viewed and made sense of the activities in the classroom. Lastly, it is important for me to recognize that my fieldnotes are *my* interpretations of the classroom work (Denzin & Lincoln, 1998b).

In addition to the above mentioned biases that impacted the research, there were other factors that caused me some concern throughout the study. First of all, the structure of dissertation research - an inexperienced graduate student working on research for the first time without the benefits of a collaboration with experienced researchers – certainly influenced the study from beginning to end. In an effort to alleviate some of the impacts of my inexperience while observing in the classroom, I asked a recently retired, experienced qualitative educational researcher who happened to live in Janet’s town, to observe her classes with me several times (with Janet’s permission) so we could talk about the class observations in depth. I found these discussions extremely helpful in identifying what I was missing during the observations, why I was focusing on particular activities and not others, as well as in thinking about the meanings of the class activities.

The quality of my research surely would have improved if I had spent extended time in the classrooms. In spite of scheduling the observations when the students and teachers were involved with the bulk of the inquiry activity, the best scenario would have involved me being in the classrooms every day and at other times of the year in addition to the period of time the students were involved with the scientific inquiry. However, I had a sense, from my experiences working with high school teachers for thirty years and understanding how they value their autonomy and independence in their classrooms, asking to observe in classrooms more often may have jeopardized finding teachers willing to participate in the study.

One of the initial goals in setting up the research sites was to include classrooms in diverse schools and in diverse communities. In spite of the five hour drive to the 4th research site, losing this 10th grade biology classroom in which classes were not leveled, five weeks into the study was a great disappointment. Unfortunately, the desired degree of diversity was not entirely

achieved with the remaining three teachers who were willing to participate. The research study could have been tremendously enhanced by including an urban school, other levels of biology, biology classes in public schools, and teachers with more diverse backgrounds and histories.

One rather unexpected limitation for which my awareness grew as the study progressed was the lack of students' voices incorporated into the research. While I did interview as many students as I could and I informally interacted with students during the observations, I feel that the research would have benefited from being more student-focused over-all and, in particular, more attentive to those students whose voices were the least represented by the research – the students in the agriculture class.

CHAPTER THREE

ADDITIONAL BACKGROUND AND FINDINGS RELATED TO THE PRACTICE OF SCIENTIFIC INQUIRY AND THE TEACHERS' INTERESTS AND PLANS TO INCORPORATE INQUIRY INTO THEIR COURSES

The purpose of this research was to investigate the practice of scientific inquiry within the context of PREP in three different high school science and agriculture classrooms. Class observations, teacher and student interviews, and related documents, including student work, were studied in an effort to gain insight into how scientific inquiry was conducted by high school students and their teachers, how nature of science was represented during the inquiry process, and how ideas were given power and voice in the classroom. This chapter will include discussions of the classrooms, technology availability and use, activities supporting the inquiry experiences, as well as the teachers' descriptions of inquiry, impressions of their students, interests for incorporating the *Arabidopsis thaliana* experiments into their courses, and intentions for the implementation of the inquiry.

General Observations of Classroom Activities During the Kick-off Session with the PREP Staff-Scientist

All three teachers (Bonnie: Stuart Springs Governor's School; Janet: St. Catherine's Academy; Sara: Riverview High School) and their students began their experiments with a similar kick-off session led by a PREP staff-scientist. Before the PREP staff-scientist, Michael, introduced PREP to the students, the three teachers participating in the research did little to prepare their students for the scientist's visit. At most, the teachers announced the visit and briefly discussed the experiments with the students. Since Bonnie and Sara had extended class periods the day Michael visited (Bonnie – 2 ½ hours, Sara – 1 ½ hours), he met with these students on one day only. The introductory session required two days with Janet's classes because her class period was only fifty minutes.

When Michael worked with students during this initial session, he followed the same general outline regardless of the class. With each class, he broke up the session into three parts starting with a general class discussion followed by the students' planning their experiments and preparing the pots, soil, and seeds. During his well-organized, general discussion portion of the

session, Michael led whole-class discussions with the students about how they benefit from plants, why *Arabidopsis thaliana* is a model organism for plant research, what role the genes play in determining the characteristics of plants, and how scientists experimentally determine a gene's function. Michael attempted to adapt this opening session to the level of the respective biology and agriculture course and his prior knowledge and experiences with high school students. He closed this part of the presentation by telling the students that the results of their experiments would help *Arabidopsis* researchers with their efforts to determine the function of the gene that the scientists had previously disabled in the plant's genome. For the most part, Michael employed a triadic dialogue format (Lemke, 1990) during which he posed thought-provoking and often leading questions to the students after providing preparatory background for the discussion (e.g., *What plants have you benefited from during the past 24 hours? How did you benefit? Why do we study Arabidopsis? What do you know about genes? How do you determine the function of a gene?*). Michael used the board to record and organize the students' contributions to the discussion.

In order to get the students to start brainstorming about the designs of their experiments to elucidate the function of the gene that had been disabled, Michael led a discussion with each class about conditions in a plant's environment that could impact the plant. Using the same triadic discussion format, Michael wrote students' suggestions on the board grouping them in different categories (e.g., temperature, light, water, soil, air) and asked leading questions to help students generate additional ideas. All of the teachers played a minor role in these discussions led by Michael.

After this class discussion about environmental conditions that might influence plant growth and development, the students reorganized themselves into small groups of two or three to brainstorm the kinds of conditions (independent variable) they were interested in altering in the plant's environment during their own experiments. For practical purposes, Michael asked them to limit their choices to one condition that (a) could be manipulated in their classrooms, (b) was relevant to plants, and (c) would not intentionally harm the plants. During the students' brainstorming sessions, Michael and the teachers walked around the rooms and talked with the students about their ideas. This activity ended the discussion portion of Michael's PREP kick-off visit.

After the teams spent 10 to 15 minutes discussing the conditions to which they were interested in exposing their mutant and wild-type *Arabidopsis thaliana* plants, Michael demonstrated how to put the soil in the four pots (without touching the soil) that would hold the mutant experimental and control, as well as the wild-type experimental and control plants. After the demonstration, the students moved to classroom tables that held the pots and soil provided by PREP, labeled the pots, and then filled them with soil. After the students put the soil in the pots, Michael demonstrated how to use a pipet to lay the nearly microscopic seeds suspended in a gel solution on the top of the soil.

After the students dropped the seeds on the soil in their pots, class time remained in Sara and Bonnie's classes for Michael to talk about the humidity dome he placed over the pots that the students had set in large holding trays positioned on plant stands. He explained to the students how to thin the plants after they germinated and sprouted to reduce the number to six plants per pot and gave the students some plant watering instructions. In these two classes, Michael also had enough time to have a short discussion about the kinds of observations the students could make while the plants were growing. This discussion essentially started the students thinking about what data they might collect during their experiments (dependent variables). The students contributed their ideas about what to measure to the short class discussion (e.g., stem height, number of seed pods, number of flowers, color of plants).

After this initial class session during which Michael led the students and teachers in preliminary discussions and planning for their research on the mutant and wild-type *Arabidopsis thaliana* plants, the students and teachers continued the experiments for the next seven - eleven weeks, for the most part, independent of PREP staff and university scientists. After the initial visit with Michael during which he helped to set the stage for the students' experiments, all three teachers tended to follow the same format due to the nature of the processes intrinsic to scientific inquiry. However, there were day to day differences among the teachers' implementations of scientific inquiry.

These introductory sessions led by Michael in all three classes were crucial in laying the foundation for students understanding the context of their scientific inquiry. It was during these sessions that Michael attempted to connect the new science content related to the PREP experiments with students' prior knowledge regarding inquiry, plants, and genetics. His discussions during these sessions also underscored the importance of plant research and the

potential value of the contributions the students may make with their PREP experiments in elucidating the unknown function of a gene. It was clear by the way that Michael directed these discussions using the triadic discussion format and encouraging and answering student-generated questions that student engagement in the discussions was important to him. His casual dress and frequent attempts and successes with humor contributed to a friendly atmosphere in the classrooms.

Because of the nature of the sources of data of this research, it is unclear to what extent these sessions with Michael influenced the students' work on their experiments. The class brainstorming sessions about the treatments and data the students would eventually collect during the experiments clearly gave the students direction in designing their experiments; however, the teachers varied in their enthusiasm of the effectiveness of Michael's visit. Because discussions were limited between Michael and Sara's students, Sara commented that she wished the introductory session that Michael conducted with her Agriculture students could be more "hands-on" (Interview, 3/16/2006, 13-15). Her comment paired with the minimal involvement of some of the students during the kick-off discussions indicate that Sara's students' experiments may not have been strongly influenced by the visit from a PREP scientist. On the contrary, Janet thought the introductory sessions with Michael went well after her students understood that they were supposed to participate in the discussions rather than sit and listen during Michael's presentation: "He did a fabulous job...I thought it went real well...he did a great job of uh bringing in some things that we talked about back in October...excellent..." (Interview, 3/30/2006, 159-172). One of Janet's students confirmed that Michael's visit the first day of the experiments was valuable in preparing him for the experiments:

He, like, told us what what we should get ready for. Like told us what we were studying, gave us seeds and said what the point of the experiments were and, you know, it was just a starting point rather than us coming to class and 'Here, there's an experiment.' You know, he got us ready for it. It was really good (Interview, 5/4/2006, 213-216).

Bonnie

Stuart Springs Governor's School for Science, Mathematics, and Technology, and Bonnie's Students. Bonnie is an experienced teacher at Stuart Springs Governor's School for Science, Mathematics, and Technology, a public school that specializes in offering a curriculum that was designed to challenge students interested in science, math, and technology. The students at Stuart Springs are recruited from two small cities and five rural school systems. The class involved with the research study was a first-year Biology class which is a dual-enrollment science course for 11th graders (students may receive credit for biology at the regional community college if they pay tuition and maintain a certain grade average). Sixteen students, nine females and seven males were enrolled in the biology class that participated in the study. Of these 16 students, 14 were Caucasian, 1 male was African American and 1 male was of Middle Eastern decent. Bonnie's students had participated in at least two previous experiences with scientific inquiry in their 9th grade Fundamentals of Research class and during their January semester independent research project.

Bonnie's Classroom

The classroom Bonnie shared with one other science teacher at Stuart Springs Governor's School was spacious, modern, and tidy. Arranged in the central portion of the room were six student tables, each designed for seating four students, that served both as desks for class work and tables for laboratory activities. Colorfully illustrative biology and biotechnology posters hung on all four walls. Large windows and cabinets with countertops spanned one wall of the classroom and a counter ran along the back wall of the classroom. The furnishings and arrangement of the room did not change throughout the scientific inquiry experience.

Technology Availability and Use

Bonnie's students had uninterrupted access to the six classroom computers sitting on the countertops, wireless internet connections, and a printer specifically set aside for their use. The school's new and novel tablet PCs were also available and used by students during the PREP experiments. A LCD projector was permanently mounted from the ceiling and was used several times during the experimental work to display class data and for PowerPoint presentations sent

from Bonnie's computer in the front of the classroom. Other technology-based equipment that students incorporated into their procedures included scientific electronic balances, digital cameras, pH meters, and a light intensity-meter.

Bonnie's Description of Her Students

When asked about her students during the first interview, Bonnie described them as "sweet" (Interview, 2/1/2006, 116) and acknowledged that she did not have any discipline problems with the students other than the occasional chattering which she sensed was most likely a result of students helping each other with the biology content. The lack of disciplinary and behavior problems observed during class indicated that behavior and academic expectations had long been established in Bonnie's classroom before the start of the research study. Bonnie reported that keeping the students busy every minute with interesting work helped her maintain order in her classroom (Interview, 2/1/2006, 221-222).

During their independent work on their experiments in Bonnie's class, the students were free to move about the room as they chose, use the computers, take pictures of their plants, and treat and observe their plants. Students even had access to other classrooms and teachers, and freely walked in and out of their biology classroom to get equipment or supplies without first checking with Bonnie. As deadlines and Dr. Wendy Hayes's (the scientist who created the mutant strain on which Bonnie's students were experimenting) visits approached, the students became more focused and anxious about the work they wanted to discuss with the scientist (Observation, 5/10/2006). In spite of some distractions, Bonnie was pleased with how diligently the students made their observations of the plants and how carefully they collected their data (Interview, 5/3/2006, 198-201).

Even though Bonnie could be stern with her students at times, she was very patient with them and kind to them when, on a rare occasion, they did not meet assignment deadlines, jammed a computer disk in the computer hard drive, and needed a little encouragement to settle back down after a class break or to focus on their work while anticipating spring break and prom around the corner. It was common for students to spend some time attending to non-science and non-school topics, but overall, the students appeared to be motivated and productive. Frequently Bonnie and the students laughed together about biology, school, and the students' lives outside of school; some gentle teasing went both ways during these conversations.

Most remarkable about the relationship between Bonnie and her students was their acceptance that she would not know all the answers to the questions they asked as they designed their unique experiments. Bonnie laughed as she reflected on not always having answers for the students' questions during their inquiry activities:

Because I don't have a starting point [of background knowledge for every experiment], you just kind of have to do the best you can and try to get something reasonable and just let it be an experiment...I do not have a problem confessing ignorance to these students (Interview, 4/5/2006, 70-76).

The biology students were accustomed to working independently on science assignments, designing experiments, and collecting data, having previously done a mini-research project during the winter term and a research project during their Fundamentals of Research course during their 9th grade year.

Bonnie's Description of Inquiry

During the initial interview before the students started their plant experiments, Bonnie described the PREP activities as involving the students in inquiry. When she elaborated on what she meant by "inquiry" she described the processes students employ when doing their experiments:

[Inquiry] means that students are acting as scientists, forming questions, generating hypotheses, designing experiments on their own, that are open-ended and that, you know, that they don't know the answer to and they don't know what the answer's supposed to be (Interview, 2/1/2006, 357-360).

Bonnie considered students' involvement with the *Arabidopsis thaliana* experiments to fit this definition of inquiry because

Students come up with the research question, they come up with an experimental design, they figure out what kind of data they're going to collect, and they go through that process, and they have to try to make some sense of their data (Interview, 2/1/2006, 345-348).

Together, Bonnie's description of inquiry and her students' involvement in the plant experiments show that she comprehends that her students will be involved with more than the procedures of the investigations; they will also be cognitively engaged in creating a design and, after collecting their data, interpreting their findings.

Bonnie's Interest in Implementing Scientific Inquiry

Administrative mandates. Since the Stuart Springs Governor's School is a part of the state public school system, the biology students are required to take the course end-of-year test, answering questions based on course objectives related to biology content, scientific inquiry, and nature of science. The preface to the state-level course objectives included in the *Biology Standards of Learning* (Virginia Department of Education, 2006) stresses the importance of addressing inquiry and nature of science in biology curricula:

Emphasis continues to be placed on the skills necessary to examine alternative scientific explanations, actively controlled experiments, analyze and communicate information, and gather and use information in scientific literature....The Biology standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with additional new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions.

The *Standards of Learning* objectives that follow the preface identify what students should have an opportunity to do while they plan and conduct investigations. Typically, her students do not have trouble excelling at the biology end-of-year test, so Bonnie was not overly concerned about the state-wide standards, nor the end-of-course tests.

School-level biology objectives related to research, posted on the school website, closely resembled the state standards. One of the twenty-five sets of Biology competencies listed on the school website addressed the "enabling objectives" for the competency: "Conduct individual and group scientific investigations utilizing the scientific method."

Interests based on the value of student involvement in the research process. In spite of her students having already taken the Foundations of Research course and also completing their independent research projects in January, Bonnie was interested in her students having additional

opportunities to be involved in the research *process* so that they could practice making decisions about how to handle experimentally collected data.

During her first interview, Bonnie pointed out one unique feature of the inquiry - the unknown outcome of the experiments – that is important to her as a science teacher:

“I think it’s so great for the kids to have something where they don’t know what’s going to happen and nobody knows what’s going to happen” (Interview, 2/1/2006, 333-337).

In her final interview after the students had completed their experiments, Bonnie again reflected about the value of the unknown outcome aspect of the experiments, even in regard to herself:

What PREP provides that’s unlike anything else I do because even if I rearrange a lab to make it inquiry-based lab, it’s inquiry for the students but it’s never inquiry for me because I still know what should happen. But this is a true experiment in that nobody knows the answer so [the students] are really engaged in what I feel is real research (Interview, 6/7/2006, 24-29).

Also during her final interview, Bonnie pointed out aspects of the research process, as well as specific questions her students had to answer during their research, which contributed to her motivation to implement the inquiry in her biology class:

I want them to know from the beginning even what research is like, like how amazing it is, you know, how cool it is that you can knock-out genes and get these mutants and figure out what it does and also how tedious it is and how you can set up an experiment and not get an answer after months and months and months...Doing an open-ended inquiry-based project you have to be able to think critically to do something like that. I mean it’s, you know, you have all this data, well, what do you do with this data? Well, what kind of graphs could you do with it, you know. Um, you know, and what’s this graph going to tell you and then where’s that going to lead you (Interview; 6/7/2006; 77-80, 86-90)?

Thinking into both the near and far future, Bonnie identified advantages for student involvement with open-ended research. For next year, she hoped that some students would continue with their experiments for the regional science fair. Many years down the road, she predicted that their involvement in the *Arabidopsis* experiments would help the students make career decisions:

It shows the students “Well, that’s what research is like and it takes a lot of patience.” So maybe they can think of the choices they’re making in their own careers and evaluate whether or not science, you know, science is for them (Interview; 2/1/06, 407-410).

Interests based on the context of PREP. Since Bonnie planned for the inquiry to take one extended class period for nine weeks from her class time, the connections she could make between her course content and the inquiry were significant to her decision to include PREP in her curriculum. Bonnie talked about the easy fit between her course content and the inquiry within the context of PREP, as well as how the PREP experience supports student learning about, and contributes to the meaningfulness of, content already a part of her curriculum:

PREP actually ends up becoming our unit on plants and [the students] don’t get anything else for plants, but that’s okay because everything is encapsulated in PREP. You can talk, well, “What is a seed?”, and you know, talk about the development, and while you’re talking about seeds you can do a quick [talk] about phylogeny on the board. I think, you know, things are more meaningful when you see them. Like if you’re talking about the development of a plant, you know, if you’re growing the plant, obviously it’s more meaningful (Interview; 2/1/2006; 366-371, 458-460).

Another aspect of the inquiry that was significant to Bonnie that is not typically found in school science activities or experiments, but is a feature of the *Arabidopsis* experiments, is the interest that research scientists at a nearby university have in the high school students’ results. Bonnie reflected about why she thinks the university scientist-student connection contributed to the value of the inquiry experience for her students:

[The students] feel... like they’re contributing a part of scientific research...the students are on the cutting edge in research, nobody knows what these mutants do; they are going to get to decide. It’s the most authentic scientific experience that can have (Interview, 2/1/2006, 387-388, 401).

Bonnie was the only one of the three teachers who worked directly with a university scientist who is actively involved with *Arabidopsis* research. Prior to the students’ involvement in the inquiry, Bonnie met with Dr. Hayes at her lab to talk about the particular mutant that she had created and with which the students would be conducting their experiments. During the students’ research, Dr. Hayes made two visits to the classroom to talk with students about their experiments. Bonnie’s excitement about her students doing some preliminary research that

would interest Dr. Hayes, and Dr. Hayes's possible visits to the classroom to work with her students was evident when she talked about her plans for the inquiry before starting the experiments:

I'm really looking forward to, we're working with a scientist at State University who just developed mutant plants so we're going to try them out this spring...we're trying to, we're hoping to get her into the classroom and interacting with the students and I think, like I said, the interaction with the scientist is really important because, I think, it makes it more meaningful to the students and more real, um, and and then you know, it's almost like a mentorship and they can see what kind of jobs are out there, what what people do with science and what science is all about (Interview, 2/1/2006, 513-525).

Bonnie's Plans for Implementing the Scientific Inquiry

Teachers at Stuart Springs Governor's School were not required to generate or turn in written lesson plans to administrators; thus, Bonnie had no written plans, goals, or objectives related to the *Arabidopsis* experiments.

Descriptions of plans for the structure of the experimental work. Stuart Springs Governor's School scheduled extended class periods on Wednesdays and Thursdays so each class would have a two and a half hour session one day a week for the students to work on projects, labs, and other activities that require more than a traditional class period. Since the extended period for the class involved in the study was on Wednesdays, this was the day that Bonnie planned for the students to be most involved with their *Arabidopsis* experiments. At the start of the experiments, after the PREP staff-scientist, Michael, introduced the experiments to the students and assisted them in planting the seeds, this extended class period was also the time that Bonnie planned for the students to do their computer searches for helpful background information related to *Arabidopsis* plants and experimental treatments. As the experiments progressed, Bonnie planned for the students to use this time to continue to work independently to design their experiments, collect their data, and record their observations in their lab notebooks. Finally, as the experiments wound down, Bonnie expected Wednesday afternoons to be used for graphing and statistical analyses of data using the classroom computers. Bonnie also planned to reserve this time for any whole-class discussions related to information they needed for their experiments.

To encourage the students to keep up with their work, Bonnie planned to collect two student assignments - an introduction to the experiments and the graphs with corresponding statistical analyses - before the final paper and completed lab notebooks were due (Online Semester 2 Calendar).

Descriptions of plans to support students in cognitively processing their research. Bonnie intended to include time every week for the students to work in their lab pairs on their experiments, which included discussing and making the various decisions fundamental to the research process. During the first interview, Bonnie reflected on her experience implementing PREP the previous school year and expressed her dissatisfaction with how she supported her students' *thinking* during the experimental process. She was hoping that she could better guide the students in cognitively engaging with their experiments this year so that the experiments did not become mere mechanical processes that the students moved through like "robots":

[The students are]...pretty good about designing experiments, uh collecting data...how do you interpret it is the part that is a bit...I'm really going to focus on that part...Um, and I think it's really good for them to have data that they don't know what to do with and think about, you know, cause a lot of labs, you know, tell them...so they know what they're supposed to be graphing. So [with PREP, students] think about the graph you're supposed to make and think about how you're supposed to communicate your data is helpful...this year...I'm really going to focus on that part and see and try to think and reflect on it a little bit more (Interview; 2/1/2006; 424-435, 458-466).

Bonnie's commitment to students making some of their own decisions in their research groups is evident in her comments about the students choosing their own experimental treatments:

I guess it's more fun for them if they have what they have, you know, decided what they want to test and it gets them, they feel more invested in the experiment than if it's just, you know, thrown at them. And actually one of the students said one time, "I really like it when we make up our own experiments." You know it's just more exciting for them and you know the two girls with alelopathy, so they have the background knowledge on the topic so why not apply it to something in class (Interview, 4/5/2006, 51-57)?

Again, Bonnie expanded upon her interest in the students designing their own experiments within the context of PREP:

It's real important to demonstrate concepts they have to learn, but it's also really important for them to learn the scientific process and the scientific process is, you know, you kind of mess around, you know, to figure out how you're gonna do your experiment and then your, you do your experiment and revise it (Interview, 4/5/2006, 91-95).

Bonnie was hoping that Dr. Hayes would visit the class at some point during the experiments to talk with the students about some of the decisions they made about their research.

Activities Supporting Scientific Inquiry in Bonnie's Classroom

Throughout the ten weeks that Bonnie's students participated in their *Arabidopsis thaliana* experiments, the students were involved in a variety of activities involving interactions among themselves as well as interactions with experts such as Bonnie, the PREP staff-scientist, and Dr. Hayes. Table 5 summarizes the activities related to the inquiry in Bonnie's class.

Typically, Bonnie reserved one day a week, Wednesday, for the students to treat their plants, make and record their observations, and analyze their data. Frequently, Bonnie used Wednesday class time for other unrelated activities such as tests, class notes, and end-of-course test review. Students conducted their lab work in

Table 5

Timeline and Summary of Observations in Bonnie's Class

Observation date	Summary of activities
March 22	1st class session with PREP staff-scientist, Michael: general discussion about plant research and genetics; students brainstormed treatments, put soil in pots and planted seeds, discussed experimental treatment
April 5	2 nd class observation: students researched experimental treatments on computers, class discussion about what to observe; students watered and thinned plants; statistical analysis of class data related to germination differences in mutant and wild-type plants
April 7	3 rd class observation: students watered and treated plants, some students still investigating details of experimental treatments
April 12	4 th class observation: Dr. Hayes and Michael visited and talked with students about treatments; students watered and treated plants, made observations, and recorded data; Dr. Hayes gave flavonoid presentation
April 26	5 th class observation: students watered and treated plants, made observations, and recorded data; students enter data into Excel on computers and take digital pictures of plants; class discussion and statistical analysis about difference in bolting of mutants and wild-type plants
May 3	6 th class observation: students made observations, recorded data, watered and treated plants; students entering data into Excel and started data analysis with Mini-Tab; students take digital photos of plants
May 10	7 th class observation: students made observations, recorded data, watered and treated plants; Bonnie handed out <i>Arabidopsis</i> Lab Guidelines; students continue to enter data into Excel and analyze data using Mini-Tab; students take digital pictures of plants
May 17	8 th class observation: students made observations, recorded data, watered and treated plants; students continue to enter data into Excel and analyze data using Mini-Tab; some students still taking digital pictures of plants
May 19	Another doctoral student observed class: Michael and Dr. Hayes visited class to talk with students about their analyzed data; students continued to work on their experiments and data analysis

Note. Bonnie's only Biology class was involved with the research.

self-selected pairs, with eight lab pairs conducting experiments designed around a variety of independent and dependent variables. Students turned in several written assignments related to their scientific inquiry; they were expected to complete these assignments outside of school time.

Bonnie's students were free to decide on a treatment for their plants after conducting limited research using online, scientific sources, as long as they followed the guidelines stated by Michael during his initial visit to the class. In their effort to find out if the disabled gene contributes to the plant coping with various environmental stresses, the students chose independent variables, or plant treatments, such as light intensity, ultra-violet light produced by black lights, juglone (natural herbicide released by black walnut trees), water pH, soil pH, and aluminum in water. During the experiments, while they exposed their plants to the various treatments, students were interested in how the treatments affected various features of the plants (dependent variables) such as the leaf surface area, number of seed pods, bolt height, number of plants that bolted, number of flowers, and general plant health. The student groups investigated the effect of one treatment on a selection of these plant features.

Students used various pieces of equipment – electronic balances, rulers, pH meters, light intensity meters, black lights, digital cameras, and tablet PCs - during their experiments.

Students-student interactions. Most of the class time was spent with students working in their pairs. While the students designed their experiments, treated their plants, and collected and analyzed their data, they constantly talked with other group members about their experiments, as well as topics unrelated to their experiments such as Prom and Spring Break plans. They conferred with each other while deciding on which treatment to use and the various parameters of their treatments (e.g., If we want to model acid rain, what pH should our watering solution have? If we want to expose the plant to a solution of pH 4, what acid should we use? How do we make that solution?). Often when measuring and recording data, the students consulted lab partners about how to make particular measurements. They talked about how to construct their data tables in the lab notebooks and how to best record and analyze their data. In addition, as they moved about the room, the students frequently stopped by other students' desks and had inter-group discussions about their experiments, comparing observations, and getting help with learning how to use the ImageJ software and the digital camera. As the experiment came to a close, students also worked together on their laboratory reports that they turned in to Bonnie for a grade.

Student-expert interactions. While her students planned and conducted their *Arabidopsis* experiments, Bonnie constantly moved unobtrusively around the classroom, making herself available to her students to answer their questions. These questions included requests for assistance and advice about experimental designs, decisions regarding experimental treatments, and help with computer software and hardware such as digital cameras. During the student group interview one of her students, followed by consensus from the other three students participating in the interview, remarked on Bonnie's willingness to listen and offer her help while the students worked on their experiments: "She always answers questions really well, like whenever you have a question, she's right there" (Interview, 5/24/2006, 716-722).

During the ten weeks that students worked on their experiments, Bonnie led several whole-class discussions related to the experiments. The lessons included plant science content, brief discussions about the choices of dependent variables, and attention to experimental results and analysis of data combined across lab groups. Twice Bonnie had the students combine all of their data related to observations of their plants for a statistical analysis of their combined data (Observations, 4/5/2006, 4/26/2006, 5/17/2006).

Bonnie's students also had two opportunities to present their ideas to Dr. Hayes and Michael, the two *Arabidopsis* specialists. During their visits to the class, Dr. Hayes and Michael moved from team to team asking the students to share with them how they had become interested in their respective experimental plant treatments, what they were expecting to happen to the plants because of the treatments, and why they had chosen their particular plant features to observe and record. The scientists shared some of their own thoughts about the inquiries with the students such as rotating the plants so all the plants were receiving the same amount of light, using the ImageJ software to calculate leaf surface area, and taking many readings of bolt height so they would have a range of readings as well as the average bolt height (Observation, 5/12/2006). In their final lab reports, some students cited these conversations as they described what they learned from their experiments. For example, Ryan commented

It was suggested by Dr. Hayes that the reason there was not a large difference between the control and experimental plants is because there might not have been certain molecules, such as heavy metals, in the soil which would have been affected by changes in pH and then hurt the plant (Student final lab report).

Another one of Bonnie's students, Mary, included several references to the contributions made by Dr. Hayes and Michael to her thoughts about her experiment that she included in her conclusion section of her lab report:

Dr. Hayes said that flavonoids are involved in the production of sunscreen. Since the wild-type plants for the control and Exp.1 groups appeared to healthier on May 10, maybe they contain a flavonoid that helps to protect them from too much light. Dr. Hayes and Michael also noticed that some plants had more leaves but had not bolted while others had bolts but also had fewer leaves....yet, this does suggest that one of the gene's functions is in the developmental stages of the plants....Michael and Dr. Hayes also suggested other aspects of the plants that could have been observed, such as the rate of growth and bolting (Student final lab report).

During a student group interview, Jennifer described her interactions with Dr. Hayes and Michael and how they helped her lab team think about aspects of the experiment they had not considered prior to the conversation:

They helped us notice a lot of conclusions that we didn't see just 'cause we looked at the number of flowers and...they pointed out "Well look...the first ones to flower ended up having less flowers but the rest of them caught up the next time you measured them and they actually hadn't had that many more flowers." So just stuff like that just helped looked more, like, at the big picture..." (Interview, 5/24/2006, 663-669).

Despite the limited time the pair of scientists could spend with each lab group (approximately 5 minutes), these short discussions evidently provided some of the students with additional insight into their experiments that contributed to the depth and complexity of their thinking about their experiments.

Bonnie also included opportunities for students to get written feedback from her while they were progressively working on their experiments. Two weeks after they had planted the seeds, her students submitted the introductions to their labs, which included background information about the plant species, why it was a good experimental model, general information about flavonoids, and the purpose of their experiments. Eight weeks into the experiments, the graphs and statistical analyses were due. Bonnie gave the students written feedback on both of these assignments and then returned them to the students. Both assignments were purposely

scheduled before Dr. Hayes's visit so the students would be prepared to discuss their experiment plans and data analyses with her (Observation, 5/17/2006, 158-163).

With regard to the final evaluation of the scientific inquiry, Bonnie's students were required to turn in a formal, typed lab report, in addition to their hand-written lab notebooks. Early in the research process students had been given detailed instructions concerning the content and format of both. Students were expected to include introduction, results, statistical analysis, and conclusions sections in the final lab report. This lab report format, similar to the Intel International Science and Engineering Fair and Virginia Junior Academy of Science formats, was the one she had learned from science teachers when she first started teaching. She continued to use the same format with her students because it "was natural and obvious because that's what we always use" (Interview, 6/7/2006, 430-432).

During the span of the investigations, Bonnie presented a very small amount of content related to plants. The students did not use textbook materials nor did they have quizzes or tests about plants. As the students were designing their experiments, they primarily searched the internet for scientifically-based information that would help them with their designs. Students took advantage of the online, scientific resources to support their decisions concerning the independent variables for their experiments. Students frequently used computer software to construct data tables and graphs and conduct statistical analyses of their data. All of the teams took digital pictures of the plants as they matured. All but one group used an online software program, ImageJ, supported by the National Institute of Health, to determine the surface area of the plants' leaves (Students' final lab reports).

Summary and Analysis of Bonnie's Interests in, and Plans for Including Scientific Inquiry in her Course, and the Activities Supporting the Scientific Inquiry in her Classroom

Despite the mutual supporting relationship between the PREP context and Bonnie's biology curriculum about plants, one of Bonnie's apparent motives for including PREP experiments in her course was the value she placed on her students' opportunities to conduct experiments that she felt reflected the authentic research performed by scientists (no known outcome) and during which they would interact with an *Arabidopsis* scientist. Bonnie found it appealing that the students' work was potentially interesting to practicing scientists, possibly contributing to the body of scientific knowledge about *Arabidopsis thaliana*, and conceivably informing the students' work in science fairs and decisions about science careers.

Bonnie's description of inquiry and intentions regarding the implementation of inquiry revealed a grasp of both the steps and processes characteristic of scientific inquiry. Bonnie recognized that her students were proficient at moving through the methodological steps of inquiry (i.e., treating the plants, collecting and recording data), and, during the plant experiments, she hoped to advance the students' cognitive engagement in inquiry.

Central to the practice of scientific inquiry in Bonnie's classroom were the students' interactions with each other. These interactions included continuous conversations among the students as they conducted their experiments, talking with each other about the many decisions they had to make (e.g., what treatment to use on their plants and which features of the plants to observe and measure for their data), as well as when sharing information they found in additional resources, discussing their observations, and the meanings of their findings.

The availability of online scientific sources and school technology resources paired with Bonnie's substantial mentoring promoted students' initial intellectual engagement in their experiments. Students made decisions about treatments and experimental designs based on considerably more than their own prior knowledge and experience. Despite the students creating multiple graphs and conducting numerous t-tests with their data, it was not apparent that the content of Bonnie's contributions to whole-class discussions and informal student conversations supported her plans to shift the students' inquiry from mechanical to both mechanical and engaging in reasoning tasks typical of scientific inquiry.

The major contributions to renovating the scientific inquiry experience from hands-on to a more complex, minds-on experience came from the exchanges between the students and Dr. Hayes and Michael during their two visits with the students. It was during their discussions with each student research team, that the students were challenged to think more critically about their experimental treatments, their experimental designs, choices of dependent variables, the implications of their results, and possible future directions of their research. Without the students-scientists discussions that occurred during these two visits from scientists, it is questionable whether or not Bonnie could have realized one of her interests for including the PREP experiments in her curriculum – that interest of more cognitively engaging her students in scientific inquiry.

Janet

St. Catherine's Academy and Janet's Students

Janet is an experienced biology, chemistry, and Earth Science teacher at St. Catherine's Academy, a small private day/boarding school located in a small city that is home to a large state university. The two classes involved with the research were Janet's Biology classes in which 1st year biology students were enrolled. The students were primarily 11th graders. Fourteen of the 20 students were female and 17 were Caucasian. One male student was African American, one was from Nigeria, and a third was from Korea.

Janet's Classroom

Janet taught all of her classes in the same classroom which was technically hers even though she shared it with other teachers for homeroom and health. The classroom is located in a relatively new wing of the school and is well-designed for transitions between classroom and laboratory work. The front half of the room was crowded with student tables that rarely were in the same arrangement on two consecutive classroom observations. Sturdy, permanent waist-high laboratory benches, enough for twenty students to participate in biology lab work, occupied the back half of the classroom. The surfaces of the back lab benches were cluttered with various plants and equipment, leaving only about half the surface available for student work. Large windows filled the back wall of the classroom. Cabinets and bookshelves, decorated with various biology-related posters, lined the side walls of the classroom. Once the whole-class instruction was completed and the scientific inquiry activities began, the students moved freely around the entire classroom doing their work in spite of being somewhat restricted by space.

Technology Availability and Use

Permanently accessible to Janet and her students were a LCD projector mounted on the ceiling, a digital camera, seven lap top computers, and wireless connections to the internet. All of this equipment, in addition to electron balances and pH meters, were used at one time or another during the *Arabidopsis* experiments. A well-equipped computer lab just down the hall from the biology classroom was also used by the students when

they searched for background information about plants and the *Arabidopsis thaliana* species.

Janet's Description of Her Students

When Janet was asked about the level of biology that she taught, she commented that her students were “regular students” (Interview, 3/8/2006, 97) and “not the strongest students” because they take the liberal arts advance placement courses instead of the hard science and math advanced placement courses (Interview, 5/11/2006, 20-26). Even though she used a college level biology book for the course, she did not try to get through the whole textbook with her students, nor would she expect the whole group to be able to meet those standards (Interview, 3/8/2006, 98-100).

Janet described her first-year Biology students as “well-behaved...they have good manners, um it doesn't take much in the way of discipline” (Interview, 3/08/2006, 849-850). She recognized that for them “to sit for that length of time [a school day] is hard and their bodies need motion more than mine” (Interview, 3/8/2006, 699-700). She expressed concern that her students may never have a chance to be in their intellectual “comfort zones” (Interview, 3/8/2006, 714). Janet described “comfort zones” as places where students have a chance to feel confident in their knowledge of the previous material before having to move on to new information. Her impression was that her students were grade conscious, “very, very busy” (Interview, 3/8/2006, 829; Interview, 5/11/2006, 63-65), and those who attempt seven classes may be a little bit “over-zealous” (Interview; 3/8/2006, 726).

Janet had noticed that when she teaches, she needs to provide quite a bit of structure and organization for her students in order for them to be successful. For those students who needed a little extra help with their grades, Janet provided opportunities for them to earn additional points. For example, during spring break she made arrangements for a young man to come to school to boil a rat that he had dissected in class, and then remove the external tissue so he could study its skeletal structure (even though she had never done this before) (Interview, 3/8/2006, 27-30). Relative to the *Arabidopsis thaliana* experiments, students could earn extra points by presenting their research to the class in addition to submitting the written, abbreviated research paper (Observation, 5/11/2006; Student Handout, 5/11/2006).

Despite Janet's impression that her students needed a little extra help with organization and structure with their work, they successfully worked independently in their student teams on their experiments during class time and seemed to understand and meet Janet's expectations

concerning how they should use class time. These expectations included using some class time for general announcements about extra-curricular activities (e.g., open-mic night, international meal, Habitat for Humanity fund-raiser) and limited, quiet, personal conversations. Janet's classroom structure comfortably supported students working on many different research-related tasks concurrently, both individually and in their teams, while she moved in and out of the conversations throughout the class period.

During class, the students systematically focused on their experiments and it was common for the class time to come to an end with students still working on their research (Observation, 5/4/2006, 53-54). Janet's trust that her students would behave and continue to work in her absence was evident twice when she left the room during class to check on the computer lab access and to photocopy materials. Janet further demonstrated her trust in her students by sharing the code for the classroom door lock with a student so he could work on his research at times when she could not be present (Observation, 4/13/2006, 41-42; Observation, 4/20/2006, 9-10, 187-188).

With regard to student discipline, Janet described herself as "probably stricter than most because I'm old school" (Interview, 3/8/2006, 974-975) but she admitted that "I play with them a little bit, I, we have fun, I laugh a lot, I sing to them, I do the dance of the microbes, you know, so they don't seem to mind" (Interview, 3/8/2006, 859-865). However, in spite of her efforts to create an informal, playful atmosphere in her classroom, Janet commented that she expected her students to be focused on the lessons while they are in class and that there were to be no "shenanigans," which she did not need to define for them (Interview; 3/8/2006, 982-985).

Janet's Description of Inquiry

During her first interview, before her students had started their *Arabidopsis* experiments, Janet discussed her efforts at the school departmental level to include independent research for students in all science classes. When she was asked if she and the other science teachers ever used the term "inquiry" during their discussions about the science curriculum, she exclaimed that she has "enquire" on her personalized license plate: "'Enquire', it says 'Enquire' ... It's the background of everything we do!" (Interview, 3/8/2006, 615-616). When she was asked how she would distinguish *inquiry* from *scientific inquiry*, she focused on the inquiry process, being able to replicate the process, and the importance of writing a paper based on experimental findings:

Well, scientific inquiry to me has has a specific protocol that you have to follow, uh, it's not uh vague...I see, I see the good use of writing a paper from a lab, you know, as as being uh, you know, able to replicate it, and having testable questions, and all those sorts of things being slightly different and more rigorous...Often with scientific inquiry you don't get an answer, the value is in the question (Interview, 3/8/2006, 615-622).

Janet's Interest in Implementing Scientific Inquiry

Janet was incorporating the *Arabidopsis* experiments in her biology course for the first time during the semester of the research study. Prior to her first research interview, Janet had reviewed the online PREP materials and had given considerable thought to implementing the inquiry in her biology classes; however, she did not have any previous experience doing so.

Administrative mandates. Since St. Catherine's Academy is a private school, Janet is not bound to state science standards for her biology course, nor are her students required to take the end-of-year tests. Several years ago, her science department wrote their own departmental standards after studying the *National Science Education Standards* (NRC, 1996) and the state science standards. During the processes of writing their own standards, Janet reported that she was one of the science teachers who advocated for time to be intentionally set aside in each science course for students to participate in relevant independent research.

Interests based on the value of student involvement in the research process. Whether or not Janet was able to convince the other science department faculty members to include scientific inquiry in their courses, Janet's commitment for finding time in her courses is clear in her description of the faculty conversation:

The main reason I'm gonna alot time for this is, I got to experience the thrill of independent research and it's been my mantra since I've been at this school for two years, 'Why don't we do more independent research?' 'We don't have time to.' 'Well, let's make time.' ...The most exciting part of science ...is to set something up and watch it and assess it and know that even a failure is okay. You know there's, there's some openness to it that you don't get in a textbook with a list of of vocabulary (Interview, 3/8/2006, 576-585).

Her interest in implementing scientific inquiry was compatible with her "ultimate purpose [which] is to engage the students in science and not just teach some things out of context" (Interview, 3/8/2006, 224-226).

Her commitment to involving her students in scientific inquiry was also evident in her course syllabus and her personal teaching targets. Both documents had general notations about students' independent projects and research; however, she did not include specific goals or student learning objectives related to the independent research in either document.

A secondary interest for incorporating the *Arabidopsis* experiments in her biology course was further reinforced during her students' recent experiences with the National Institute of Health Sleep Study that involved the students in collecting data about their own sleep habits. One of her goals with the sleep study was to help the students learn how to write a scientific research paper. She was disappointed, however, in the quality of the students' final Sleep Study research papers and she was hopeful that the *Arabidopsis* research would give her students another chance to work on their scientific paper writing skills:

So we got through that and then we, they need, they need another experience now on writing a paper. Uh, where they all knew how to do the hypothesis; they all knew how to apply the statistics; but um, uh, they didn't quite get the literature search part of it...so with the plant unit that we're doing with you guys here what we want to do is is uh, really teach them the important of using other people's background information" (Interview, 3/8/2006, 252-257).

Helping her students learn how to write a scientific research paper was an important goal for Janet. She talked about it repeatedly during her interviews:

Where [the students] fell down in the quality of their work [during the Sleep Study] was in the literature search...I would also like them to understand that uh the paper is uh an important part of communicating in science; there's a standard protocol for them to follow (Interview; 3/30/2006; 87-88, 109-110).

Interests based on the context of PREP. During her initial interview, Janet was clear that the context of the inquiry, PREP, contributed to her interest in committing extended class time to the students' involvement in scientific inquiry. Besides the advantage she attributed to the PREP inquiry being age-appropriate, providing opportunities for the students to connect with people outside of the classroom, and being part of a successful pre-structured, larger, relevant independent research project, she had given considerable thought before starting the inquiry to the degree to which her course content and the inquiry were mutually supportive:

I'll start with that structure and organization of plants, organization of roots, stems, leaves, uh, nutrition and transport in plants, control of growth and responses in plants, and then reproduction in plants....the experimental design, uh, I think it will go along with pretty well...the interpretation of [the experiments] will be based on what they have studied in this plant unit. It ties together what we've had from the beginning of the year, and and [the students] see it as a, as a review whether they know it or not. Um we're reviewing phenotype, genotype, and homologues, and you know, what what a gene is, wha how does a gene differ from a chromosome, uh, you know, how can you zap are there under a different, in a different context so it connects it (Interview, 3/8/2006, 276-286; Interview, 4/3/2006, 116-122).

Janet's Plans for Implementing the Scientific Inquiry

Janet did not write up plans, goals, or objectives related to her daily lessons during the *Arabidopsis* experiments. Her school administration does not require teachers to have or turn in written lesson plans.

Description of plans for the structure of the experimental work. During her initial interview, Janet commented that she considered her first year implementing PREP to be an exploratory year for herself. She did "not see it as the total curriculum for eight weeks..." Instead, she viewed it

as the first 10 or 15 minutes of class and then they keep their notebooks here and then they come (pointing to the front section of the classroom) and learn about structure and function and photosynthesis...and I will allow time at the end for them to write their papers (Interview, 3/8/2006, 1094-1097).

She projected that she would start her plant unit right after spring break so that she could weave her chapters about plants with the scientific inquiry of the plants. She scheduled Thursdays for her students to do their most intensive work on their experiments which included the watering, treating, making and recording observations, and analyzing the data. Other days of the week she thought she would give students 5 – 10 minutes to observe their plants before moving on with other class work. She intended for the students to work mostly in teams of three that were organized by Janet because she thought it was important for the students to have an opportunity to work with someone they would not typically choose.

Janet had given quite a bit of thought to how she would support the students while they work independently on their experiments based on observations she had made about her students throughout the year:

They still, most of them, prefer an underlying structure that's really organized and then once that structure is there, once that scaffolding, I think the educators call it, then they feel secure enough to work very hard....What works for [the students] is if that underlying structure is there and they're aware of it and uh, you know, that's where I come in (Interview, 3/8/2006, 841-857).

Descriptions of plans to support students in cognitively processing their research. Janet's plans to insert the inquiry about plants into the midst of her unit on plants went beyond an interest in corresponding content; she hoped that by working on plant-related content and the experiments at the same time, the students would be better able to base their interpretations of their results on what they learned about plants during the plant unit.

Janet planned for her students to make as many of the decisions as possible related to the experimental design and data analysis because of the sense of ownership that this gave the students. As she explained during her initial interview, she hoped her students would have an experience in uh independent research, so giving them the phenotypes to study is probably is not what I would want to do unless it simplifies it for everybody. But, I'd like to give them as much of a chance to make decisions from the very beginning – then they own it....I'm tending to want them to design it (Interview, 3/08/2006, 1213-1221).

A second intention of Janet's when implementing the PREP inquiry with her biology students resulted from the less than acceptable quality (in Janet's opinion) of the research papers the students turned in related to the National Institute of Health Sleep Study they had worked on during the past winter. Janet was very committed to supporting her students as they transferred their research experience to written scientific documents:

So we all got through that and then we, they need, they need another experience now on writing a paper. Uh, where they all knew how to do the hypothesis, they all knew how to apply the statistics, but um, they didn't quite get the literature search part of it....with the plant unit that we're doing with you guys here what we want to do is is uh really teach them the importance of using other people's background information as a way to understand what they're seeing. Since the hypothesis starts with a question that starts

with an observation, you have to see that observation through educated eyes (Interview, 3/8/2006, 252-263).

Janet viewed this additional experience for students to engage in scientific inquiry as another opportunity for her to support them in learning how to write a quality science research paper.

Activities Supporting Scientific Inquiry in Janet's Classroom

After the initial kick-off session with Michael, the PREP staff-scientist, Janet grouped her students in pairs or groups of three for their experimental work. Generally, Janet reserved one day a week for seven weeks for the students to conduct their experiments. Janet incorporated a wide variety of instructional activities to support the students' scientific inquiry. For a summary of these activities, see Table 6. These activities included interactive, whole-class discussions led by Janet, as well as informal discussions among the students and between Janet and her students. Students turned in several written assignments related to their experimental work; they were expected to complete this work outside of class time.

The team members brainstormed ideas for the independent variables and were free to choose treatments within the guidelines Michael had presented during his kick-off session. In addition to limiting their treatment choices to those that are possible to reproduce in the classroom, that are relevant to plants, and would not intentionally kill the plants, the students based their decisions of the experimental treatments on their own prior knowledge and interests (e.g., drought, darkness, sodium chloride solution, crowding, lemon juice, refrigeration, copper (II) sulfate solution, various growth mediums, and soil pH). In their efforts to gain insight into the role that the disabled gene played in helping the plants cope with these conditions, students chose features of the plants (their dependent variables) such as the length of leaves, plant height, bolt height, plant color, number of surviving plants, and the number of leaves to observe. During their procedures, students used rulers, pH meters, and balances to mass chemicals for making their own solutions. During the course of the inquiry, students noted general observations about the plants in addition to recording observations regarding their specific dependent variables.

Table 6

Timeline and Summary of Observations in Janet's Class

Observation date	Summary of activities
March 30	Second class session with PREP staff-scientist, Michael: students brainstormed treatments, put soil in pots and planted seeds (1 st period)
April 3	2 nd class session observation: Janet shows students PREP online information. Handed out and went over Guidelines for <i>Arabidopsis</i> Independent Research Project; students watered plants, computer research for background info, wrote hypotheses (7 th period)
April 13	3 rd class observation: students observed, watered, thinned, and treated plants; recorded observations on data sheet provide by Janet; worked on methodologies; took digital pictures of plants; some discussion about the introductions they got back graded (7 th period)
April 20	4 th class observation: students peer-reviewed methodologies; watered, observed, treated plants, and recorded observations; Janet shows time-lapse video of Arab. growth on website; Janet presented PowerPoint about flavonoids (7 th period)
April 27	5 th class observation: students watered, treated plants, and made observations; Janet led discussed about representation of data and different kinds of graphs; students take digital pictures of plants (1 st and 7 th periods)
May 4	6 th class observation: students watered, treated plants, and recorded observations; 3 males in 7 th period agreed to interview during class time; homework about genetically modified plants (1 st and 7 th periods)
May 11	7 th and last class observations: students disposed of plants, a couple presented their research, group class discussions of experiment, two group student interviews (1 st and 7 th periods)

Note. Observations were made in Janet's 1st period class or 7th period class, or on some days, both.

Student-student interactions. While the students conducted their plant experiments, they were constantly involved in discussions with their lab partners. Among themselves, students discussed and made decisions about their experimental treatments, what data to collect, how to represent the data after they had collected it, and how to go about jointly writing the final research paper.

In addition to lab group discussions facilitating the students' experiments, Janet included a peer review of the students' methodologies three weeks into the inquiry. Using a rubric designed by Janet, each student's methodology was analyzed by two other classmates who were not part of their lab group. The grading rubric directed students to evaluate the ease of understanding the experiment description, whether or not they could follow the directions, if the variables and control conditions were clearly stated and described, if the hypothesis and materials were included, and if the text had been spell- and grammar-checked (Observation, 4/20/2006).

Students benefited from an additional, structured opportunity for peer feedback five weeks into the inquiry experience when they presented their "talking points" during a roundtable discussion about genetically modified crops. Each student used a grading rubric designed by the Exeter Humanities Institute that Janet had gotten at a conference to evaluate the other students. The rubric included objectives related to the student's participation, critical thinking, text references, and listening behavior.

On the final day of the experiments before the students disposed of their plants, students who were interested in adding extra credit to their final grades had the opportunity to either present a PowerPoint talk or a poster talk about their experiments. In each of the three classes observed that day, one group presented their experiments. The students followed a presentation format that Janet had previously given to them. After each of the presentations, Janet encouraged other students to ask questions and make comments (Observation, 5/11/2006).

Finally, during the last class session, Janet held round table discussions with the students about their experiences with the *Arabidopsis* experiments. She asked them to talk about both their individual experiments and the inquiry experience in general. To make sure each student had a chance to share some thoughts about the experiments, each student who contributed a comment threw a ball to another student who then had to contribute some comment about their experiment. Each student was expected to add to the roundtable discussion concerning general

experimental concerns or issues specific to their own experiments. The first student to get the ball in first period, Anne, commented, “I thought it was a fun experiment but um, I don’t think I was very good doing it because it was a lot of detail and I had trouble counting the bolts and the flowers.” Anne threw the ball to Margaret who responded to Anne’s comment with: “It was interesting watching for a long period of time but we had problems. If we could do it over, it would be better.” Mark added his thoughts when he caught the ball from Margaret’s throw: “It would have been better if we had longer” (Observation, 5/11/2006, 51-56). The students continued with the roundtable discussion talking to Janet and each other about their difficulties and what could have made the experiments go smoother. Both the extra credit presentations and roundtable discussions were designed so students could give each other feedback about their experiments; however, the students rarely initiated comments or questions unless they were directed to by Janet.

Student-expert interactions. Janet’s students connected with experts during several different activities. The week following Michael’s visit, students spent time online searching for information about *Arabidopsis* plants. While this information was not scientifically research-based, students did access both general and technical information about the plants. Despite Janet’s compliments regarding Michael’s presentation to and interactions with her classes, she did not necessarily agree that inviting additional scientists to work with her students would be beneficial (Interview, 5/11/2006, 120-140). Janet described her reluctance to involve her students with more interactions with Dr. Hayes or other scientists

Many scientists I’ve worked with, I I was actually the um University Environmental Sciences Information Officer for a while so I worked with lots and lots of scientists, as well as participating in research over there, and some of them would not be the best representatives....I don’t know this Dr. Hayes...uh whether eh uh, you know, her time might be best spent in the lab or writing grants or, you know, if this is where her talents are and uh if someone from that project [PREP] also has the ability to relate to teenagers, you know, which [Michael] did, uh, that’s great (Interview, 5/11/2006, 128-139).

Janet incorporated several different whole-class discussions with her students to assist them in understanding either science content related to the plants or different aspects of the scientific inquiry. These whole-class discussions included a PowerPoint presentation about flavonoids, an interactive presentation to help students understand the different ways scientists

graph their data, and an examination of the PREP *Research Guide* on the PREP website (Observations, 5/3/2006, 5/20/2006, 5/27/2006). As the experiments came to a close, Janet interacted with her students when the few teams gave the extra credit presentations and when all of the students talked about their research experience during the round-table discussion (Observation, 5/11/2006).

In addition to the whole-class discussions, Janet systematically moved around the classroom to answer students' questions and talk with them during their experimental work.

Janet also interacted with her students in writing. Students progressively turned in and received feedback from Janet on various written assignments (hypothesis, lab report introductions, results discussions, methodologies) while they conducted their experiments. Paul, one of Janet's students cited these staggered opportunities to get feedback as helpful for getting ready to write the final paper: "I think this [final lab report] is not going to be that bad because we've been writing it all along" (Interview, 5/4/2006, 197). As a final laboratory report, Janet required the students to turn in a two page abstract consisting of their research question or hypothesis, an abbreviated procedure, a summary of the results, and a conclusion. Students were also encouraged to submit a bibliography and any relevant photos, graphs, or tables. Janet graded the assignments and wrote comments on them before returning them to the students.

During the inquiry experience, Janet's students completed three textbook chapters that addressed content about plants such as plant structures, the functions of the structures, plant reproduction, plant nutrition, and transport in plants. The students were tested or quizzed on this information and received feedback from Janet regarding their textbook knowledge of plants.

Summary and Analysis of Janet's Interests in and Plans for Including Scientific Inquiry in her Course, and the Activities Supporting the Scientific Inquiry in her Classroom

During interviews with Janet, it was clear that, to her, scientific inquiry was more than a set of steps, or even a complex process that scientists employ during their research. When she talked about inquiry, Janet became quite animated; it was as if she considered scientific inquiry as both an intellectual and emotional endeavor. However, when she described scientific inquiry during her interviews, she focused on the protocol of conducting an experiment and the need for students to be able to write a coherent research paper containing a well-developed literature review.

Her interest in spending a considerable amount of class time on the plant experiments partially evolved from her dissatisfaction with the students' Sleep Study research papers they had recently submitted. In addition to wanting to provide the opportunity for students to appreciate both the written paper as a form of communicating in science and the previous scientific work upon which they were going to build their own research, Janet viewed the plant experiments as an ideal way to engage the students in science during their textbook work on plants. Also very important to Janet was the connection of the research to scientists beyond the walls of the school, the relevance of the research, and the history of success PREP had earned in schools across the state.

Despite the lack of written lesson plans, goals, and objectives relating to the scientific inquiry, Janet had given quite a bit of thought to how she would incorporate the plant experiments into her course. Most of her comments about her plans related to structuring the experience for her students; however, she was anxious for her students to have as much control of the decisions that would need to be made during the inquiry process and she planned to support them in learning how to use other scientists' work to understand their own experiments.

The practice of inquiry in Janet's classroom reflected her plans to both provide structure for her students and allow them to have some independence in decision-making during their experiments. As was the case with Bonnie's students, Janet's students spent a large amount of their class time involved in conversations with team members about their experiments. While Janet's students did not interact with scientists beyond Michael's initial visit, Janet did conduct several class sessions during which students were involved in interactive discussions about the guidelines provided on the PREP website, how to write the introduction and methodology portions of their research papers, how to make observations, and how to decide the most appropriate way to graphically represent data. Janet's goal of having the students write a research paper with a thorough literature review was abandoned as time grew short. The students turned in abbreviated forms of the paper because the school year came to a close and Janet felt they did not have time to compose a quality scientific research paper.

Janet's students had additional opportunities to grow in their abilities to communicate about their scientific inquiry during class time. Students who needed extra credit had a choice of presenting their experiments to the whole class using either a poster or a PowerPoint format. Following the presentations, Janet posed a number of questions to the presenting teams, as well

as to the students in the audience, encouraging them to think more deeply about their experiments. During this final class session, Janet also held a round-table discussion with the students about their experiments. Each student was required to contribute a thought about the inquiry, to which Janet posed questions.

Sara

Riverview High School and Sara's Students

Sara is a novice agriculture teacher at Riverview High School, a small, rural, public high school. The school's student population includes 8th – 12th graders who are likely to be Caucasian. Over one-fourth of the students qualify for free or reduced meals (state average – 1/3). Despite the balanced student population of males and females at Riverview High School, students in Sara's Agricultural Mechanics and Basic Plant Science I course involved in the study were 80% male. Students in grades 8, 9, and 10 enrolled in Sara's Ag I class.

Sara's Classroom

Sara's classroom and shop are located in a red brick annex connected to the rest of the school building by a covered walkway. The annex contains a small office next to Sara's classroom used by Sara and the other vocational teacher who teaches in the annex, and two classrooms each with an adjacent, large shop area that is used for teaching the skills associated with their respective vocational courses. The students worked on their *Arabidopsis thaliana* experiments at their tables in the classroom which were arranged around the perimeter of the classroom in a rectangle with a large open space in the middle and a narrow entrance at the front of the room by Sara's desk. This permanent, rectangular arrangement of tables, which Sara claimed was necessary for managing student behavior, made it difficult for anyone to walk behind the students or work alongside of them. The arrangement also made it difficult for the researcher to casually wander around the room, look at student work right-side up, listen to conversations, and chat informally with the students. When Sara infrequently moved to students' tables to answer their questions or help them, she used the central portion of the rectangle. Natural light from outside flowed into the classroom through five large windows along one wall. A few posters about acetylene torch and machine safety and other agricultural topics hung on the walls. Cabinets, tables, and a cart holding a television lined two walls of the classroom.

Technology Availability and Use

Sara's classroom was sparsely furnished with current technology and little was incorporated into the scientific inquiry experience. Daily school announcements were broadcasted from a television hanging from the ceiling in the front of the classroom. Sara had a computer at her desk in a front corner of the classroom, but the students had access to computers only in the computer lab and library. Sara took her students to the computer lab once during their work on the experiments so they could transfer their hand-written observations and data to a table Sara provided for them in an electronic file. The students appeared to be comfortable while working on the assignment using the computers with only a few students needing Sara's help accessing the file containing the data table (Observation, 5/5/2006). These computers were reserved for spring, online end-of-course testing when Sara had hoped to use them for the *Arabidopsis* experiment data analysis. Hand-held calculators were not available when students needed to calculate averages of their data.

Sara's Description of Her Students

Sara reported that her Ag I students either voluntarily signed up for her Agricultural Mechanics and Basic Plant Science I course as an elective or they were assigned to the course by their guidance counselor because she thought it was important for the students not moving on to college after high school to have some practical skills (Interview, 1/27/2006, 100-104). Sara estimated that roughly 40% of her students were planning to attend college (Interview, 1/27/2006, 108-109). Sara suspected that her class was a depository for special education students were placed in her course because the course does not have a required end-of-course SOL test (Interview, 1/27/2006, 274-275). Approximately one-third of Sara's students have IEPs (Individualized Education Plans) for learning disabilities or attention deficit issues but no in-class support was available for these students or Sara because her course is not SOL-based (Interview; 1/27/2006; 260-267; 272-273, 282-286). She expressed concern over having so many ADHD students in a course that required students to learn how to use power tools and she was especially concerned about these students in her afternoon classes because their medications wore off after lunch (Interview, 1/27/2006, 272-277).

Sara credited some her of difficulties with successfully covering all the tasks and competencies required by the Virginia Department of Education (Office of Career and Technical

Education) to student behavior issues that she felt were inherent when teaching a classroom crowded with 8th, 9th, and 10th grade boys (Interview; 1/27/2006; 306-310, 340-343). Sara blamed the seemingly irresolvable problem of limited classroom space and crowded seating arrangement for the excessive student talking during class (Interview, 1/27/06, 340-346). While no serious discipline issues and very few minor problems were observed in either the classroom and the shop during the ten class observations, Sara commented that when the students got rowdy she had to limit their use of power tools because of the potential safety hazards (Interview, 1/27/2006, 234-240) and she reflected that she wished she could keep them from “get(ting) away with things... and somehow figuring out how to make them interested in everything... and somehow make them creative and energetic all the time” (Interview, 1/27/06, 393-399).

Each morning as the students entered the agriculture classroom, Sara was typically at her desk, located at the front of the classroom, working either on paperwork or at her computer. She frequently had short greeting-type interactions with the students who came in early and then she went back to her work at her desk. Several times Sara shared humor with the students. For example, one morning while she was teaching the class and using the front board, Sara laughed with the students about her tractor drawings (Observation, 4/21/006, 21-24). Another time when she had suspicions that a student was aiming a laser pointer at her backside, she laughed it off with the class rather than turn the incident into a major disciplinary incident (Observation, 4/12/2006, 37-39). Rarely did Sara move away from the front of the classroom during class time and circulate in the open space created by the students’ tables. Typically, Sara stood in the front of the classroom, conversing with a student-aid (senior male) who helped her with the class. In contrast, Sara gave the students individual, undivided attention in the shop when she was teaching them skills related to cutting metal with an acetylene torch (Observation, 5/17/2006, 92-99).

Sara was aware of how important it is for students to be interested in what they’re working on in class. She reported that she considered their comments and interests when she planned her lessons (Interview, 1/27/2006, 238-240). For example, she recognized the students’ interests in cars and hunting and incorporated these interests into their bimonthly magazine reading and journal entries (Interview, 1/27/2006, 140-156). She also was beginning to formulate plans to add an equine course and a small engine course to the school’s course offerings because

she believed students at Riverview High School are interested in horses and engines (Interview; 3/31/2006; 58, 66).

Sara's Description of Inquiry

During Sara's first interview, she described what her students would be doing during the PREP activities: "The research process...the different variables, and keeping recording data, and then, you know, making a chart of something out of it and then having a conclusion, 'This is how a affected b'" (Interview, 1/27/2006, 476-483). She explained why she considered the PREP experiments to be inquiry-based: "'Cause, I mean [the students] are, they're looking at um, like you know, 'Does caffeine affect this plant?' and then if not, 'Was it the gene they took out or not?'" (Interview, 1/27/2006, 513-515). When Sara was encouraged during the interview to elaborate about what students do when they are involved with inquiry-based instruction, she responded that they are "just just trying to find an answer to a question" (Interview, 1/27/2006, 520). During the interview, Sara displayed a limited understanding of the scientific reasoning tasks typical of the inquiry process.

Sara's Interests in Implementing Scientific Inquiry

Administrative mandates. During the eleven weeks that the research study was conducted in Sara's first period agriculture class, she was completing the second half of her first year teaching. She had implemented PREP once before – in the same course with her first semester agriculture students. While Sara did not have any written goals or objectives for her students related to the *Arabidopsis* experiments, she did draw attention to the state-wide Career and Technical Education Competencies for growing and reproducing plants upon which she based her lessons about plants. Sara explained how student involvement with plant research will support the students learning these competencies related to plants:

You know, [the competencies] say they need to be able to understand the different things that affect plant growth, and just various things like that, and to me they'll understand it more by having to water their plants three times a week, and you know, looking at blue light and red light on their plants, and then also keeping the data is important, too (Interview, 1/27/2006, 460-464).

She referred to the competencies as a "guide" for her planning and did not feel like they restricted her because she retained the freedom to decide what activities or projects would best

meet the competencies. Sara commented that she did not feel like her course was being micro-managed by her school.

Interests based on the value of student involvement in the research process. Part of Sara's interest in taking time for her students to be involved with the plant experiments was related to the benefits of their participation in scientific inquiry. She believed that through participation in the experiments the students would "gain an understanding of...the research process" (Interview, 1/27/2006, 475-476). She maintained this interest for the duration of the experiments: "[One] goal was to get them to get them familiar with the research design and just having experiments and why do we have experiments" (Interview, 6/7/2006, 22-24).

Contributing to Sara's interest in incorporating the experiments into her agriculture class were her concerns that the science teachers in her school had cut back on experiments because of pressures related to the end-of-course tests:

I thought it would be a good idea for them to do 'cause a lot of science classes now they have taken out any types of experiments and labs because of SOLs so I want them to be able to do the hands-on thing in here (Interview, 1/27/2006, 658-661).

By offering students the opportunity to conduct science experiments in the Agriculture I class, Sara felt like she could partially make-up for the lack of activities in science classes due to the pressures the science teachers felt to cover the mandated course content.

Interests based on the context of PREP. For the first time this year the national student vocational organization (FFA-name of organization; not an acronym) included an agri-science category in their research fair and Sara saw student participation in that category as a future possibility because of their involvement in the PREP experiments:

I saw [PREP] as a good way to um have something for the kids to do in our plant unit and um also for the FFA with agri-science. [Agri-science] is a new area in FFA and if they do a little research experimentation project they can qualify for different things in the FFA (Interview, 1/27/2006, 452-455).

In addition to the value of the connection between the *Arabidopsis* experiments and her required course content about plants, Sara described two other benefits for students who participate in PREP: "They...gain an understanding of how to take care of plants...and um somewhat understanding of the genome" (Interview, 1/27/2006, 475-477). This genetic dimension of the experiments was especially important to Sara because of economical and

geographical characteristics of the students' communities. In addition, Sara believed that since the research is valuable to scientists and will contribute to their research, it would be more meaningful to her students:

I think they get a much better understanding of what is happening with genetics right now in the world, and living in a very rural area, low income, um, I don't think they're exposed to that very much and really understand how that might impact their lives. But, I think, you know, they're like, "We're working with little plants that these fancy scientists have taken genes out of and we're helping with this huge project" (Interview, 1/27/2006, 527-532).

These same interests were described in Sara's final interview when she was asked to reflect on her goals for her students' experiences with the *Arabidopsis* experiments: "Um my goals for them were mostly to increase awareness of biotechnology that's happening right now ...and...to make them aware that there are things going on with genes and what the implications of those things are" (Interview, 6/7/2006, 18-24).

Sara's Plans for Implementing the Scientific Inquiry

Sara was not required by her administrator to turn in written lesson plans, goals, or objectives and thus she did not have anything written regarding her intentions or plans related to the students' activities with the experiments. Because Riverview High School uses the semester block schedule, Sara was implementing PREP for the second time with her Ag I students.

Descriptions of plans for the structure of the experimental work. Sara planned for her students to work on their experiments on Mondays, Wednesday, and Fridays with time the first two days reserved for watering and treating the plants, and making and recording observations of two different dependent variables (Interview, 1/27/2006, 568-574; 3/16/2006, 49-53). She reserved time in her mental plans every Friday for the students to record data, have discussions about the treatments, work on their data analysis, and write their final paragraphs about their experiments. Because the students during fall semester had difficulties holding onto their data until the end of the six week experiment, Sara decided to increase the structure of the data recording by giving the students a pre-designed, pre-printed data table on which they would record their observations (Interview, 1/27/2006, 568-574; 3/16/2006, 43-46). She also planned to check the data table each week to make sure students were keeping up with their data recording.

Her decision to schedule the experiments starting mid-March were based on her previous experience with difficulties of running long-term plant experiments over school holidays when the plants cannot be watered. She also thought this timing would be compatible with the timing of the plant unit she would be doing in the spring so she can do both at the same time (Interview, 1/27/2006, 560-562; 3/16/2006, 22-26).

Descriptions of plans to support students in cognitively processing their research. After the plants had germinated, Sara intended for her students to have team discussions about the experimental treatments, or independent variables. It was important to her that the students have as much of a role as was possible in the decisions about their experimental treatments (Interview, 1/27/2006, 613-617; 3/16/2006, 28-33).

Sara expressed concern that her fall semester students missed the connection between their experimental results and the implications of their results, and thus she expected to spend more time at the end of the experiments with this class to help them build the connections. Another missed connection during the fall experiment was how the Genome Project related to the students' experiments, so Sara anticipated spending more time strengthening that connection with this semester's group. During her initial interview, Sara described what the students this semester would get out of their research process working with the wild-type and mutant plants: "They will gain an understanding of...different variables, and keeping and recording data, and, you know, making a chart of something out of it and then having a conclusion, 'This is how a affected b'" (Interview, 1/27/2006, 481-483). Beyond this "understanding of ...different variables," Sara did not demonstrate that she was aware of other reasoning tasks in which students would be engaged during the inquiry.

Activities Supporting Scientific Inquiry in Sara's Classroom

During the eleven weeks Sara's students conducted their *Arabidopsis thaliana* experiments, Sara's students were involved in only a few different activities that supported their inquiry experiences. Sara reserved the beginning portion of her classes on Fridays, and periodically on Monday and Wednesday, for the students to treat their plants and make and record their observations. After the students experimental work was finished during these class periods, Sara continued with other lessons related to the course. The student lab teams were made of students who sat next to each other in class.

When they were designing their experiments, students chose their plant treatments from a list Sara wrote on the board: magnesium, potassium, copper, nickel, zinc, iron, calcium, and salt. With regard to the features of the plants that the students observed during the experiments (dependent variables), students picked two of the following: height of plant, number of leaves, number of stems, width of plant, and the number of petals on flowers. The only pieces of equipment that the students used were rulers and graduated cylinders. Sara's students did not have any written assignments outside of class time related to their scientific inquiry. Table 7 summarizes the activities in Sara's class that supported the inquiry experience.

Student-student interactions. The majority of the work done on the plant experiments involved students working in their lab pairs, quietly talking to each other about their experiments. Inter-group discussions about the experiments and results were rare.

Student-expert interactions. While the students designed their experiments, treated and observed their plants, and collected and recorded their data, Sara primarily situated herself in the front of the classroom. She had little interaction with the students during their inquiry process except when students infrequently asked her direct questions, at which time she usually moved to their desks to answer the questions and then returned directly to the front of the classroom.

The students did not consult online sources; however, they did read about plants out of their textbook (Interview, 3/11/2006, 184-185). While Sara appreciated Michael's first-day introduction to the PREP experiments with her students, she did not feel additional interactions with scientists would be beneficial (Interview, 6/7/2006, 233-239).

Table 7

Timeline and Summary of Observations in Sara's Class

Observation date	Summary of activities
March 16	1 st class session with PREP staff-scientist, Michael: general discussion about plant research and genetics; students brainstormed treatments, put soil in pots and planted seeds, discussed experimental treatment
March 24	2 nd class observation: Bell assignment question related to watering plants; students watered plants
March 31	3 rd class observation: Bell assignment question related to plant structures and their functions; students watered plants and decided on treatment; students turned in list of materials they would need, which chemical they want to use for treatment
April 7	4 th class observation: students watered and thinned plants
April 12	5 th class observation: bell assignment is about plant parts and their functions; Sara handed out data recording sheet; class discussion about independent and dependent variables; students decided what they were going to observe and they made observations and recorded the data, watered and treated plants; students took a test that had questions about plant parts and functions, different leaf arrangements, plant growth factors
April 21	6 th class observation: students watered and treated plants, observed and recorded observations
May 5	7 th class observations: students watered and treat plants, observed and recorded data; entered data into table using Excel in computer lab
May 12	8th class observation: students watered and treated plants, made and recorded observations; some plants had died and were disposed of
May 17	9th class observation: a few students made observations of the plants that are still alive, recorded observations on data sheet
May 24	10 th and final class observation: Sara helped the students write their final paragraphs about their research and then they turned them in

Note. Research study involved Sara's 1st period class.

Sara led several whole-class discussions during the inquiry experiences. At the start of the experiments, Sara listed on the board the chemical treatments students could choose from for their independent variables (Observations, 3/31/2006, 50-51). During the 5th week, Sara presented an underdeveloped, simplistic whole-class discussion about dependent and independent variables (Observation, 4/12/2006, 43-69). During this presentation, she gave the students several features of the plants that they could choose from to observe and record as the plants matured. In the midst of the scientific inquiry activities, Sara taught the unit about plant structure, the functions of the plant parts, different plant leaf arrangements, and insect interactions with plants. Four weeks after beginning the PREP experiments, the students took a test designed to evaluate their knowledge about plants.

On three different occasions, Sara incorporated either plant or PREP-related information into the short bell assignment questions she used to start class each day. The five questions were:

1. How do you know if your plants need watering (Observation, 3/24/2006, 9)?
2. Explain the Genome Project and how your *Arabidopsis* experiment relates to it (Interview, 3/31/2006, 131-132).
3. Name two plant structures and their functions (Observation, 3/31/2006, 22)?
4. Name three plant parts and their functions (Observation, 4/12/2006, 27)?
5. What was the purpose of the *Arabidopsis* experiment (Observation, 5/24/2006, 15)?

The bell assignment questions were always written on the board when the students arrived in class and they were supposed to work on the questions while Sara took attendance and did the lunch count. After these clerical tasks, Sara asked the students for their answers to the bell assignment question and then followed with a brief explanation of the correct answers with minimal student involvement.

Sara collected two assignments from the students directly related to their experimental work. For the first assignment during the experiment planning, students turned in their lists of the chemicals and materials they needed, as well as how they would make the plant treatment solutions. For example, Jane and Chuck wrote on their paper:

We're going to add iron
Iron diluted
in 1 L of water

Toby and Dave submitted a paper on which the following was written:

Chemicals: Zinc in the plant

Materials needed

Chemicals diluted

In 1 L water

The second paper the students turned in for a grade was their final lab report. The students wrote these paragraphs during class as Sara dictated to them what to write:

Write this on the top of your papers: “The purpose of this experiment was to discover if the gene removed from the plant was related to the use of” and then you’re going to write whatever chemical you used on your plant...The next thing you’re going to write is the hypothesis. Does anyone know what that means (Observation, 5/24/2006, 88-93)?

There was a brief discussion about what a hypothesis is and then Sara gave the students an example of what they would write next: “For example, ‘I think the gene controlled for potassium usage’ or ‘I don’t think the gene controlled for potassium usage’” (Observation, 5/24/2006, 97-98). After Sara asked the students to make sure they had their data sheets out, she moved on to the next part of the paper:

Okay, there’s only two more sections, okay? The next thing you’re gonna write is “results.” Okay, so here you’re gonna write one sentence about each of the plants...one short sentence for each one. For example, “The mutant experimental plant grew best, or had the most leaves, or grew the tallest” or whatever you measured...Okay, you’re last section is called “conclusion” and you’re going to write “The gene did or did not control for gene usage” depending on what happened (Observation, 5/24/2006, 106-120).

Sara collected the papers and data tables from those students who had not been called out of the room to take SOL tests.

During the final interview, Sara explained her rationale for how she graded the final papers and how she supported the students in writing the final papers:

Um, basically I just gave them a grade if they turned something in was how it was because, I mean, I haven’t figured out exactly how I’m going to do it or whatever yet...I basically told them, “Write this down” and dictated to them...a sentence with a fill in the blank kind of thing because, and I don’t know if it’s just, they’re 8th graders, you know, they can’t seem to put it together yet on their own without someone telling them exactly what they need to write down (Interview, 5/24/2006, 133-142).

Sara also explained why she had not handed back any of the three of the papers: “Everything I ever give back to them they just throw away so it really doesn’t matter” (Interview, 5/24/2006, 331). Of the two final assignments that were turned in, nine of the fifteen students had turned in the lab report and two groups (four students) had turned in the data tables as of June 7, two weeks after the papers were written during class.

Summary and Analysis of Sara’s Interests in and Plans for Including Scientific Inquiry in her Course, and the Activities Supporting the Scientific Inquiry in her Classroom

Sara interests in incorporating scientific inquiry within the context of PREP into her Agricultural Mechanics and Basic Plant Science I course stemmed from a number of different sources. With regard to meeting the state standards for growing and taking care of plants, Sara felt that the plant experiments provided support and reinforcement for students’ hands-on learning related to plants. Concerning the national student organization, she hoped that the plant experiments would contribute to the students’ readiness to participate in one of the national vocational student organization’s agri-science projects. In addition, through involvement with the inquiry, she valued her students having the opportunity to do experiments, particularly one in which scientists were interested in the results, and become familiar with how scientists do their research. Sara’s awareness of her students’ geographical and economic communities and their possible disconnect with cutting-edge biotechnology was an added incentive for Sara to include the inquiry in her course.

Sara articulated an under-developed description of inquiry and she began the inquiry with no written or verbal plans, goals, or student objectives related to the experiments. Her consideration of the practice of inquiry in her classroom tended to relate to the structural aspects of conducting the experiments, rather than the substance of scientific inquiry – the reasoning tasks that typically accompany scientific inquiry such as formulating the research question, making decisions about the treatment and what observations to make and record, analyzing the data, drawing conclusions, and communicating and defending the findings.

During their inquiries, students had valuable opportunities to work with lab partners to talk about their experiments, make observations, and record data. Despite her plans to include discussions with students about their experiments, experimental results, implications of the results, and connections to the Genome Project, there was a large disconnect between Sara’s interests in her students conducting scientific inquiry and the students’ actual experiences. Sara’s

attempts to talk with students about their experiments and biotechnology were limited to her very brief direct instruction during which she told students what independent and dependent variables are, what to write down in their final paragraph about their experiments, and several bell assignment questions that she briefly went over in class. In addition, there is no evidence that students connected their experimental findings with the over-arching research question about the function of the gene that had been disabled in their plants.

While Sara's students did have worthwhile experiences participating in an extended, hands-on activity related to their study of plants, moving through the steps of treating their plants and making and recording their observations, they had minimal opportunities to use technology in their studies of *Arabidopsis thaliana* or to advance their understanding of the substance of scientific inquiry and biotechnology through interactions with people more expert than themselves in science and the processes of scientific work.

CHAPTER FOUR

FINDINGS: REPRESENTATIONS OF THE NATURE OF SCIENCE AND VOICES IN THE CLASSROOMS DURING THE PRACTICE OF SCIENTIFIC INQUIRY

The over-arching purpose of this study was to gain a more in-depth understanding of how scientific inquiry is conducted in high school classrooms. Part of the focus of the study was to examine how the nature of science was represented during the practice of scientific inquiry in the three classrooms and how different voices participated in the classroom inquiry activities. The first part of this chapter will describe how the assumptions and values intrinsic to the generation of scientific knowledge were attended to during the students' involvement with their plant experiments in each teacher's classroom. The second part of the chapter will describe the various voices, both written and verbal, that contributed to the scientific inquiry activities in all three classroom experiences.

Representations of the Nature of Science

Rather than examine every possible aspect of the nature of science for this study that are relevant and understandable for students, this study focused on three tenets of the nature of science that are frequently discussed in educational literature (AAAS, 1993; Lederman et al., 2002; NRC, 1996; Schwartz, Lederman, & Crawford, 2004). These three features, summarized in Table 8, were chosen because of their potential alignment with the PREP experiments. Also considered was the compatibility of the content of these three tenets with the three different courses and the students' varying ages and experiences with inquiry-based instruction.

During the analysis of the practice of scientific inquiry in the three classes, the class observations, interviews, and documents were examined for evidence that the features of the nature of science summarized in Table 8 were either implied or were explicitly addressed during the scientific inquiry. These three features of the nature of science included (a) the empirically-based aspects of scientists' work, (b) the social and cultural embeddedness of scientists' work (This tenet will be examined in two different parts: Part 1, the norms of scientific practice and, Part 2, the societal influences within which science operates), and (c) the theory-ladenness of scientists' work. The features were considered to be explicitly addressed during the inquiry if there was an

Table 8

Tenets of the Nature of Science Investigated During the Practice of Scientific Inquiry

Feature of the nature of science	Elaboration of the feature of the nature of science
Tenet 1: Scientific knowledge is usually generated through empirical practices.	<p>There is no single set of procedural steps used by scientists during their work.</p> <p>The empirical practice is based on direct observations of the natural world or inferences about that which cannot be observed.</p> <p>The observations may be enhanced by equipment.</p> <p>The observations may also be limited by human interactions with the equipment (e.g., assumptions about the use of equipment).</p>
Tenet 2: Scientific knowledge is socially and culturally embedded.	<p>Part 1: Scientific work has established norms for practice and evidence within which scientists operate.</p> <p>Part 2: Additional norms result from political, economic, philosophical, social, and religious influences from the society within which science operates.</p>
Tenet 3: Scientific knowledge is theory-laden (or subjective).	<p>Decisions made by individual scientists are influenced by their personal and profession backgrounds, education, values, beliefs, past experiences, and training. These factors impact the decisions about what scientists decide to observe, how they observe it, and what they expect to observe.</p> <p>Scientists attempt to maintain objectivity during their practice, but it cannot be completely eliminated due to these factors.</p>

intentional student reflection on, discussion of, or attention to the features during the class discussions or if they were incorporated into assessment or evaluation tasks. Simply telling students that scientists valued research about plants was categorized as implicit rather than explicit because the comment was not drawing attention to the over-arching idea that scientists are influenced by the society within which science is practiced. Other occasions during which the tenets of the nature of science were inherently part of the scientific inquiry, but had no purposeful attention drawn to them, were considered to be implicit (Schwartz, Lederman, & Crawford, 2004).

During their interviews, the teachers expressed strong interest in implementing scientific inquiry in their classes within the context of PREP because it involved “real research,” would be the most “authentic scientific experience” the students could have at their educational stage (Interview with Bonnie, 6/7/2006, 29; 2/1/2006, 401), the independent research was an ideal way to “engage the students in science and not just teach some things out of context (Interview with Janet, 3/8/2006, 224-226), and because it would help students become “familiar with the research design and just having experiments and why do we have experiments” (Interview with Sara, 6/7/2006, 22-24). All of the teachers valued the scientific inquiry because of the experience it afforded their students to learn about how scientific work is conducted. Throughout the practice of scientific inquiry, how were these values and assumptions intrinsic to their inquiry explicitly represented in the three classrooms? How were these values and assumptions implicitly, rather than explicitly, represented by the activities of the students during their inquiries? To what extent did the students’ practice of scientific inquiry support values and assumptions of scientific knowledge that are compatible with those summarized by science education researchers?

Intentional, Explicit Attention Given to the Nature of Science during the Inquiry

Prior to starting the *Arabidopsis* experiments, none of the three teachers had any written lesson plans, goals, or student objectives related to the scientific inquiry. During the interviews, when teachers described “inquiry” or “scientific inquiry,” they primarily spoke of mechanical steps and, to a limited degree, the reasoning tasks their students would make as they moved through the mechanical process of inquiry. It is these aspects of the steps of “doing” science, not the values and assumptions associated with the knowledge product of scientific inquiry that the teachers envisioned their students involved with during their plant experiments. There was no evidence that

the teachers explicitly addressed the nature of science by involving their students in intentional discussions or reflections about the nature of science during the inquiry activities.

Features of the Nature of Science Implied during the Practice of Inquiry

Because of the PREP context of the scientific inquiry, several features of the nature of science were naturally embodied in the students' participation in the inquiry. In many cases, the students' experiences during the scientific inquiry may have reinforced some aspects of the values and assumptions fundamental to the generation of scientific knowledge that are the focus of this study: scientific knowledge is (a) generated through empirical practice, (b) socially and culturally embedded, and (c) theory-laden or subjective. Ironically, the practice of inquiry in these three classrooms may also have promoted contradictions of these same tenets of the nature of science.

Tenet 1: Scientific knowledge is frequently generated through empirical practices. Scientists use many different methods for conducting their research. Scientists make direct observations of the natural world or infer relationships that cannot be observed. Scientists' observations, which are often enhanced by using equipment, are also often limited by human interactions with the equipment. The students' work in designing and conducting their experiments supported the tenet that empirical practices may lead to the generation of scientific knowledge because essentially that was the ultimate purpose of their investigations – to learn more about the function of a disabled gene in a plant. In addition, during their experimental work, students made direct observations of plant characteristics, such as bolt height, the number of leaves, and the leaf surface area. Supportive equipment, such as rulers, microscopes, pH probes, digital cameras, and computer software, was used to enhance the students' observations. Table 9 summarizes the ways that the tenets of the nature of science were both reinforced and challenged implicitly during the practice of scientific inquiry in all three teachers' classrooms.

At St. Catherine's Academy and Stuart Springs Governor's School for Science, Mathematics, and Technology, Janet and Bonnie's students were encouraged to make preliminary observations of the growing plants before deciding on their dependent

Table 9

Summary of NOS Features Addressed Implicitly

Tenets of the nature of science	Implicit	
	Reinforced NOS tenet	Contradicted NOS tenet
Tenet 1: Scientific knowledge is usually generated through empirical practice.		
There is no single set of procedural steps used by scientists during their work.	B, J: Revisited observations before deciding on dependent variable	S: Students moved through process, step by step. B, J, S: PREP is cause-and-effect, controlled experimentation. B, J, S: Lab reports reflect linear process
The empirical practice is based on direct observations of the natural world or inferences about that which cannot be observed.	B, J, S: Nature of PREP	
The observations may be enhanced by equipment.	B, J, S: All used equipment	
The observations may be limited by human interactions with the equipment (e.g., assumptions about the use of the equipment)		B, J, S: Little to no emphasis on assumptions about use of equipment
Tenet 2: Scientific knowledge is socially and culturally embedded. Scientific work has established norms for practice and evidence within which scientists operate.	B, J, S: Collaborative efforts B, J: Scientific and non-technical resources; literature reviews B, J, S: Conventional ways of recording findings B, J: Conventional ways of presenting data patterns B, J: Conventional format for lab reports J: Conventional format for verbally presenting research	S: Non-conventional format to write up lab report S: Students did not base experiments on previous work done by scientists S: Students did not graph or analyze data

(table continued)

Table 9 (continued)

<p>Additional norms results from political, economical, philosophical, social, and religious influences from the society within which science operate.</p>	<p>J: Discussion about genetically engineered plants B, J: Considered the benefits of research about flavonols B, J, S: Michael addressed societal benefits of plant research</p>	<p>S: Students were not involved with any aspect of societal aspects of scientific practice</p>
<p>Tenet 3: Scientific knowledge is theory-laden (or subjective) Decisions made by individual scientists are influenced by their personal and professional backgrounds, education, values, beliefs, past experiences, and training. These factors impact decisions about what scientists decide to observe, how they observe it, and what they expect to observe. Scientists attempt to maintain objectivity during their practice, but it cannot be completely eliminated due to these factors.</p>	<p>J, B, S: Students made decisions about treatment, dependent variables, and research design B: Technical decision-making</p>	<p>S: Superficial decision-making. J: Non-technical decision-making B, J: Did not address subjective nature of observations S: Promoted objective observations with her students</p>

Note. B = Bonnie, J = Janet, S = Sara

variables - the characteristics of the plants they were going to report as their data. Making observations at the beginning of their inquiry, instead of only as a means for collecting data, challenged the assumption that scientific knowledge is generated by “the Scientific Method,” a single method that is done in a linear, step-by-step manner. Also possibly disrupting the conception of this mythical linear method by which scientists do their work were Bonnie’s efforts, after talking with Dr. Hayes and Michael, to get her students to cycle back through their inquiry process to revisit and possibly revise their decisions about the types of observations they would make and the kinds of data analyses they planned to perform.

On the contrary, the misrepresentation of one single method for conducting scientific work, that of a linear, lock-step process, may have been reinforced by the final lab report formats that teachers required of their students. Regardless of the actual multiple methods and iterative investigative cycles employed by scientists as they conduct their work, scientists traditionally report their research in scientific journals in such a way as to give the impression of a linear, step-by-step process. All of the students in this study represented their work in a specific, linear format (with a little variation between classes) similar to the conventional format used by scientists when they report their research: general information, purpose of the experiment, results, analysis, and conclusion. Just as may be true when scientists report their findings, the students communicating their experiments using this format may have reinforced the notion that scientific knowledge is generated by means of empirical practice that is conducted in one way - a rigid, lockstep process.

Some students reported new perspectives of the experimental process. For example, during the student group interview with four of Bonnie’s students at the end of their inquiry, Tony commented that he had learned that “experiments take a long time” (Interview, 5/24/2006, 829). Patricia reported that she now understood that during experiments, “you have to learn to revise your experiment” (Interview, 5/24/2006, 80). These new student discoveries about inquiry may seem minor, but they could potentially contribute to students shifting their conceptions of the scientific practice beyond the common public perception of a linear, lock-step, and rigid procedure.

The context of the *Arabidopsis* experiments, may have also promoted contradictions to the assumptions and values of the empirical practice of scientists. For example, because of the context of the PREP experiments, students may interpret the empirical practice of scientists as

being limited to cause-and-effect, controlled experiments, when in actuality scientists use many different methods to solve problems and answer questions that are both empirical and conceptual or theoretical.

In addition, the practice of inquiry in all three classrooms may have implied that during empirical practice, observations were nonproblematic especially when equipment enhanced the observations since there were no class discussions about the equipment, equipment choices, and equipment use. For example, in Bonnie's class twelve of the fourteen students who turned in their final papers reported using the National Institute of Health software ImageJ to determine the surface area of the plants or leaves. The surface area data was collected by using a stylus (connected to a tablet PC) that was used to trace around the digital camera produced images of the plants taken from looking down on the plants. Having not used this software, the tablet PCs, and the stylus before, the students took the initiative to teach themselves and each other how to use them; however, students were observed regularly misusing the program. Just as the students were finishing up their experiments, three students realized some of the limitations of the ways they used the software and hardware and acknowledged these problems in their final lab reports when they explained why they were not basing their experimental conclusions on the leaf surface area data. During the group interview these students talked about some of the problems they had discovered about their use of ImageJ and the stylus:

Tony: Well, when [the plants] grew, there were, like, three other plants mixed together and it was hard to tell which plant was which (Interview, 5/24/2006, 470-471).

Tony: Then we opened up the program and we had to calibrate the picture...

Patricia: That's where some of the errors came in (laughter)...

Tony: [to calibrate it] I measured the side of the pot with a ruler then I drew a line with the, using the program that said how long it was...the problem is that, uh, I didn't, the pots are, like, all the pots are not squares [because of the different angle of the digital camera when the images were taken] (Interview, 5/24/2006, 419-426).

When this lab group discussed their ImageJ problems with Bonnie, she insisted that the students use the data that they knew had been compromised by their incorrect use calibration. When the students attempted to get Bonnie's permission to *not* use the leaf surface area data, she responded, "No, you're using surface area data. Is there something wrong?...You're going to

use that surface area data – you spent a lot of time getting that data and you’re going to use it!” (Observation, 5/17/2006, 76-83).

Eleven other students, who had used ImageJ, included the leaf surface area data, graphs, and statistical analyses of this data in their lab reports. There was no mention of any limitations or problems with the use of the technology and equipment in their discussions or conclusions in their final lab reports. It appeared that most of the students in the class considered the data collected using this technology and equipment meaningful and valid regardless of possible limitations resulting from its misuse. Table 10 summarizes the aspects of the practice of scientific inquiry in each teacher’s classroom that supported each tenet of the nature of science. Table 11 summarizes the activities in each classroom that contradicted each NOS tenet.

Tenet 2: Part 1. Scientific knowledge is socially and culturally embedded. Scientific work has established norms for practice within which scientists operate. The practice of scientific inquiry within the context of PREP in all three classrooms supported certain norms of practice of scientific work from which scientific knowledge is generated [e.g., scientists work collaboratively with other scientists on their investigations; base their investigations on public records of previous scientific work; design and conduct their manipulative experiments in certain ways; collect, represent, and analyze data in certain ways; communicate their experimental findings using a certain format (AAAS, 1990, 1993; NRC, 1996; Valiela, 2001)].

For example, just as scientists collaborate with others as they work, all three teachers structured the inquiry so students worked with each other during their experimental work. Throughout each stage of the inquiry activities, students were observed talking with their lab partners, making decisions together, and treating the plants, making the observations, and analyzing the data as partners. While Sara’s agriculture students at Riverview High school did not move their discussions beyond their immediate lab pairs, Janet involved her students in a peer review of each others’ methodologies so the students could get constructive feedback from at least two other students in the classroom. Again, at the culmination of the experiments, Janet involved her students in both presentations and roundtable discussions as a whole class during which she structured the discussions so that students were required to ask questions of, or make comments to, their peers about the investigations. Bonnie’s students also compared their observations several times across lab teams and frequently helped students outside of their lab teams with using equipment and computer software.

Table 10

Summary of Activities That Implicitly Supported the Tenets of NOS in Each Classroom

	Bonnie	Janet	Sara
Tenet 1: Scientific knowledge is usually generated through empirical practices.	<p>Students conducted investigations through experimental process.</p> <p>Students made direct observations of plants.</p> <p>Students used equipment to enhance observations.</p> <p>Data collection supported interactive process.</p>	<p>Students conducted investigations through experimental process.</p> <p>Students made direct observations of plants.</p> <p>Students used equipment to enhance observations.</p> <p>Data collection supported interactive process.</p>	<p>Students conducted investigations through experimental process.</p> <p>Students made direct observations of plants.</p> <p>Students used equipment to enhance observations.</p>
Tenet 2, Part 1: Scientific work has established norms for practice and evidence within which scientists work.	<p>Students collaborated with each other and more-expert others to plan and conduct investigations.</p> <p>Students based their work on work of other scientists.</p> <p>Students displayed their findings in using conventional formats.</p> <p>Students used conventional ways to present data patterns.</p> <p>The format for the final paper reflected conventions for scientific writing.</p>	<p>Students collaborated with each other and more-expert others to plan and conduct investigations.</p> <p>Students based their work on work of other scientists.</p> <p>Students displayed their findings in using conventional formats.</p> <p>Students used conventional ways to present data patterns.</p> <p>The format for the final paper reflected conventions for scientific writing.</p> <p>Oral presentations reflected conventions for scientific presentations.</p>	<p>Students collaborated with each other to plan and conduct investigations.</p> <p>Students displayed their findings in using conventional formats.</p>
Tenet 2, Part 2: Additional norms result from political, economic, philosophical, social, and religious influences from society within which science operates.	<p>Michael stressed potential medical benefits of scientific research.</p> <p>Discussion about human benefits of flavonol research.</p>	<p>Michael stressed potential medical benefits of scientific research.</p> <p>Discussion about human benefits of flavonol research.</p> <p>Students considered intended and unintended consequences of attempts to reduce corn borer.</p> <p>Students did reading and had discussion about genetically modified crops.</p> <p>Final exam question about transgenic corn.</p>	<p>Michael stressed potential medical benefits of scientific research.</p>
Tenet 3: Scientific knowledge is theory-laden (or subjective).	<p>Students involved with decision-making based on previous experiences, prior knowledge, interests, and values.</p>	<p>Students involved with decision-making based on previous experiences, prior knowledge, interests, and values.</p>	<p>Students involved with decision-making based on previous experiences, prior knowledge, interests, and values.</p>

Table 11

Summary of Activities That Implicitly Contradicted the Tenets of NOS in Each Classroom

	Bonnie	Janet	Sara
Tenet 1: Scientific knowledge is usually generated through empirical practices.	Format of final lab report reinforced one, linear empirical process. Context of investigations reinforced notion of empirical practice as cause-effect, controlled experiments. Little to no consideration for limitations due to human interactions with equipment.	Format of final lab report reinforced one, linear empirical process. Context of investigations reinforced notion of empirical practice as cause-effect, controlled experiments. No consideration for limitations due to human interactions with equipment.	Structure of process was rigid, linear. Format of final paper reinforced one, linear empirical process. Context of investigations reinforced notion of empirical practice as cause-effect, controlled experiments. No consideration for limitations due to human interactions with equipment.
Tenet 2, Part 1: Scientific work has established norms for practice and evidence within which scientists work.			Students used unconventional format for final paper. Students did not base their investigations on previous scientific work. Students did not present data patterns.
Tenet 2, Part 2: Additional norms result from political, economic, philosophical, social, and religious influences from society within which science operates.			Students were not involved with discussions about societal aspects of scientific practice other than during Michael's kick-off session.
Tenet 3: Scientific knowledge is theory-laden (or subjective).	Students conducted investigations without considering the subjective nature of decision-making.	Students conducted investigations without considering the subjective nature of decision-making.	Students learned about the objective nature of their work.

In Bonnie's class the social aspect of students' empirical work even extended beyond their teams to conversing with other students in the classroom. Several times Bonnie's students collated their observations about certain characteristics of the mutant and wild-type plants, followed by a whole class discussion and the students performing statistical analyses to compare the combined data. Bonnie's students' discussions were also extended beyond the regular classmates to others outside of the classroom. The conferences between the student pairs in Bonnie's class and the visiting scientists further promoted the image of the social nature of scientists' work. One of Bonnie's students remarked about how her idea of scientists' work had changed because of their opportunities to confer with Dr. Hayes and Michael during their classroom visits:

I always thought that, okay, scientists go in their lab and do their own little thing and figure out their experiment but it sounds like, you know, obviously, we're helping out with this experiment and a lot of different people are working on it and so, I don't know, I guess it's like that stereotype you think of, like one little chemist in their laboratory, like messing around, but it's not like that at all (laughter) (Interview, 5/24/2006, 837-842).

Another aspect of the nature of scientific knowledge that reflects its social and cultural embeddedness is that its generation is customarily based on the work of other scientists who are either currently providing or have previously contributed valuable science that established a basis from which other scientists build their work. Two teachers, Bonnie and Janet, incorporated this feature of the nature of science into their implementation of inquiry by emphasizing the importance of their students doing preliminary research on the internet before starting their experiments. For example, the students in Bonnie's class who treated their plants with juglone, a natural herbicide produced by the roots of the black walnut tree, searched scientific publications on the internet looking for information about other experiments that involved exposing plants to juglone. As a result of their search, the two students designed their experiments to reflect the juglone concentrations based on those described in one of the scientific papers they found. Six of the eight lab teams in Bonnie's class cited at least one reliable internet source about *Arabidopsis*, flavonols, or their experimental treatments in their final papers even though including a bibliography was not a required part of the final paper. Using online scientific resources (e.g., PubMed) was further emphasized by Dr. Hayes when she brainstormed the experimental work with Bonnie's students. In addition to the online sources, Dr. Hayes was a valuable resource to

the students during her class visits because she shared her expansive knowledge about *Arabidopsis* and flavonol research with the students as it related to their experiments.

During an interview, Janet included this aspect of the nature of science in her reasons for finding class time for her students to perform the *Arabidopsis* experiments. One of her main interests in the inquiry, which she stressed during her first interviews, was to “teach [her students] the importance of using other people’s background information” (Interview, 3/8/2006, 257). Janet reinforced the value of considering published scientific work about plants and *Arabidopsis* to her students by requiring them to include a bibliography as part of their abbreviated final paper; however, just a little more than half of the lab teams’ final papers given to the researcher included a list of references within the final paper. While she did not ask her students to intentionally reflect or write about the tradition of scientists building on each other’s work, on the last day of the experiments when the students had their roundtable discussion, Janet stressed how science builds on itself and asked students to generate ideas about how the next group of students could build upon this year’s work with the *Arabidopsis* plants (Observation, 5/11/2006, 173).

The practice of the scientific inquiry in Sara’s class did not involve her students in searching for background information about *Arabidopsis thaliana*, plants, or their experimental treatments.

Traditionally, scientists have particular ways that they document and display their observations, analyze their data, and represent their analyses. Data are commonly organized in data tables and compared using graphs so readers can examine the data and recognize the patterns and trends. Averages, or means, of numerical data may be calculated and statistical analyses, such as t-tests, may be performed on data to further organize it into a format that may be useful to readers.

Janet, Bonnie, and Sara built these conventional scientific formats of organizing and displaying data into their implementation of inquiry in the classroom. Both Sara and Janet gave their students a specific table on which to record their observations and data; Bonnie’s students designed their own data tables. Sara required students to record only their collected quantitative data on their data sheets. For example, Larry recorded the number of leaves on the plants in each pot and plant height each time he and his lab partners made their observations. Bonnie and Janet both required their students to include descriptive observations, as well as their collected

quantitative data. For example, one of Janet's students, Linda, included observations about when the flowers started to bloom, first bolted, and germinated. In his lab notebook, one of Bonnie's students, Rajeev, described the bolts inability to stand up and the unhealthy appearance of some of the plants.

During her first interview, Sara talked about her plans to take her students to the computer lab so they could use Microsoft Excel to create data tables and graphs from their collected data. The students went to the computer lab one morning to transfer their data from their written data tables into data tables using Microsoft Excel. However, Sara was not able to return to the computer lab so the students could graph their data because the computers were reserved at the end of the year for the online end-of-course testing required by the State Department of Education.

After collecting and recording data, scientists customarily re-present their data in other forms such as diagrams and graphs. During the analysis of data, both Janet and Bonnie required their students to use graphs to compare their observed data. Students in both classes were familiar with bar and line graphs and using Microsoft Excel software to create their graphs, but they still required some support when making decisions about whether the line graph or bar graph format was most appropriate for the types of data they collected. Janet led a whole class discussion about data representation, different ways to show data patterns depending on the continuous or discrete nature of the collected data, and how to correctly construct graphs with the dependent variable identified with the y axis and the independent variable associated with the x axis. After the whole-class discussion, Janet roved the classroom answering students' individual questions about their graphs and emphasizing other aspects of the graphs such as not using pencil and how to label the axes correctly (Observation, 4/27/2006). Most of the lab groups who included graphs with their final paper successfully followed these graphing rules.

Bonnie also reserved class time for her students to work on the class computers to create their graphs. Bonnie did not hold a class discussion about graphing but she was continually available to students, answering their questions about graph formats as they worked on the class computers. Since her students' graphs from last year's PREP experiments were "all over the place," Bonnie intentionally built in class time this year to help the students while they worked on their graphs (Observation, 5/10/2006, 159). Most of the students followed the conventions for the graphs they included in their final lab reports.

In addition to presenting data in graphs and diagrams, scientists are expected to conduct various statistical analyses on their collected data from which to base their conclusions. For their final lab report turned in for a grade, Bonnie's students were required to include the results from at least three t-tests carried out on their experimental data, two of which were required to be based on class-wide data collected about the plants. The students chose the third set of data from which to calculate the remaining t-test. There was no whole class discussion concerning how to do a t-test using MiniTab or the meaning of the results of a t-test and this may be because

[The students] are expected to do statistical analysis in their research projects [for Fundamentals of Research and the independent research project] so they all have been exposed to it. ...[Minitab] is really, it's a pr program that does it so you really don't have to understand anything about a t-test except you're looking for a p value less than 0.05 (Bonnie Interview, 6/7/2006, 289-293).

In their final lab reports, the students included between eight and forty different t-test results calculated by comparing some aspect of the four different plants - mutant experimental and control and wild-type, experimental and control. Bonnie recounted how the results of the t-tests also helped Dr. Hayes during her conversations with students about their experimental results:

I think Dr. Hayes really helped them make sense of their data and, um, they're still, you know, kids who've done, like, twenty t-tests and have some differences and some not significant differences and, you know, it's like, "What do I do with this?" and it's like "Well you know, hard to say." (Interview, 6/7/2006, 317-320).

When scientists report their findings in writing to the scientific community, their manuscripts traditionally conform to an established standard format. Modifications of this format are used for both high school science fair research papers and experiments done in science classes. All three teachers required their students to submit a written document that described their inquiries and each had different requirements and expectations for the contents of each part of the paper.

Throughout the practice of inquiry in her classes, Janet emphasized the process of writing the final research paper. In her first interview, she cited the opportunity for her students to write another research paper as a major factor that influenced her decision to include the inquiry experience into her course (Interview, 3/8/2006, 252-253). Janet followed-through with this

emphasis during the inquiry, giving her students class time to write the various parts of the paper and peer review each other's methodologies. Janet also reinforced the importance of this paper and how it should be written by taking up parts of the paper in sections, making extensive comments on the papers, and then returning them to the students for correcting before turning in the final paper. The format that Janet gave her students was summarized on a two page handout "How to Write a Scientific Lab Report for Biology" and included details about what should be included in each of the sections: title, introduction, procedure and materials, results, discussion and conclusions, and a bibliography. Janet reported that she had based the format from "guidelines [that] came from, among other places, the Virginia Junior Academy of Sciences" (Interview, 4/20/2006, 37-28). As the experiments progressed, Janet realized that they were running out of time so she reduced the expectations for the final experiment report to an abstract format. Again, she provided detailed instructions to her students about what should be included in the abstract. The importance that Janet placed on her students' learning about writing lab reports was also evident in her thorough final exam question that required students to critique the introduction, methodology, and conclusion sections of a sample *Arabidopsis* experiment lab report.

The format for the final experiment reports that Bonnie's students turned in was very similar to the format followed by Janet's students: introduction, results, statistical analysis, and conclusions. Students documented the procedures and observations in their lab notebooks they turned in when the experiments had been completed. When Bonnie was asked during an interview to comment on how she knew what format to give her students to use, she gave credit to couple different sources - a format she learned to use early in her teaching career and the formats required by the Virginia Junior Academy of Sciences and the science fair.

Sara attempted to have her agriculture students write a short lab report after they had completed their experiments. The modified lab report included the sections purpose, hypothesis, results, and conclusion. Essentially, she dictated the majority of the content of the seven sentences the students were supposed to write, leaving blanks for them to fill in the words reflecting their particular experimental treatments and dependent variables. She commented during an interview that she handled the final experiment assignment in this way because her students "have a weakness in writing and I really try to do anything with writing that I can" (Interview, 6/7/2006, 185-189).

In addition to producing written scientific works, scientists also orally present their research at professional conferences and meetings. Of the three teachers, Janet was the only teacher that offered her students opportunities to present their work using a spoken format. The format she gave the students to use followed the traditional oral presentation format used by scientists: introduction, procedure/methodology, results/data, and discussion/conclusions.

Tenet 2: Part 2. Scientific knowledge is socially and culturally embedded. Additional influence on the practice of science results from political, economic, philosophical, social, and religious influences from the society within which science operates. In all three classes little direct attention or reference was given during the scientific inquiry activities to the ways in which perspectives generally not considered to be scientific (e.g., religion, politics, economics) influence the practice of science. One exception to this was Janet's lesson about genetically engineered plants that she built into the scientific inquiry about plants. Part of this lesson involved Janet presenting a PowerPoint presentation "Monarch, Milkweed...and the Bt Corn Controversy" to her classes during which students considered the intended and unintended consequences of trying to reduce the impact of the European corn borer on corn crops. In addition, her students read two pages in their textbook about genetically engineered plants and were required to use the internet to prepare "talking points" for a class roundtable discussion. When one of Janet's students, Henry, showed his two pages of "talking points" to the researcher, he added the observation that he had trouble finding information in favor of genetically modifying foods. Along the same theme, Janet included a question on her final exam related to genetically modified crops. To answer the question, students had to assume the perspective of a US Department of Agriculture employee and write a justification for either awarding or denying a permit to an international company that requested permission to grow transgenic corn in the US.

Another example of a consideration for influences on scientific work outside of pure science was evident in presentations that Michael gave to all three classes. Built into his presentation was the notion that scientists value their research on plants for many reasons, including the potential medical insights that could be gained (Bonnie Observation, 3/22/2006, 35-40). In addition, this idea that research is important to scientists because it may potentially improve the human condition was implied during PowerPoint presentations Bonnie and Janet gave to their classes about flavonols. Both Janet and Bonnie's students were conducting research

on a mutant *Arabidopsis* strain generated by Dr. Hayes's research team. Because Dr. Hayes and her research team believe that the gene disabled in this mutant, FLS1, is somehow involved with flavonol production, both Janet and Bonnie took class time with their students to talk about flavonols. Students in both classes had an opportunity to consider the value of research related to flavonols due to their anti-cancer, anti-inflammatory, anti-allergic, anti-viral, and anti-oxidant properties.

Tenet 3: Scientific knowledge is theory-laden (or subjective). Decisions made by individual scientists, including those about what to observe, how to observe and what is expected upon observing, are influenced by their personal and profession backgrounds, education, values, beliefs, past experiences, and training. Throughout the inquiry activities, students in all three classes made several decisions with regard to their experiments. Of course, their decisions were neither as numerous nor as complex as those made by professional scientists involved with scientific research, but students were involved with decision-making that was influenced by their individual prior knowledge, experiences, interests, and values.

At the beginning of the experiments, students were involved with choosing the treatment to which they would expose their four different pots of plants. While Michael had asked the students to narrow their treatment to something that would not kill the plants, was natural in the plants' environment, and was practical in the classroom, the students in Janet and Bonnie's classes had quite a bit of leeway in making their choices for the plant treatments. The students varied in the depth of the thought they gave the treatments they chose. For example, Carol, one of Bonnie's students, decided to use limewater on the plants because

when we were learning kinda about flavonoids, it talked about how a lot of times that could be used in pigment and then I remembered that a lot of times acidity of soil can affect pigment of flowers so we kind of just came that, came about that way (Interview, 5/24/2006, 159-161).

Christie, who was in the same class, talked about how she and her lab partner decided on their treatment: "Oh, I don't know. I think we were like, 'Oh, let's do [photoperiods]' when we were talking about ideas, I guess (Laughter)" (Interview, 5/24/2006, 118-119).

When some of Janet's students were asked during an interview about how they chose their independent variable, they reported varying degrees of connecting the choice to prior knowledge. For example, when Kathy was asked how her group chose their drought environment

as the treatment for the plants, she laughed and responded, “Eenie, meenie, minie, moe” (Interview #2, 5/11/2006, 55). During a different group interview, Doug linked his choice of drought conditions to the lack of rain in his region of the state during the time the class started the experiments: “I chose mine because uh at the time [our state] wasn’t getting any rain so I thought about current events and how the drought would affect these plants” (Interview, 5/4/2006, 128-129).

Students in Sara’s class were given a list of chemical solutions to choose from for their plant treatments: magnesium, potassium, copper, nickel, zinc, iron, calcium, and salt. During the researcher’s ninth visit to Sara’s classroom, she wandered around and talked informally to the lab pairs about how they chose the plant treatments while they worked on their experiments. Several of the lab pairs shared no reasons for the question with the researcher about how they chose their solutions that they were pouring on the plants. Three different students answered the question:

1. She picked it (Observation, 5/17/2006, 47).
2. I picked it from the list. (55).
3. We just picked it. (76).

There was no student discussion, reflection, or writing in any of the classes about factors that influence the decisions that scientists make when they are designing the experiments or those that had affected the students’ decisions.

A second important decision that lab pairs had to make during the experiment involved the characteristics of the plants they would observe and monitor through data recording. All three teachers gave their students the choice of the aspects of the plant development they wanted to observe. Bonnie brainstormed with her students various plant features that might interest them for their experiments, such as number of seed pods, length of stem, and bolt length. Pointing out that their decisions might have to be modified as the experiment progressed, she reminded them to “keep their eyes open, have an idea of what you want to measure but be flexible and observant for other things that might happen” (Observation, 4/5/2006, 125-126). One lab group in Bonnie’s class based their decision on a past experiment that Tony had done with *Arabidopsis* plants. Carol gave a detailed explanation about how her lab pair chose what they were going to measure, considering the flavonoid connection to the mutant plants:

The first day we measured plant height but then we decided to change that into bolt height because some of our plants bolted sooner than others so we thought maybe we'd be able to see a trend in that. And then we did numbers of flowers because pigmentation – same kind of thing – seeing if that would affect anything with em flavonoids. And then we also, we after they had flowered, we counted the number of, like, seed pods or fruits (Interview, 5/24/2006, 305-310).

During a class discussion early in the inquiry, Janet reminded her students that they needed to delay their decisions about the data they would collect during the experiment

What we're really looking for is what happens when we stress these plants. Does it have a wider range of drought tolerance? Does it have a wider range of light tolerance? In this case we're hoping to keep them alive. In this case we're hoping to see difference. We don't know what to look at yet (Observation, 4/3/2006, 36-39).

As the plants germinated and started to grow, the students began treating the plants and making their observations. At the end of the experiments when the students were asked how they made the decision about what data to collect, Edward explained

The leaves were the first ones we could measure on, rosette leaves, and the, there were, there were the bolts were coming out...those were pretty much the only measuring, obvious measuring we could do so we started (Interview, 5/4/2006, 138-140).

To Linda, it was not a difficult decision:

It just seemed kind of obvious. It was like everyday you come into the classroom and there'd be more leaves or the bolt would have grown like three inches over night, you know, it just seemed to be the ideal, um, like the ideal measurement to show how much was growing or decreasing (Interview #1, 5/11/2006, 148-151).

Kathy and her lab partner decided to measure the length of the leaves, the height of the plants, and the color and number of the flowers because "it just seemed kind of, just the easiest way to see how the plant was growing and, and changing" (Interview #2, 5/11/2006, 86-91).

Another aspect of the theory-ladenness of scientific knowledge results from scientists approaching their research questions by choosing different observations to make based on their prior experiences, education, and training. This was implied during conversations Bonnie's students had with Dr. Hayes when she visited the class to talk about their research. In her final

interview, Bonnie commented that she felt Dr. Hayes had helped her students interpret the data in ways that neither she nor her students had thought of looking at it:

Dr. Hayes had noticed that, I, and this is something I didn't notice and the kids hadn't noticed, really, is that the, um, at the end the mutant plants, they seemed to produce flowers and fruits earlier but their seeds didn't seem to be fully developed (Interview, 6/7/2006, 258-261).

A few students also reported that Dr. Hayes and Michael had looked at their data differently than they did and talked with them about what they saw when they looked over their results:

[Dr. Hayes and Michael] pointed out "Well look, like these, uh, something about the first ones to flower ended up having less flowers but the rest of them caught up the next time you measured them and they hadn't really had that many more flowers." (Interview, 5/24/2006, 665-667).

During the practice of the scientific inquiry, there was no attention drawn to the idea that, in spite of important attempts to maximize objectivity, scientists' work is inherently subjective. Sara was the only teacher to address the objectivity/subjectivity topic by reinforcing the notion that one goal of scientific work is to eliminate subjectivity. She included this discussion when her students were making their decisions about what they were going to measure during their experiments. After explaining to her students the difference between a dependent variable and an independent variable she guided them in writing on the data sheets she had just handed out:

Dependent variable – you are going to do two different things....These can be number of leaves or height of plants. We want to do objective observations, not subjective. We want to use numbers. What else could you measure? You can pick two of these and write them in for your dependent variables. I think the easiest ones to do would be height of plant and number of leaves but you can do whatever your little heart desires (Observation, 4/12/2006, 52-57).

After her explanation, she wrote a few other choices on the board for students to pick from when making their decision about what to measure: width of the plant, number of stems, and number of petals on the flowers. After this class discussion, students collected their data and recorded it on their data sheets.

A month later, the researcher wandered around Sara's classroom and tried to informally get some feedback from the students about their choices related to data collection. While talking

with one group about their experiment, the student simply did not respond to the question about how he decided to count flowers and leaves. A student in another group shrugged his shoulders when he was asked how he had decided to count leaves and measure the plant height. Another student said that he and his lab partner did not have a reason for their choice. Only one student in the class talked with the researcher about their choice. Larry explained why he and his lab partner had picked bolt height and the number of leaves as their data: "I thought the height would be taller for the mutant than the control, so that's why we picked it" (Observation, 5/17/2006, 77-78).

All three teachers reported during interviews that it was important to them that their students make as many of their own decisions as possible during the scientific inquiry. Students in all three classes did make their own choices with regard to the treatment they used on their plants and the observations they made as the plants matured; however, students in the three classes varied in the depth to which they considered their choices when making decisions. Bonnie's students used more technical resources (e.g., online scientific documents, scientists) when making decisions; Janet's students based their decisions more on prior, nontechnical knowledge; Sara's students did not appear to have much basis for the decisions they made during their experiments. Other than Sara's comment to her students about making "objective observations, not subjective" there were no other discussions about objectivity.

Summary

All three teachers, regardless of the subject they taught, who their students were, and where their schools were located, reported that they were interested in their students having experiences that reflected the experimental work conducted by scientists. The teachers were particularly intrigued by the PREP context of the inquiry because the experiments were original, and through their work, the students could potentially contribute to the generation of new scientific knowledge. None of the teachers reported intentionally planning for student discussions or reflections that explicitly addressed the values and assumptions relevant to the construction of this scientific knowledge.

Despite the lack of explicit attention to the values and assumptions typical of the process of generating scientific knowledge, various aspects of the practice of inquiry supported these assumptions. Due to the context of the inquiry, the PREP activities, students were involved with the empirical practice of designing and conducting experiments that involved variables and

controls, and during which equipment was used to enhance human capabilities for observations. To some degree, the structure of the experiments in Bonnie and Janet's classes reinforced the notion of experiments as non-linear, non-recipe-like procedures.

All three teachers reinforced the social nature of scientific work by involving their students in teams as they conducted their experiments. Bonnie strengthened the collaboration by encouraging inter-team discussions and conversations with *Arabidopsis* scientists; Janet's students peer-reviewed each other's methodologies and conducted roundtable discussions about their experiments. Both Janet and Bonnie required their students to base their experiments on information provided on the internet by both scientific and non-technical sources. With respect to documenting their findings, all three teachers' students adapted conventional data table formats; however, only Bonnie and Janet's students followed the data recording with traditional ways of conducting and presenting their data analyses, and writing up their lab reports.

Scientists' decisions about their work are influenced by the society within which they conduct their work. This feature of the nature of science was lightly touched upon in Bonnie and Janet's classes when they connected the benefits of the study of flavonols to their students' experiments. In addition, Michael stressed the medical and health benefits of plants during his class discussions. A more powerful example of the societal impacts on science was demonstrated during the discussion among Janet's students about genetically engineered crops.

Finally, students in all three classes made decisions about their experimental treatments and what features of their plants to observe and record during their experiments. Just like scientists, but probably with less complexity, the students used their unique prior knowledge, experiences, values, and education in their decision-making about their experiments.

Unfortunately, portions of the students' work with the PREP experiments in the three classes may have contradicted the features of the nature of science commonly agreed on by science educators as those pertinent to high school courses. The context of PREP, itself is a dichotomy because while it does support the empirical nature of scientific research, it may have reinforced the misconception that scientific work is *always* designed as cause and effect, controlled experiments that are conducted in science laboratories.

While the aspect of scientific practice often relying on additional equipment for making observation was supported in all three classrooms, no attention was given to using the equipment properly. This was an issue in Bonnie's class in particular when students used a new software

program without considering the limitations and proper use of the equipment. Despite Bonnie and Janet attempting to engage their students in conventional written and verbal scientific reporting, the format used by Sara's students (fill-in-the-blank) fell short of representing the traditional way that scientists present their findings.

While the decision-making in Janet and Bonnie's classes reflected some of the same factors that influence scientists when they make their decisions, Sara's students appeared to make their decisions by default rather than conscious decision-making. Finally, because no attention was brought to the subjective nature of scientific work in Janet and Bonnie's classes, the students' experiences may have reinforced the commonly held belief that scientific work is objective. Sara overtly contradicted this feature of scientific work with her students when she told them they needed to be objective.

In summary, despite teachers' interests in their students learning how scientists conduct their work, none of the teachers explicitly engaged their students in reflections or discussions specifically concerning the three tenets of the nature of science described in this study. While only a small number of activities in Sara's classroom reinforced current conceptions of NOS, many of the students' activities in Janet and Bonnie's classes implicitly supported these current conceptions. Activities in Sara's class may have even promoted conceptions of the NOS contradictory to current conceptions, while the activities in the biology classes were less likely to run contrary to the current values and assumptions of scientific knowledge. Regardless of the class, there were missed opportunities during which the students could have been engaged in thinking deeply about the values and assumptions inherent in the way scientists conduct their professional work.

Voices Participating in the Scientific Inquiry Experiences

Involvement in scientific inquiry during the study of the natural world is facilitated through language, both spoken and written. When scientists participate in their investigative, theoretical, and practical work, they collaborate with other scientists, as they research previous studies, pose questions, brainstorm their experimental designs, compare data, evaluate evidence, explain and defend their findings, write research journal articles, and present at science conferences. It is not expected that the scientific inquiry of high school students will mirror the work of scientists, but instead, will be practiced in such a way as to complement the courses and the students' prior experiences and abilities to conduct inquiry-based investigations (NRC,

2000). Regardless of the level to which students are engaged in inquiry, they will use language, both spoken and written, to conduct their scientific investigations.

In addition to science students using language to communicate during their inquiries, language is a tool that mediates the students' reconstructions of their understandings of science content, the processes of science, and the nature of science. Because language is socially constructed and the use of language is socially-situated, the knowledge the students construct about science and how science is done is influenced by politics, religion, economics, and culture (Wertsch, 1991).

Because of this social construction of scientific knowledge, the voices that have contributed to the construction of what a student knows about the theory of evolution, for one example, may seem limitless. To examine just a few voices that may have influenced a student's knowledge of evolution, consider the contributions of Darwin, Darwin's mentors, textbook authors, parents, science teachers, school system mandated content standards, ministers, newspapers, and television news stories. This same exhaustive tracking could theoretically be conducted with any knowledge constructed by students; however, that is not the focus of this study. Instead, the attention is directed to the voices prevalent *during* the activities in which the students reconstructed their knowledge of the scientific inquiry process, the nature of science, and the science content related to their experiments. These voices are important to consider because of the vital role that language plays in mediating the students' learning about science.

To formulate a picture of who was doing the talking and whose written and spoken voices were potentially being heard during the inquiry activities, the field notes of the class observations were analyzed for occurrences of written and verbal communication during the inquiries. The general context of the communication was also noted. The classroom discussions were neither audio nor video recorded, thus no discourse analysis was conducted of these conversations. However, informal, qualitative observations of these discussions were noted. In addition to verbal communication, data were collected regarding written forms of communication. These voice contributions, both spoken and written, that contributed to the implementation of scientific inquiry in the three teachers' classrooms included (a) students' voices, (b) teachers' voices, (c) scientist and other technical experts' voices, (d) the voices of the local community college and state-mandated standards, (e) the voice of technology, (f) the voice of the teachers' prior experiences teaching and with scientific research, and (g) the voice of the

values and expectations in each school and classroom community. Table 12 summarizes the primary voices that contributed to the practice of scientific inquiry in Bonnie, Janet, and Sara's classes.

Students' Voices

Talking with other students. As the students conducted their *Arabidopsis thaliana* experiments in Bonnie, Janet, and Sara's classes, most of the class time committed to the inquiry involved the students working with their lab partners. As they collaborated with their lab partners, the students continually chatted with each other about both their inquiries and topics unrelated to the research. Quite often in Bonnie's class, these conversations extended outside of the lab pairs to include students from other teams. Because Bonnie's students were more deeply involved in the designing of their experiments, their team conversations focused on the many decisions that had to be made relevant to the methodologies. Janet's students conversed with each other in teams, but since their methodologies were not as complex as those of Bonnie's students, their team conversations were more related to making observations, recording data, and their data analyses. Sara's students were the quietest during the experiments; their discussions primarily involved one student collecting data and telling the other student what to write down.

Talking with teachers. Students also had opportunities to talk with people more expert than themselves about their scientific inquiries. Bonnie and Janet constantly roved their classrooms, situating themselves near their students as they worked. During this physical proximity with their students, the students often asked questions related to their experiments. However, Sara positioned herself in the front of the classroom, away from her students throughout the inquiry, and the students' discussions about the experiments with her were infrequent.

Students' voices in all three classes could also be heard during instruction intended to involve each entire class. In addition to the informal conversations with students as they worked on their experiments, students participated in a number of whole-class discussions about the inquiry. In Janet's class, whole-class discussions included (a) how to write an experimental methodology (Observation, 4/13/2006), (b) how to represent data using a graph (Observation, 4/27/2006), (c) a PowerPoint presentation about flavonoids (Observation, 4/20/2006), (d) general roundtable discussions about genetically modified crops and the entire inquiry experience (Observation, 5/11/2006), and (e) class discussions that followed a few students' oral

presentations about their experiments (Observation, 5/11/2006). During these whole-class discussions, Janet purposefully involved students' contributions to the discussions.

Since Bonnie incorporated few whole-class discussions related to the plant experiments during the inquiry experiences, her students infrequently participated verbally in this format. Students did not contribute to the flavonol PowerPoint presentation (Interview, 4/4/2006, 47-49); however, the students did offer comments during whole-class discussions about what data they might want to collect, as well as during two class discussions about the analyses of their collective data (Observations, 4/5/2006, 109-156; 5/17/2006, 134-154). Students in Sara's class were involved with few whole-class discussions related to the inquiry and these discussions were primarily delivered in a lecture format, with little interaction with the students.

Talking with scientists. Students' voices were also heard during conversations with the PREP staff-scientist, Michael, and the visiting *Arabidopsis* scientist, Dr. Hayes. These conversations involved both informal, team-focused conversations, as well as whole-class discussions. On Michael's first visit with all three classes, he was successful leading an interactive discussion with the students about plants, plant research, and simple genetics. Students in Bonnie's class were quite vocal during the presentation, even posing some of their own related genetics questions (Observation, 3/22/2006); Sara and Janet's students participated much less (Observations: Bonnie, 3/30/2006; Sara, 3/16/2006). While Sara recognized the students' lack of participation, she could not think of any way that she could change her role during the kick-off session to encourage student participation; however, she did suggest that Michael could make the session more hands-on (Interview, 3/16/2006, 18-20). Janet felt her students were quiet during the first half of Michael's visit because they were treating him as a guest *speaker* rather than a scientist who was interested in interacting with them throughout his presentation. The second day Michael was with the students, the students were much more involved with the discussion about the experiments (Interview, 3/30/2006, 149-165; Observation, 3/30/2006).

On an informal basis, Michael and Dr. Hayes returned twice to talk with Bonnie's students about their experiments. On both visits, the pair moved from team to team, asking students probing questions to get them to talk about their experiments (Observations, 4/12/2006, 5/19/2006).

Students' written voices. Students' voices were also active in their written work. All three teachers required written work by students during the inquiry experience (e.g., recording data when making observations); however, there were distinct differences in the students' other written assignments. For Janet, students' success with expressing their thoughts in writing about their experimental work was a major motivation for including the *Arabidopsis* experiments in her biology curriculum. She cited her dissatisfaction with the students' previous written work about their NIH Sleep Study as part of her interest for the students having a second opportunity to write a scientific laboratory report (Interview, 3/8/2006, 252-257). While Janet's students were required to document their observations during their experimental work, Janet's emphasis was more focused on the several written assignments progressively turned in while the student did their experiments. These assignments included their experimental hypotheses, methodologies, introductions, and results discussions. Students also turned in a final paper in a modified report-like format. Students' voices in Janet's class were also evident in the answers to the questions related to plants and their experiments on written quizzes, tests, and exams. The optional PowerPoint and poster presentations gave Janet's students additional opportunities to express their inquiry accomplishments through a written format (Observations, 5/11/2006). Janet expanded the opportunities for students to express their understandings of the inquiry process and their proposed experiments by including the peer-review of the methodologies (Observation, 4/20/2006).

In addition to using spoken language throughout the entire inquiry experience, each day that they collected data, Bonnie's students recorded detailed observations in lab notebooks, which were turned in when the experiment was over. Twice during the inquiry, the students turned in rough drafts of parts of their final lab reports. At the conclusion of the experiments, the students turned in their quite extensive final lab reports and lab notebooks within which observations had been thoroughly noted.

Table 12

Summary of Voice Contributions to Scientific Inquiry

Teacher	Voice Contributor	Example	
		Spoken	Written
Bonnie	Students	Significant intra- and inter-team discussions Many team questions/interactions for Bonnie A few whole-class discussions Contributions to whole-class discussions with scientists	Experiment observations Several complex progressive assignments Final extensive lab reports and lab notebooks
	Teachers	Contributions to team discussions with scientists Spent majority of time talking with teams	Comments on students' submitted work
	Scientists	Several whole-class discussions Short discussions with teams (three times- Michael and Dr. Hayes) Whole-class discussions with Michael and Dr. Hayes	Established over-arching research question and limited input into experimental design Online scientific resources Virginia Junior Academy of Science, Intel Science Fair lab report format
	Other	Syllabus for community college offering dual-enrollment credit State-mandated Biology course standards Extensive technology School community expectations Teacher's experiences: "expert" teacher, science research, and classroom scientific inquiry	
Janet	Students	Intra-team discussions Many team questions/interactions for Janet Many whole-class discussions Contributions to whole-class discussions with PREP staff Optional PowerPoint and poster presentations	Experiment observations Several complex progressive assignments Final, modified research report Answers on quizzes, tests, final exam Optional PowerPoint and poster presentations
	Teachers	Spent a lot of time talking with teams Numerous whole-class discussions	Comments on students' submitted work
	Scientists	Whole-class discussion with Michael Short team discussions with Michael	Established over-arching research question and limited input into experimental design Online science and less technical resources Virginia Junior Academy of Science lab report format

(table continued)

Table 12 (continued)

	Other		Multiple textbook chapters Extensive technology School community expectations Teacher's experiences: "expert" teacher, science research, classroom scientific inquiry
Sara	Students	Intra-team discussions Few team questions for Sara Limited, brief whole-class discussions Limited contributions to whole-class discussion with PREP staff	Experiment observations One simple assignment during inquiry Seven sentence final report
	Teachers	Spent little time talking with teams Few, brief whole-class discussions	Did not give students feedback on written work
	Scientists	Whole-class discussion with Michael Short team discussions with Michael	Established over-arching research question and limited input into experimental design
	Other		State-wide agriculture standards Limited technology School community expectations Teacher's experiences: novice teacher, limited experiences with classroom inquiry

Sara's students were required to turn in two written assignments: a list of equipment needed for the experiments and the experimental treatment and a final, seven sentence paragraph about the experiments. Sara supported her students writing the final paper by dictating parts of the paragraph to them and leaving blanks for the students to insert information from their own inquiries (Observation, 5/24/2006).

Teachers' Voices

Talking with students. Teachers in all three classes played the role of a facilitator or guide during the scientific inquiry experiences. Rather than formally direct the students' work, each teacher spent the majority of her time being available to students in case they had questions. These short interactions were usually student initiated and directed with the teachers answering the students' questions. Periodically, the teachers interjected their own comments if they noticed something about what the students were doing that warranted a short discussion. Of the three teachers, Sara initiated the fewest conversations with her students about their experiments while they were working in their teams; these kinds of discussions were a rare occurrence.

Teachers' voices were heard throughout the practice of scientific inquiry during whole-class discussions. Janet wove more of these whole-class discussions into her instruction than Bonnie or Sara. Her whole-class discussions related to the inquiry spanned the entire experimental process included going over the Guidelines in the PREP manual with the students (Observation, 4/3/2006), presenting extensive notes about plants, introducing the appropriate use of different kinds of graphs, posing questions and making comments during the roundtable discussions at the end of the inquiries, and leading discussions during the students' poster and PowerPoint presentations (Observations, 4/27/2006, 5/11/2006).

The brief notes Sara gave her students included information about plants and plant parts and functions, independent/dependent variables, and how to write up their final lab reports (Observations, 3/31/2006, 4/12/2006, 5/24/2006). Equally as brief, were Sara's discussions of the bell assignments related to plants and the experiments that she went over at the beginning of the class period (Observations, 3/24/2006, 3/31/2006, 4/12/2006, 5/24/2006).

During Bonnie's whole-class discussions, she provided information about flavonoids, the structure of plants and functions of various plant parts, and the possible dependent variables. Several times she stopped the students as they were working on their experiments to point out

other students' observations and to lead the class analyses of their combined data (Observations, 4/5/2006, 4/26/2006, 5/17/2006).

Teachers' written voices. Teachers' voices within the context of written words were evident during the implementation of PREP in the feedback they gave students on the work they handed in for a grade. During their progress on the experiments, Janet made extensive comments on the students' submitted hypotheses, introductions, methodologies, and discussions of the results of their experiments. Bonnie also made thorough comments on her students' report introductions and the graphs/statistical analyses that were turned in during the inquiry activities. Both teachers expected students to consider their comments when revising their work before turning it in for final grades. Sara collected several very short written assignments from her students but she did not make comments on them and turn them back to the students. She explained why she did not hand back either of these written assignments to the students with feedback from her: "Everything I give back they just throw away so it really doesn't matter" (Interview, 6/7/2006, 331).

Scientists' Voices

Scientists talking with students. Student teams in all three classes had brief opportunities to talk with Michael on his visit with the classes before they began their plant experiments (Observations: Bonnie, 3/22/2006; Janet, 3/30/2006; Sara, 3/16/2006). These conversations consisted of Michael moving from group to group talking with the students and helping them brainstorm ideas for experimental treatments and possible dependent variables. Bonnie's students had additional opportunities to converse with scientists; on two different occasions Michael and Dr. Hayes visited the class to talk briefly with each lab pair about their plans for the experiment and the analysis of the data (Observations, 4/12/2006, 5/19/2006).

In addition to these semi-private conversations with students while they were planning and conducting their experiments, students in all three classes interacted with Michael in whole-class discussions on the first day of their investigations. Bonnie's students also listened to a PowerPoint presentation about flavonoids delivered by Dr. Hayes (Observation, 5/19/2006). Despite the possibility of additional visits from *Arabidopsis* scientists, neither Janet nor Sara was interested. For Janet, this lack of interest in having a scientist visit the classroom was partially based on her own experiences working as an Environmental Sciences Information Officer with

scientists whose strengths were in areas other than relating to teenagers about science (Interview, 5/11/2006, 120-140).

In Sara's class, Michael was successful involving a few of the agriculture students in his discussion, but Sara commented that the whole-class discussion format could have been more effective with her students if more hands-on activities had been included (Interview, 3/16/2006, 13-15). Sara could not imagine how additional visits with scientists would benefit her students:

I don't really know what they would do with them. I mean if they thought of something good to do with them about it then that would be fine, but I can't really see how it would change a whole lot...of things (Interview, 6/7/2006, 236-239).

Scientists' written voices. Scientists' written voices also impacted the students' experiences with scientific inquiry. In all three classrooms, the over-arching research questions, "What is the role of the disabled gene of the *Arabidopsis thaliana* plant in adapting to certain environmental conditions?" was pre-determined by research scientists. In addition, the scientists and PREP materials recommended suitable plant treatments for the experimental design. Essentially, all student inquiry activities were directed at designing experiments in hopes of contributing to the answers for this question.

Both Janet and Bonnie's students sought scientific and less technical information on the internet to incorporate into their research paper introductions (Observations, Bonnie: 4/5/2006; Janet: 4/3/2006). Bonnie's students actually based their experimental designs on this web-accessed information. Janet was the only teacher who repeatedly brought the content of the online written materials provided by PREP into her classroom discussions and expected her students to take advantage of the PREP resources (Observations, 4/13/2006, 20-25,74-75; 4/20/2006, 4; 4/27/2006, 87, 108-109).

In addition, both Janet and Bonnie required their students to write their research papers using a format similar to that recommended by the Virginia Junior Academy of Science and the Intel Science and Engineering Fair for students participating in their events. It was important to both teachers that their students learn how to write science research papers that reflect the conventional format for a scientific paper.

Other Voices

The voice of the course content and mandated standards. Voices in the classroom are not limited to those utterances spoken or written by the students, teachers (Wertsch, 1991), and

visiting scientists. If the practice of scientific inquiry in these three classrooms was “listened to” carefully, other voices emerged because of historical, cultural, and institutional influences. For example, all three teachers referred to a certain biology or agriculture course content to which they connected the scientific inquiry experiences. Janet connected her inquiry to textbook chapters about plants (See Janet’s Biology Course Sequence and Content document and Observation, 4/13/2006, 10-12) and Bonnie and Sara linked theirs to the state standards in their respective fields (Interviews: Bonnie, 2/1/2006, 285-296; Sara: 1/27/2006, 219-231). Bonnie was also required to meet the biology course standards designed by the local community college which grants her students dual credit for their biology course provided their grades are high enough (Interview, 5/3/2006, 78-97). This “voice of the curriculum” (Wertsch, 1991, p.144) established by the textbooks, the State Department of Education, and the local community college communicated course content expectations for the teachers; however, they used the mandated standards and textbooks as rationales for including the experiments in their respective courses rather than as excuses to avoid the experiments.

The voice of technology. The “voice of technology” influenced the scientific inquiry in the three classes to different degrees. Sara’s students incorporated scant technology into their inquiries, limiting technology use to one visit to the computer lab when they entered their data onto a pre-formatted data table created by Sara (Observation, 5/5/2006). The students did not have access to calculators when they were required to average the plant data they were collecting (Observation, 4/21/2006, 43-46).

While working on their plant experiments, Janet’s students had access to a digital camera for taking pictures of their plants as they grew. In addition, a classroom set of laptops and computers located in a computer lab down the hall from their classroom were incorporated into the inquiry experience by Janet’s students (Observations, 4/3/2006, 4/27/2006). The students used the computers to create their data tables and graphs (Excel), and both Janet and her students used the wireless connections to the internet to access the PREP and other online materials several times during the inquiry experience. (Observations, 4/3/2006, 4/4/13/2006, 4/20/2006). At the end of the inquiry experience, students who were interested in extra credit to boost their grades had the option of creating a PowerPoint presentation of their research (Observation, 5/11/2006).

Many of these same technological resources that contributed voice to the practice of scientific inquiry in Janet's classroom were also available in Bonnie's classroom. Her students made extensive use of software programs on classroom computers (e.g., MiniTab, Excel, and Word) and wireless access to the internet. Most students incorporated digital photos of their plants into their final lab reports. After Dr. Hayes's first visit with the students, most students used the new tablet PCs and ImageJ software to analyze their leaf surface area data. Despite the lack of training and improper use of the ImageJ software, most students included statistical analyses of the leaf surface area data in their final lab reports. The importance of using the new tablet PCs, beyond the additional data that could be collected, was evident when the school director visited the class to take pictures while the students were collecting and analyzing their leaf surface area data (Observation, 5/10/2006, 53-54).

The voice of the school and classroom community. A more elusive voice, but one that influenced the inquiry experience in the three classrooms, was that of the expectations and values of the school and classroom communities. Bonnie's school, Stuart Springs Governor's School for Science, Mathematics, and Technology, had previously established expectations that students would participate in scientific inquiry at least twice during their attendance at the school. As 9th graders, all students enrolled in the Fundamentals of Research course and, later as juniors and seniors, they conducted independent scientific research which they exhibited at local, state, and national science fairs. These students indicated a strong interest in science by applying for admissions to Stuart Springs Governor's School and were expected to continue in math, science, or technology-related study in college.

While St. Catherine's Academy, Janet's school, did not have a program that focused specifically on science, mathematics, and technology, the school was proud of its reputation for preparing graduates for admissions to competitive colleges. This reputation may be one of the reasons the students and parents *chose* St. Catherine's Academy over other schools. For both Bonnie and Janet's schools and classrooms, it had been previously established that students benefited from learning environments that incorporated social interactions, encouraged self-directed learning, valued more than factual learning, and expected students to risk being wrong from time to time.

On the other hand, Sara's students, a large number whom she felt were tracked into her class by guidance counselors, had a high probability of having learning/behavior disabilities,

were likely enrolled in her class because they were not academic, and were primarily 9th and 10th grade males. Sara felt she had to be very strict with these students, severely limit talking, and she felt she could not expect them to keep up with their work or care about the scientific inquiry. If it was important to Sara that her students make few mistakes, that she have control of the classroom activities, and for her to always know the answers to students' questions, she may have been uncomfortable with taking on the role of facilitator and she may have struggled with knowing how to manage the social aspects of the inquiry (Crawford, 1999; Eggen & Kauchak, 2001; Layman et al., 1996; Llewellyn, 2005). The expectations for Sara's students by members of the faculty (e.g., guidance counselor, Sara) at Riverview High School may have reinforced the view that learning is a process by which students learn facts and rules with little emphasis on understanding and process; thus, Sara may have stressed mechanical, rote behaviors and discrete factual information rather than support the processes and understanding characteristic of scientific inquiry (Anyon, 1981; Marx et al., 1994; Oakes, 1992; Roehrig & Luft, 2004).

While it was beyond the scope of this study to conduct a systematic and thorough study of the compatibility between the values and assumptions reflected in the voices of the school-class community, those characteristic of scientific inquiry, and those reflected in the students' identities, these relationships may be worth considering when investigating practices in classrooms. According to Gee (2000-2001), each student's identity, or "what it means to be a 'certain kind of person'" (p. 100), does have educational implications, is amorphous, and can be viewed from four different, inextricable perspectives. The four perspectives differ in the process that establishes a particular trait, the power that contributes to it, and the source of this power. These four perspectives include traits defined by nature (e.g., male), institutions (e.g., agriculture student), discourse (e.g., intellectual), and membership in affinity groups (e.g., Science Club). The traits are negotiable and contestable depending on how individuals interpret them.

Costa (1995) suggested that the compatibility of the expectations and values of the classroom and school with students' self-identities may influence their success in science. The incompatibility of these self-identities and the expectations and values with those associated with scientific inquiry grounded in Western science may create an additional challenge for students. It is likely that the school-classroom voice resonated with the self-identities of Bonnie and Janet's students, and that both resonated with the perspectives of Western science, thus facilitating the students' transitions from being teenagers to young scientific inquirers. The value of

participating in inquiry and the expectations of how to go about participating in science class activities, such as inquiries, were likely already a part of the students' identities; thus, the students probably required minimal effort to negotiate moving from their identities outside of school to the identities that included being scientific inquirers (Costa, 1995). For these two groups of students, there was most likely strong alignment among the students' identities and the values and expectations of both the school-class community and scientific inquiry.

On the contrary, the voice of Sara's school and classroom did not seem to reflect the values and assumptions that aligned with those of scientific inquiry: student-centered, highly social, student-directed classroom activities. In addition, Sara's students, similar to students described by Lee & Fradd (1998), may not have seen themselves as the "kind of students" who shared the values and assumptions of the practice of scientific inquiry, thus the students' self-identities may have been in contrast to the expectations of science activities (Costa, 1995). This lack of alignment may have stifled the other voices in Sara's classroom particularly if Sara and her students did not share the same values and expectations (Yerrick & Hoving, 2003). Sara's students may also have been unaccustomed to class experiences such as scientific inquiry since non-academic students are frequently placed in classes where science is taught as the basic level (Yerrick, 2000). For the scientific inquiry in Sara's class to have been a rich learning experience for her students, Sara would have needed to bridge both the gap between the students' identities and the expectations of student participation in scientific inquiry, as well as between the expectations of the school-class community for students' participation in class lessons and that characterized by involvement in scientific inquiry.

The voice of experience. Finally, the three teachers brought different "voices of experience" to their implementations of the scientific inquiry. Not only did Janet and Bonnie have the perspectives based on their years of teaching and previously implementing inquiry with their students, but they also had participated in science research when they were students (Interviews: Bonnie, 2/2/2006, 403-406; Janet, 3/8/2006, 576-578). Steffy, Wolfe, Pasch, and Enz (2000) might have identified Janet and Bonnie as "expert" teachers because of their professional backgrounds and activities. On the other hand, Sara was a "novice" teacher and had little experience implementing scientific inquiry with her students.

Summary

Who was doing the talking during the practice of scientific inquiry in the three classrooms? In all three classrooms, many voices, both spoken and written, contributed to shaping the scientific inquiry experience. These voices originated from a variety of sources including the students, teachers, scientists, textbooks, technology, the school and classroom communities, the teachers' prior experiences, and the standards required by groups outside of the school such as the local community college and the State Department of Education.

However, rather than continuing to consider the origins of the voices with each class since the sources of the voices are the same in the three classes, the findings suggest that it is the pervasiveness of the voices that characterizes the practice of scientific inquiry in the three classrooms. For example, the practice of inquiry in Sara's class involved the same voices that were present in Bonnie and Janet's classroom; however, the voices of the teachers, scientists, technology, students, and curriculum were less prevalent in Sara's class compared to Bonnie and Janet's classrooms. The same voices were present in Janet and Bonnie's classrooms and they were more frequently heard in both environments.

Instead of thinking about the presence of the *voices* of the school-class communities and the teachers' prior experiences teaching and conducting research as previously presented, evidence from this study suggests that these contributions might act more like frequency-controls. In the classroom and school communities where the values and expectations and the students' identities were not aligned with those of scientific inquiry and the teacher, Sara, had limited teaching experience and no science research experience, the occurrence of voices of the students, scientists, and her own, was infrequent, and thus did not make a significant contribution to the richness of the scientific inquiry experience. On the contrary, when the expectations and values of the school-classroom communities and the students' self-identities were compatible with the expectations and values of the science inquiry experience, and the teachers were experienced both with teaching and science research, the other voices were more pervasive and thus made a larger contribution in shaping the practice of the inquiry.

How does this translate into power in the three classrooms? Where was the locus of power that influenced the scientific inquiry experiences for the students in the three classes? Did the scientists hold the power? Despite the scientists pre-determining the over-arching research question and contributing to discussions about experimental design, they had little power in

Sara's classroom because their voices were hardly heard. In Bonnie and Janet's classrooms, the scientists were more powerful because their voices played a larger role in the talking and writing in which the students were involved during the inquiry. Did the students have the power to control the inquiry? Students in Janet and Bonnie's classrooms were much more vocal and more powerful, but in Sara's classroom, the students' voices were hardly heard and carried little power during the inquiry process. Did the voice of technology influence the inquiry experience in each classroom? Not so much in Sara's classroom where technology hardly had a place in the inquiry; but the voice of technology was powerful in the biology classrooms where it played a key role in the practice of inquiry. Were the teachers' spoken and written voices all-powerful such that they controlled the quality of the inquiry in each classroom? In Sara's classroom, her voice was infrequently heard during the inquiry; Bonnie and Janet's voices were more pervasive, and thus were more powerful. Did textbooks or expectations from state standards and the local community college have a tremendous influence on the progress of the inquiry? While these voices were present, they did not appear to have great influence in any of these classes.

While all of these voices contributed to the scientific inquiry experience in each class and joined together to significantly shape the scientific inquiry experience in the three classrooms, the contribution each had to the over-all practice of the inquiry experiences appeared to be related to the teachers' prior experience teaching and involvement with scientific research and the compatibility of the school-classroom community values and expectations and students' identities with the expectations and values associated with the process of scientific inquiry. Thus, the power was not held by "who was doing the talking" during the scientific inquiry, but instead it was embodied in (a) the teachers' prior experiences teaching and with research, and (b) the compatibility between the school-classroom community expectations and values and the students' identities with the expectations and values reflected in scientific inquiry.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

For over a decade, scientific inquiry has been promoted as an instructional strategy that supports optimal student learning about science and the scientific processes (NRC, 1996, 2000b). This emphasis on scientific inquiry is grounded in the premise that students who have opportunities to participate in scientific inquiry will grow in their knowledge and skills related to understanding science principles and concepts as well as scientific ways of thinking, and thus, will be better prepared to access this knowledge and set of skills when making future decisions and taking actions related to the welfare of the Earth's inhabitants and their surroundings (AAAS, 1993; NRC, 1996). Current research about student learning contributes to the argument that inquiry-based instruction promotes student understanding and retention, as well as the application of science concepts (Brown et al., 1989; Cobb, 1994; Dewey, 1938; Fetsco & McClure, 2005; Leach & Scott, 2003; Pea, 1993).

Despite the teacher professional development activities advocating for inquiry-based instruction, the ubiquitous articles and activities in practitioner and research journals about inquiry, and other instructional support materials such as textbooks and websites containing examples on inquiry lessons, students continue to be involved in class activities unsupportive of various aspects of scientific inquiry (Chinn & Malhotra, 2002; Driver et al., 2000; Hofstein & Lunetta, 2004; NRC, 2005a; Watson et al., 2004). Research has clarified some of the possible reasons inquiry-based instruction falls short of its optimal practice in classrooms (Abd-El Khalick et al., 2004; Chinn & Malhotra, 2002; Crawford, 1999; Hofstein & Lunetta, 2004; Llewellyn, 2005; Magnusson & Palincsar, 2005; Tobin & McRobbie, 1996; Wallace & Kang, 2004).

Part of the researcher's motivation for conducting this particular study was due to the unexpected widespread interest by teachers across the state for incorporating scientific inquiry in their courses. This commitment during the 2005-2006 school year by 34 teachers to involve their 1,043 students in scientific inquiry challenges the literature summarized in *America's Lab Report* (NRC, 2005a) that "most high schools provide a narrow range of laboratory activities, engaging students primarily in using tools to make observations and gather data, often in order to verify established scientific knowledge" (p. 34). The three classrooms involved in the research provided

unique and intriguing sites for this study because the obstacles cited by other teachers for not including scientific inquiry in their courses were not viewed as insurmountable barriers by these teachers since they involved their students in scientific inquiry. What could be learned about the practice of scientific inquiry in these two biology and one agriculture classrooms where teachers were interested in committing a significant amount of class time to the plant experiments?

The purpose of this study is to contribute to an understanding of how scientific inquiry is practiced in three different high school classrooms, particularly with regard to the teachers' interests and intentions for conducting the inquiry, the voices involved with the inquiry, and opportunities for students to reconstruct their conceptions of the nature of science. It is hoped that the findings will inform teacher professional development and the instructional support materials such that more teachers and students will have opportunities to participate in scientific inquiry and thus expand their knowledge and application of science content, scientific processes, and the nature of science.

Question 1: What are teachers' interests and intentions regarding the implementation of scientific inquiry in their classes?

Despite the different courses, student populations, and schools, the three teachers, Bonnie (Stuart Springs Governor's School for Science, Mathematics, and Technology), Janet (St. Catherine's Academy), and Sara (Riverview High School), shared several interests in reserving a significant amount of time in their classes for their students to conduct scientific inquiry within the context of PREP. During interviews, all three teachers talked about their interest in their students being involved in the plant experiments because (a) of what their respective students would learn about scientific research, (b) the experiments supported the course content, and (c) the inquiry was connected to a larger project involving scientists and their research.

During the interviews with the teachers, it was clear that the three teachers had intentions with broad goals for their students' involvement in the experiments. These goals reflected the complexity of the individual courses and the teachers' and students' prior experiences with science and scientific inquiry. Bonnie hoped to support her students as they developed their abilities to interpret their data; Janet was very focused on scaffolding her students' experiences so they could learn how to communicate their methods and findings; Sara's goals included helping her students become more responsible and organized with recording data. All of the

teachers planned for the inquiries to be very student-directed with students working in their lab teams making many of their own decisions related to the experiments.

However, as is common with the implementation of labs in science classes (NRC, 2005a), none of the teachers had clear learning outcomes for their students' participation in the inquiry or specific, formulated instructional objectives addressing students' learning related to the scientific inquiry. The absence of student learning objectives may indicate that the teachers had not considered their students' learning outcomes or the strategies and instructional frameworks for activities that would assist the students in reaching the teachers' goals of students learning about science research (Moore, 2005).

The practice of inquiry in the three classes may have been enriched had the teachers asked themselves pointed questions such as, "What specific content and skills do I hope my students know more about when they're finished with the experiments than they knew when we started?" and "What kinds of discussions and activities can I incorporate into the inquiries that would facilitate students growing in their understanding of these concepts and skills?"

The Practice of Scientific Inquiry in the Three Classes

The practice of scientific inquiry in all three classes was student-directed in that all of the teachers wanted their students to manage as much of the inquiries as possible, including the decisions about treatments and dependent variables. The teachers primarily responded to students' questions as they took on many of the roles that Crawford (2000) identified as being typical during inquiry-based instruction: guide, facilitator, motivator, diagnostician, experimenter, and learner. Bonnie and Janet seemed to be the most comfortable and adept in these roles, while Sara interacted very little with her students and was much less involved with supporting her students as they conducted their experiments.

During the inquiry activities in the biology classes, Janet and Bonnie introduced topics for discussions related to the inquiries while in the agriculture class, Sara did not initiate any class discussions during the experiments other than those concerning procedural matters related to the students' work with the plants. Various outside, scientific and non-technical resources were included in the inquiry activities in the biology classes, and Janet and Bonnie's students used technology to enhance their data collection and analysis, while in Sara's class, technology and outside resources had little impact on the inquiries. Overall, Bonnie and Janet built in to the inquiry experiences many more opportunities for interactions, both verbal and written, with other

students and with more-expert others during their inquiries than did Sara. The additional scientists' visits to Bonnie's classroom contributed greatly to her students engaging in thinking about their experimental designs and the data analysis.

The National Research Council (2000b) reminded science educators that it is not enough for students to participate in inquiry; the "teachers need to introduce students to the fundamental elements of inquiry; they must also assist students to reflect on the characteristics of the process in which they are engaged" (p. 14). This omission of discussions during inquiry that engage students in scientific reasoning is common, for these are the kinds of conversations that teachers may be unaccustomed to having with their students and may not have the pedagogical knowledge necessary to facilitate (Crawford, 1999; Driver et al., 2000; Rowell & Ebberts, 2004). In particular, Sara's limited experiences with teaching and scientific inquiry, and her concern for her students getting out of control may have contributed to her lack of direction with facilitating the scientific inquiry (Crawford, 1999; Eggen & Kauckak, 2001; Llewellyn, 2005; Roehrig & Luft, 2004). Janet and Bonnie's extended teaching careers, as well as their own scientific research experiences may have contributed to their more purposeful facilitation of the scientific inquiry experiences with their students (Crawford, 1999).

Interestingly, if an administrator, another teacher, a parent, or community member had walked into any of these three classes on almost any day during the students' inquiries, they would have most likely been impressed with the student-directed activities of observing the plants; treating them with heavy metal solutions, light intensity treatments, watering them with "acid rain"; making numerous measurements of bolt height, leaf surface area, and counting flowers; taking pictures with digital cameras; and organizing and analyzing data using Excel and Minitab. However, if these visitors had understood the cognitive processes associated with the procedures of scientific inquiry and not accepted the display of activities in the classrooms as evidence of student intellectual engagement in inquiry, they would have realized that the students and teachers were occasionally involved with the *procedural display of scientific inquiry* (Bloome, Puro, & Theodorou, 1989) rather than both the manipulative activities and thought processes associated with scientific inquiry. In other words, there were times when the students and teachers were apparently more involved with enacting a ritual of scientific inquiry than engaging in the scientific reasoning tasks that typify scientific inquiry. This procedural display was more prevalent during the practice of scientific inquiry in Sara's classroom; Janet and

Bonnie's students were engaged in a more authentic scientific inquiry because the practice of inquiry in their classrooms more closely reflected practices characteristic of scientists as they conduct their work (Chinn & Malhotra, 2002).

The practice of scientific inquiry shifting to more of a procedural display occasionally in Janet and Bonnie's classrooms and more frequently in Sara's classroom may have been a result of the teachers' own understandings, or lack thereof, of the scientific reasoning characteristic of scientific inquiry. From the class observations and teacher interviews, there was some evidence that Bonnie and Janet were aware of these cognitive processes; however, there was little evidence that Sara considered the students' involvement with scientific inquiry deeper than at the procedural level. It could be the case that Bonnie and Janet had more advanced pedagogical skills and competence with the discourse necessary to facilitate scientific inquiry than Sara (Driver et al., 2000; NRC, 2000b; Rowell and Ebbers, 2004). Or, in her efforts to provide a more student-directed experience, Sara may have intentionally relinquished her role as the facilitator of inquiry. Sara may even have been unaware of the responsibilities she has as a mentor for the students' cognitive apprenticeship with scientific inquiry. In all three classrooms, the students could have benefited from a greater emphasis through teacher direction, unique to each classroom and student population that encouraged the continued development of student scientific thinking about their inquiries.

The National Research Council (2000b) urged science educators to place more of the direction of the practice of inquiry with the students and less from the course materials or teacher. While the practice of inquiry in all three classrooms was highly student-directed, this is not sufficient; the classrooms must also be student-centered and knowledge-centered (NRC, 2000a). Student-centeredness results from teachers being aware of and planning instruction based on students' backgrounds, prior knowledge, and abilities so that the instruction will reasonably challenge the students. Knowledge-centeredness results from teachers planning instruction based on their intentional thought for what knowledge and skills students need and what activities will support that learning. Scientific inquiry activities that are student-directed, but lack student- and knowledge-centeredness, may fall short in providing students with opportunities to grow in their understanding of the processes of science and the nature of science because of the limited attention to the students and their readiness to engage in certain concepts and the content and pedagogy of inquiry and the nature of science. It is possible that the practice

of inquiry in all three classrooms could have been enriched if Bonnie, Janet, and Sara had planned the inquiry activities, within the context of their students' prior knowledge, abilities, and backgrounds, and with an understanding of the content and pedagogy related to the conceptions of the nature of science and the intellectual and procedural processes typical of scientific inquiry.

Question 2: How was the nature of science represented by the scientific inquiry?

This research study focused on three tenets of the nature of science: scientific knowledge is frequently generated through empirical practices, scientific knowledge is socially and culturally embedded, and scientific knowledge is theory-laden. Because the purpose of the study was to investigate the practice of inquiry in the three classrooms, no attempt was made to determine the teachers' views of the nature of science. While the teachers expressed a strong interest in their students learning about scientific research and how science is done, teachers verbalized few specifics during the inquiries related to these assumptions and values characteristic of the generation of scientific knowledge. None of these features of the nature of science were explicitly addressed during the three inquiry experiences; however, aspects of the nature of science implicitly represented during the inquiry both promoted and challenged current conceptions of the nature of science.

In support of the current conceptions of the nature of science, the inquiry experiences in all three classes, but particularly in Bonnie and Janet's classes, reinforced the social nature of scientists' work, the expectation that scientists will build upon previously conducted science, the particular formats for presenting scientific findings, and that scientific work may be conducted through experiments using instruments to aid in observations and which are not lock-step processes. Briefly implied in Bonnie and Janet's classroom was the idea that science is influenced by society (i.e., genetically engineered plants, advantages of studying flavonoids).

In all three classes, the notion that scientific research may be conducted solely as a cause-and-effect, controlled experimentation process rather than considering the multitude of ways that scientists go about their work, may have been promoted due to the nature of the research question and the context of PREP itself. In addition, the teachers, particularly Sara, may have reinforced the linear, lock-step process of doing science because of the linear way that they conducted the inquiries in their classes and because of the linear format they required their students to use when writing up their experiments. Students made decisions about equipment,

treatments, and dependent variables with little to no consideration of the values, beliefs, education, and experiences that contributed to these decisions.

Evidence collected during this study was compatible with previous studies that classroom activities may not include or promote an understanding of the tenets of the nature of science and the scientific processes (Chinn & Malhotra, 2002; Hogan & Maglienti, 2001; Khishfe & Abd-El-Khalick, 2002) even if the teachers hold current conceptions of NOS (Lederman, 1999) and recognize the value of incorporating NOS in their instruction (Bell, Lederman, & Abd-El-Khalick, 2000). Because this study did not attempt to determine teachers' views on the nature of science, it is not clear what conceptions Janet, Bonnie, and Sara held concerning the nature of science. It may be that the teachers held their own misconceptions about the nature of science as many high school teachers do (Abd-El-Khalick & BouJaoude, 1997; Lederman, 1992; Zoller et al., 1991) and spend little time reflecting about the nature of science (Lakin & Wellington, 1994).

Most notably absent from these three inquiry experiences was the teachers' intentional consideration concerning the aspects of the nature of science that they hoped their students would learn from their inquiry experiences. Ryder, Leach, & Driver (1999) recommended that if teachers want their students to address their conceptions of science, then the teachers need to consider the views of science they want to incorporate into the lessons and then give careful thought to how these will be brought into the lessons. In addition, Schwartz & Lederman (2002) recommended that the teachers have both a strong background in content and NOS as well as specific intentions to include NOS in their activities. This explicit attention seems to be vital if students are going to grow in their conceptions of the nature of science (Khishfe & Abd-El-Khalick, 2002; Schwartz & Crawford, 2006; Schwartz, Lederman, & Crawford, 2004). Schwartz and Crawford (2006) proposed that teachers treat NOS as science content and as such, design, practice, and assess activities in the classroom with NOS cognitive student outcomes in mind. Experiences with their own scientific research concomitant to metacognitive reflections about NOS and the experiences from the outside looking in may assist teachers with strengthening their own connections between scientific inquiry, NOS, and inquiry practices in their own classrooms (Schwartz & Crawford, 2006).

Question 3: How are different ideas given power and voice during the scientific inquiry?

During the practice of scientific inquiry in the three classrooms, many different voices, both spoken and written contributed to the inquiry experiences. The same voices were present in all three classrooms – the voices of the students, the teachers, scientists, technology, textbooks, and standards mandated by state agencies and the local community college. One difference in the voices involved in the inquiry experiences in the three classrooms was the prevalence of the voices, rather than the source of the sound. This frequency of occurrence of the voices may be influenced by the teachers' experiences in the classroom and with scientific research, as well as by the alignment of the expectations and values of students' participation in scientific inquiry with those of the school-class communities and the students' self-identities. In Bonnie and Janet's classrooms where the teachers were experienced professionals who participated in their own scientific research, and the expectations and values associated with student participation in scientific inquiry aligned with the expectations and values of the school-classroom communities and the students' identities, the voices of the curriculum, technology, scientists, students, and teachers were heard more often. In Sara's classroom, where the inquiry was led by an inexperienced teacher who had no background in research, and where there was less compatibility among the school-classroom communities' values and expectations, students' identities, and the values and expectations of student participation in scientific inquiry, these voices were less common.

Through Janet and Bonnie's experiences in the classroom and labs, they gained essential knowledge about how to support and manage their students from previous teaching experiences and as they conducted their own lab work. This knowledge of content, general pedagogy, content pedagogy, and some awareness of how to guide students during their inquiries, which is vital knowledge for teachers when supporting students' laboratory work (Minstrell & vanZee, 2003; NRC, 2005a; Windschitl, 2004b), influenced Janet and Bonnie's decisions about how much to promote the various voices during the experimental process. Janet and Bonnie expected vociferous student conversations during student collaboration and they planned for their students to demonstrate their understandings of their inquiry in a variety of formats through spoken and written language. Scientists' voices may have been more frequently incorporated into the inquiry in Janet and Bonnie's classrooms because both of the teachers understood how the contributions of scientific resources and scientists' involvement could benefit the students' experiences with

inquiry. The voice of technology may have been more common because both Janet and Bonnie had knowledge and experiences using the different forms of technology and they understood how the technology could support their students' involvement with collecting and analyzing their data. Consistent with studies of science preservice teachers (Lemberger, Hewson, & Park, 1999; Windshilt, 2004a; Windshilt & Thompson, 2004), Sara, a novice teacher, lacked the experience with and understanding of scientific inquiry, the content, and teaching, and thus did not have the content knowledge, general or content pedagogy, or awareness how to guide students during their inquiries. Thus the voices of the teacher, students, scientists, technology, and curriculum in Sara's classroom were less frequent.

All three teachers were clear about their students having a great deal of control over their experiments by making their own decisions related to the experimental design, collecting and analyzing their own data, and considering the implications of their findings. This emphasis on the students directing their own investigations as the experiments were conducted in all three classrooms, is consistent with the inquiry process as described by educators (Eggen & Kauchak, 2001; Llewellyn 2002; NRC, 1996, 2000b). From the perspective of language and learning, the students learning about both the content of the inquiry and the process of inquiry was mediated by their language use in both spoken and written forms (Wertsch, 1991); thus, the more opportunities they had to articulate their thoughts and ideas, the more opportunities they had to learn from their inquiry experiences.

In order for the students' knowledge of content, the process of inquiry, and the nature of science to develop, the students also needed to hear more from the voices of others who were more expert than themselves with regard to conducting scientific inquiry. In all three classrooms, the voices that could have guided the students from that which was familiar to them (choosing a treatment, picking a dependent variable, measuring and recording data, creating graphs) to that which was new (analyzing data, defending findings, communicating findings, tenets of the nature of science) needed to be heard more frequently. Mortimer and Scott (2003) recognized the need for both the students and their teachers (and/or scientists as relevant to PREP activities) to contribute to classroom discussions through a spiral rhythm that moved the students from their initial understandings communicated through student talk to more scientific understandings communicated through science talk. Despite Janet and Bonnie's experiences and knowledge about inquiry and facilitating inquiry-based activities, and Sara's lack of experience and

knowledge, increasing the incidences of the all voices in all three classrooms could have contributed to richer inquiry experiences for the students.

It is not only the prevalence of the many voices that could have contributed to richer inquiry experiences for the students. Students in Sara's class in particular, but to some extent also those students in Janet and Bonnie's classes, had limited opportunities to conduct the open inquiry to the extent that was possible within the PREP context because the voices of the teachers seldom made visible the thinking that characterizes scientific inquiry or guided the students in how to think scientifically. For the most part (with the exception of the scientists' visits to the classes), participating in scientific inquiry in the three classes meant that students often conducted a procedural display of scientific inquiry (Bloome et al., 1989) or moved through the mechanical aspects of the experiments instead of also being challenged to engage in the unfamiliar scientific inquiry of "experts" so they could learn how to conduct scientific inquiry as they were in the midst of their own inquiry experiences (Collins, Brown, & Newman, 1989). There was little modeling of scientific reasoning, little scaffolding of how to evaluate data and defend findings, little transparency of how scientists go about thinking about their inquiries.

A second source of power that influenced the occurrence of the various voices in the classroom was the compatibility between the values and expectations of the school-class communities, students' identities, and the values and assumptions characteristic of scientific inquiry. In Sara's class of 9th and 10 grade males who were tracked into her class, and many whom were identified with a special education label, the students' identities and values and assumptions of the school-classroom may have contributed to a practice of scientific inquiry that involved little input from the voices of students, teachers, scientists, curricula, or technology. To support her students in making the transition to being inquirers, Sara would need to gain an understanding of her students' values and assumptions as a result of their own families, friends, and communities, and the pedagogical implications related to these values and assumptions (Gay, 1993). Finally, for Sara to be able to begin building bridges between her students and the school-class community with class lessons involving scientific inquiry, it would be beneficial for her to continue to develop a philosophy for teaching these students (Gay, 1993).

In contrast, Janet and Bonnie's school-class communities were filled with students who had self-tracked into either a math, science, and technology specialty school or a private, college-prep school. The students were working towards gaining entrance to competitive colleges, and

their families most likely valued and could afford a private school education or valued a public science, math, technology school education. The teachers and others in the communities most likely displayed values and attitudes similar to those required during the practice of scientific inquiry: social interaction skills, independent thinking, self-motivation, and responsibility (Anyon, 1981). It is more likely that these students, when compared to Sara's students, had self-identities more compatible with Western science (Costa, 1995) and had previously participated in school lessons that emphasized discovery, creativity, participation, reasoning, problem-solving, and analytical thinking (Anyon, 1981; Oakes, 1992). While, the practice of scientific inquiry still involved some procedural display and the students were not engaging in many new and complex scientific reasoning processes, the power of the compatibility between the students' identities and the values and expectations of the school-class communities and school science provided an environment in which the voices of the scientists, teachers, students, curriculum, and technology were heard more often.

In summary, the practice of scientific inquiry in the three classrooms within the context of PREP provided the students' with unique opportunities to participate in research during which they designed and conducted their own original experiments. All of the students were socially involved with their investigations and some of the students incorporated scientific sources, prior scientific works, or non-technical resources in their work. Course content about plants was woven throughout the inquiries so that students were learning about plants at the same time they were conducting their experiments. Despite all three teachers' interests in conducting scientific inquiry with their students because they wanted their students to experience scientific research and learn about experiments, there were missed opportunities for students to engage in the reasoning tasks reflective of scientists and to learn about the nature of science. The practice of scientific inquiry in the three classes was, to some extent and more so in Sara's class than Janet or Bonnie's, a procedural display of scientific inquiry, rather than authentic scientific inquiry. In addition, while some aspects of the inquiries may have reinforced current conceptions of the nature of science, there were instances that the inquiry activities contradicted these conceptions. In addition, opportunities for students to explicitly confront their conceptions of the nature of science were available but not realized. Finally, the practice of scientific inquiry in all three classes involved a wide variety of voices from different sources—students, teachers, scientists, and standards. While the sources of the voices were constant across the classrooms, the voices were

heard more frequently in Janet and Bonnie's classrooms than Sara's. The power in the classrooms that controlled for the occurrence of the voices was related to (a) the depth of the teachers' experience with scientific research and teaching and (b) the degree of compatibility between the values and expectations typical of conducting scientific inquiry, represented by the school-class community, and those reflected in the students' identities.

Recommendations

The scientific inquiry experiences within the context of PREP provided many opportunities for students to confront and grow in their understandings of science content, the nature of science, and the processes of science. So that these experiences might promote this growth in understanding, the following are recommended:

1. Developers of scientific inquiry curriculum with the goal of teacher adoption should make strong and explicit connections between the required course content and the subject of the inquiry. In addition, the scientific inquiry should continue to involve students in topics that are included in mandated course standards, support their interests, and involve finding solutions to unanswered questions for which scientists outside of the classroom have an interest.
2. During preservice and inservice teaching courses and seminars, more emphasis needs to be placed on providing experiences for teachers to grow in their own understandings of the scientific reasoning that is typical when students design procedures, analyze data, make decisions about evidence, defend conclusions, and communicate findings. This concerted focus on the cognitive processes of scientific inquiry needs to be complemented with attention to the pedagogy of scientific inquiry. Ideally this explicit attention to scientific inquiry should occur when teachers are engaged in their own authentic practice of scientific research; however, if this is not possible, at the very least, the professional development seminars or courses should reflect the same contexts of scientific inquiry that will be practiced in the schools with the students. In addition, teachers may benefit from opportunities to consider how to align inquiry experiences with students' prior knowledge and experiences with inquiry since this prior knowledge and experience will influence students' readiness to engage in both the methodological and cognitive processes of scientific inquiry.

3. Preservice and inservice teaching courses and seminars need to continue to support teachers as they re-construct their own knowledge of NOS. More emphasis is needed on how these tenets can be translated into learning objectives and resulting student outcomes and how they can be explicitly addressed during class lessons at levels complimenting students' prior knowledge and experiences. For example within a context such as PREP where students are making many decisions, teachers could use the "Decisions" theme to initiate intentional and reflective student discussions about the factors that influenced their decisions during their investigations and might influence the decisions scientists make during their practice. Explicit attention could be focused on the conventional ways that scientists determine what counts as evidence; organize, present, and analyze data; and communicate findings. Students could reflect on how their plant experiments compare with the empirical, iterative nature of scientists' investigations and consider the multiple ways that scientists conduct their practice. Discussions about equipment decisions and use could support intentional student discussions about scientists' equipment choices and interactions with equipment.
4. Future research efforts need to continue to examine the practice of scientific inquiry in high school classes particularly with a focus on how to promote practice that reflects more of an authentic and less of a procedural display of inquiry. Researchers need to continue to attempt to answer questions such as, "How do teachers know about scientific inquiry and the nature of science?" and "How do teachers know how to support an authentic practice of scientific inquiry that involves students in engaging in the reasoning tasks that reflect those of scientists, thinking about the nature of science, and focusing on their own thinking about inquiry and NOS?" It is important that these questions be investigated in a variety of classrooms to include those where the practice reflects more of a procedural display, as well as those in which the practice is more authentic. In addition, teachers and researchers should continue to investigate the design and effectiveness of professional development directed toward supporting teachers in their efforts to expand their content knowledge and knowledge of the pedagogies of scientific inquiry and the nature of science, particularly when the practice of inquiry involves students who may not share the

same values and assumptions promoted by the student-centered, student-directed, and highly social nature of Western science.

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APPENDIX A1

INTERVIEW QUESTIONS FOR TEACHERS

Part I (These will be done during the pilot study.)

1. Describe your current teaching position and responsibilities.
 - Courses including levels
 - How were you assigned to teach these courses?
 - Describe professional development-in-service training participation.
 - Describe other responsibilities in the department and school besides teaching
2. Describe the class that is doing PREP.
 - Student make-up: grade level, gender, ethnicity, race, language preference, socio-economic level
 - How do students get assigned to this class?
 - Describe the daily routine in the class (lecture, labs, group work, individual seat work, homework)
 - What instructional strategies work well or do not work well? Why?
 - How would you describe your classroom management style? What works well? Does not work well? Why?
 - Describe availability of textbooks, supplies and equipment.
 - How is this class different from the other (Biology, agriculture) classes?
3. Describe how you decide **what** to teach (all) your classes.
 - Where do you get your ideas?
 - Describe any outside factors that influence content of course.
 - Describe what you think the content would be in a perfect situation.
 - Describe the factors that you think keep it from being this way.
4. Describe how you decide **how** to teach (all) your classes.
 - Describe factors that influence how you teach.
 - Describe how your course would be taught in a perfect situation.
 - Describe the factors that you think keep it from being this way.
 - Describe differences in how you teach your different classes? Similarities?

5. Describe what you know about the PREP project.
 - How did you find out about PREP?
 - How was PREP explained to you? Who explained it to you?
 - Do you know other teachers using PREP in their classrooms?
6. Describe how you see PREP fitting into the rest of your instruction during the year.
 - Is PREP replacing something else or is it an addition to what you already teach?
 - Describe how it compares with other similar projects that have tried with their students.
 - How much experience do their students have with inquiry-based lessons?
7. Describe what you think your students will learn from participating in the PREP project.
 - What biology or agriculture content will they learn?
 - What will they learn about how science is done?
8. How would you describe “inquiry” to a new teacher who has not had any experience teaching?
9. How do you think you will change the implementation of PREP this year compared to past years (if this is not the first time the teacher has used PREP)?
10. Tell me about your educational background.
 - Degrees
 - Teacher training
 - Science research experience
 - High-school experiences

Interview Questions for Teachers after Each Class Session in which PREP is Used

1. Describe your goals for today's PREP activities.
2. How did you know how to guide the students in
 - Choosing the conditions to expose the pants to?
 - Choosing what data to collect?
 - How to analyze their data?
 - How to formulate explanations from their analyzed data?
 - How to defend their explanations?
3. How was it decided what the
 - culminating student product would be?
 - format for the culminating product would be?
4. Is there anything about how the students worked through the PREP curriculum that you would change looking back on the last 7 weeks?
5. In an ideal world, what would *you* do differently with the implementation of PREP?
6. In an ideal situation, describe what you would like to have been different.
7. In a real situation, describe what you might try differently next time.
8. Describe what you might change about the students' participation.
9. Describe what you might change about the scientists' participation.
10. Describe what you might change about your own participation.
11. Other questions might arise based on classroom observations that day.

APPENDIX A2

STUDENT INTERVIEW QUESTIONS

1. Suppose that a friend of yours, who had been absent on the days that the class worked on PREP activities, asked you to describe PREP, what would you say?
 - Describe the purpose.
 - Describe what you did during the class sessions. Outside of class?
 - Describe what you learned about science and doing science.
 - Describe other activities you have done in previous classes like PREP.
2. Describe some of the decisions you had to make during PREP?
 - What decisions did you make? Which ones were made for you?
 - Describe how you made these decisions.
 - What treatment did you use with the plants? Describe how this treatment was picked or decided on. Why was this an important treatment to consider?
 - What kinds of data did you collect? How did you collect them? Describe how these kinds of data and methods for measuring were picked.
 - How did you analyze your data? How did you know how to analyze the data?
 - What kinds of things did you do with your data after they had been analyzed? (Draw conclusions? Make explanations?) How did you know how to do this?
3. Describe your final student product (e.g., lab report, poster presentation, PowerPoint presentation). How did you know how to create this product?
4. Describe any other way that you were graded on your PREP work (Content? Process?)
5. Describe what your teacher did during the PREP activities.
 - Describe the kinds of background information the teacher provided.
 - Describe the kinds of help the teacher gave you during the PREP work.
6. Think about the ideal classroom for students...describe how you think PREP could have been different to make it a more effective experience for students. What should *not* change?

APPENDIX B1

IRB EXPEDITED APPROVAL FOR EXPLORATORY STUDY



VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY


Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice President for Research Compliance
1880 Pratt Drive, Suite 2006(0497), Blacksburg, VA 24061
Office: 540/231-4991; FAX: 540/231-0959
email: dmoores@vt.edu

DATE: December 28, 2005

MEMORANDUM

TO: George E. Glasson Teaching and Learning 0313
Erin L. Dolan Fralin Biotechnology Center 0346
Julia Grady Curriculum and Instruction

FROM: David Moore 

SUBJECT: **IRB Expedited Approval:** "An Exploratory Study of Teacher Plans for the Implementation of Inquiry-Based Instruction" IRB # 05-782

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective December 22, 2005.

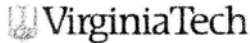
Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File

Department Reviewer: Jan K. Nespor

APPENDIX B2

IRB APPROVAL FOR FULL STUDY



Office of Research Compliance
Institutional Review Board
1880 Fran Drive (0497)
Blacksburg, Virginia 24061
540/231-4991 Fax: 540/231-0959
E-mail: iaored@vt.edu
www.irb.vt.edu

DATE: March 2, 2006

MEMORANDUM

TO: George E. Glasson
Erin L. Dolan
Julia Grady

Approval date: 3/2/2006
Continuing Review Due Date: 2/15/2007
Expiration Date: 3/1/2007

FROM: David M. Moore 

SUBJECT: **IRB Expedited Approval:** "An Investigation of the Implementation of Scientific Inquiry in Secondary Science and Agriculture Courses", IRB # 06-127

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective March 2, 2006.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

Important:

If you are conducting **federally funded non-exempt research**, this approval letter must state that the IRB has compared the OSP grant application and IRB application and found the documents to be consistent. Otherwise, this approval letter is invalid for OSP to release funds. Visit our website at <http://www.irb.vt.edu/pages/newstudy.htm#OSP> for further information.

cc: File
Department Reviewer: Jan K. Nespor

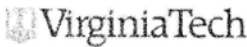
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OSP comparison options Copy

APPENDIX B3


IRB APPROVAL TO COLLECT INFORMATION FROM STUDENTS

 **Office of Research Compliance**
Institutional Review Board
1880 Dean Drive (0397)
Blacksburg, Virginia 24061
540/231-4991 Fax: 540/231-0999
E-mail: osrc@vt.edu
www.ith.vt.edu

DATE: February 28, 2006

MEMORANDUM

TO: Erin L. Dolan

FROM: David M. Moore 

Approval date: 10/7/2005
Continuing Review Due Date: 9/22/2006
Expiration Date: 10/6/2006

SUBJECT: **IRB Amendment 2 Approval:** "Partnership for Research & Education in Plants",
IRB # 05-516

This memo is regarding the above referenced protocol which was previously granted approval by the IRB on October 7, 2005. You subsequently requested permission to amend your IRB application. Since the requested amendment is nonsubstantive in nature, I, as Chair of the Virginia Tech Institutional Review Board, have granted approval for requested protocol amendment, effective as of February 28, 2006. The anniversary date will remain the same as the original approval date.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

cc: File

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APPENDIX C1

TEACHER'S CONSENT FORM FOR EXPLORATORY STUDY

Virginia Polytechnic Institute and State University
Informed Consent for Participants
In Research Projects Involving Human Subjects

Project Title: An Exploratory Study of Teacher Plans for Implementation of Inquiry-Based Instruction

Investigators: Julie Grady (PhD student, Department of Teaching and Learning)
Dr. George Glasson, (Dissertation Committee Chair, Department of Teaching and Learning)
Dr. Erin Dolan (PREP Principal Investigator, Department of Biochemistry)

Purpose of Research

The purpose of this research is to begin to investigate how teachers shape inquiry-based instruction in their unique science or agriculture classrooms. Specifically of interest are the teachers' backgrounds and their discussions about their students and schools, as well as how the teachers see inquiry-based projects fitting into their yearly plans, how they are planning to shape this experience for their respective students, and how they view the nature of science being represented during these experiences.

Procedures

If you agree to participate, I would like to interview you about your plans for implementing the PREP project in your class this coming semester. I am also interested in hearing about your experiences related to planning the content of your course, as well as how you teach that content. In addition, I would like to learn more about your students, school, and community. I would like to do one interview that should last about 30-45 minutes at a location and time convenient for you. With your permission, I would like to audio-tape the interview. The audio-tape will be transcribed by me.

Confidentiality

To preserve the confidentiality of what you tell me, all identifying information (real names, gender identifiers, references to specific schools or work or family situations) will be removed from the interview transcripts. The interviews will not be shared with administrators or others associated with your schools. I may, however, share the transcripts with other professors at the university. These people will not have access to any identifying information. When not in use, the audio-tapes of the interviews will be kept in my possession in a locked location. Audio-tapes of the interviews will be erased or destroyed upon completion of the research. Bear in mind, however, that there is always an extremely slight chance that if I publicly present this research, someone who knows you well or works with you might be able to guess your identity in spite of pseudonyms.

Risks

The risks should be no more than minimal. It is unlikely that any reader will be able to associate a quoted passage with you.

Benefits

While there is no direct benefit for you, the investigation may lead to a better understanding by science educators of implementing inquiry-based instruction in secondary science and agriculture classrooms.

Freedom to Withdraw

There is no penalty if you decide to withdraw from participation in this project. If you decide to give me permission today, and then decide later that you want to take it back and not participate, just let me know. My phone number is (540)443-1821 and my email address is jgrady@vt.edu. If for some reason you do not want to talk to me, you can contact the Chair of my Dissertation Committee, George Glasson at (540)231-8346 or glassong@vt.edu, or the Chair of the Virginia Tech Institutional Review Board, David M. Moore, at (540)231-4991 or moored@vt.edu.

Subjects Permission

If you agree to participate in this study, please sign below and date the form. I have extra copies if you would like to keep one.

Subject's signature

Date _____

APPENDIX C2

TEACHER'S CONSENT FORM FOR FULL STUDY

Virginia Polytechnic Institute and State University Informed Consent for Participants In Research Projects Involving Human Subjects

Project Title: An Investigation of the Implementation of Scientific Inquiry in Secondary Science and Agriculture Courses

Investigator: Julie Grady (Ph.D. student, Department of Teaching and Learning)
Dr. George Glasson (Dissertation Committee Chair, Department of Teaching and Learning)
Dr. Erin Dolan (PREP Principal Investigator, Department of Biochemistry and Fralin Biotechnology Center)

Purpose of Research

The purpose of this research project is to investigate how the Partnership for Research & Education in Plants (PREP) is shaped in high school science and agriculture classrooms. An understanding of how the inquiry experience is implemented will inform science educators so they can continue to evaluate and revise their own understanding of the inquiry process. The observations of how scientific inquiry is implemented in high school classrooms may also be used for future publications and presentations to contribute to the body of knowledge regarding science learning.

Procedures

In order to learn more about the shaping of inquiry experiences in the high school science and agriculture classrooms, I would like to

1. Observe each class session that involves the students in PREP activities (five to six times). I will take field notes of class activities during the class sessions. No audio- or video-taping will take place in the classroom.
2. Interview you before starting PREP as well as after each class session that involves PREP activities. The first interview will take about 30-45 minutes and the interviews following the class sessions will take about 20 minutes. These audio-taped interviews will be scheduled at a time and place convenient for you.
3. Collect copies of your lesson plans that have any references to PREP activities.
4. Collect copies from you of any student evaluation (e.g., quiz or test questions) items that relate to PREP.
5. Collect copies from you of any supplemental student handouts or other written materials used in class related to PREP activities

Risks

The risks should be no more than minimal. It is unlikely that any reader will be able to associate a quoted passage with you.

Benefits

The results of this investigation will inform science educators how scientific inquiry-based activities are implemented in secondary classroom environments. While there is likely no direct benefit for you this year, the results of the research will assist science educators in evaluating the implementation of the PREP curriculum and other curricula based on scientific inquiry so that they may be revised in order to offer teachers and students a higher quality inquiry experience. In the event that revisions or additions are made to the PREP curriculum, you and other participating teachers may benefit from these changes if you implement the curriculum in your classrooms in the future.

Confidentiality

To preserve the confidentiality of what you tell me during the interviews, what I find in the documents, or observe in classes, all identifying information (real names, gender identifiers, references to specific schools or work or family situations) will be removed from the interview transcripts and observations. The content of the interviews, observations, and documents will not be shared with administrators or anyone associated with your school. I may, however, share the information with my Dissertation Committee members. However, these people will not have access to key identifying information. When not in use, the audio-tapes of the interviews will be kept in my possession in a locked location. The audio-tapes will be destroyed upon completion of the research. Bear in mind that there is always an extremely slight chance that if I publicly present this research, someone who knows you well or works with you might be able to guess your identity in spite of pseudonyms.

Compensation

If you participate in the research study until it has been completed, you will receive a \$100 gift certificate to be used for equipment and/or supplies for your classes. If you decide to withdraw from the study before it is completed, you will receive \$17 for each researcher visit and corresponding interview completed before you leave the study.

Freedom to Withdraw

There is no penalty if you decide to withdraw from participation in this project. If you decide to give me permission today, and then decide later that you want to take it back and not participate, just let me know. My phone number is (540)443-1821 and my email address is jgrady@vt.edu. If for some reason you do not want to talk to me, you can contact the Chair of my Dissertation Committee, George Glasson at (540)231-8346 or glassong@vt.edu. You may also contact the Chair of the Virginia Tech Institutional Review Board, David M. Moore at (540)231-4991 or moored@vt.edu.

Subject's Permission

If you agree to participate in this study, please sign and date the form. I have extra copies if you would like to have one to keep.

_____ Date _____
Subject's signature

This Informed Consent is valid for one year from the date of signing.

APPENDIX C3

PARENT/GUARDIAN CONSENT FORM

PARENT/GUARDIAN CONSENT FORM Partnership for Research & Education in Plants (PREP) Study

Dear Parent/Guardian,

Your child has been invited to participate in a study being conducted by the staff of the Partnership for Research & Education in Plants (PREP) project at Virginia Polytechnic Institute and State University (VPI). Current guidelines for VPI require that all minors who participate in such studies must obtain permission from their guardians. Please read the following information and sign below to give us permission to include your child in this study.

Your child's teacher is participating in a program to introduce scientific research in genetics, genomics, and biotechnology to high school students, in partnership with the Fralin Biotechnology Center at VPI and Compass Consulting Group (CCG), an education evaluation group based in Carrboro, NC. The teacher is implementing one or more lessons in his/her classroom and, as part of this study, will be sharing plans and information about implementation. Our research is designed to evaluate the impact of this program on students' learning and understanding of biology and scientific research.

As part of this study, your child's science or agriculture class may be visited by educational evaluators from VPI or CCG. Your child may be asked to participate in a brief interview about what s/he is learning, and may be asked to share his/her science research project related to the PREP program. **PLEASE NOTE THAT YOUR CHILD'S PARTICIPATION IN THIS STUDY IS COMPLETELY VOLUNTARY. S/HE WILL NOT BE AFFECTED IN ANY WAY BY PARTICIPATION IN THIS EVALUATION PROJECT.** Your child will be told about this study and will be asked to sign an assent form stating whether s/he wants to participate in the study.

Your child's name will not appear in any public document, including articles or reports on the project. All research findings will be completely anonymous. Your child's teacher will be happy to share materials from this program with you at any time.

More information about this project, including details about evaluation, risks, and benefits are outlined on the subsequent pages. If you have any questions about this project, please feel free to contact me or any of the personnel named at the bottom of the consent form.

Sincerely,

Erin L. Dolan, Ph.D.

Principal Investigator
PREP Study
Fralin Biotechnology Center
Virginia Polytechnic Institute and State University

(540) 231-2962
edolan@vt.edu

**VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
PERMISSION FORM FOR PARENT/GUARDIAN OF MINOR PARTICIPANTS**

Title of Project: Partnership for Research & Education in Plants (PREP)
Investigators: Erin Dolan and Compass Consulting Group (Carrboro, NC)

I. Purpose of this Research/Project

Your child is being invited to participate voluntarily in the above titled research project. The purpose of this project is to examine the impact of the PREP program on all participants. As part of the PREP project, an educational evaluator (personnel from Compass Consulting Group or PREP staff) will determine the efficacy of different program components using standard educational assessments (pre- and post-tests, interviews, surveys, field observations, instructor notes, and student work). Data acquired from human subjects will be used for programmatic evaluation and for gaining insight into the implementation of inquiry-based instruction in science and agriculture classrooms. PREP staff may share the results of the research at future presentations or in professional publications.

The subject pool for PREP includes: high school science and agriculture teachers, high school students, and research scientists. In the five years of the project, we will collect data from approximately 100 teachers, 1,000 high school students, and 25 research scientists participating in PREP. Although we will be working with significantly larger numbers of participants, we will confine our data collection to these numbers to ensure reasonable and timely data management and analysis. The only criterion for selection will be that the participant falls into one of the categories of the subject pool (high school science or agriculture teacher, high school student, research scientist).

II. Procedures

This evaluation will make use of both quantitative and qualitative methodologies to gather data about the effects of the PREP project on all participants. Your child may be asked to complete surveys and pre- and post-tests, and may be interviewed to examine his/her understanding of genetics, genomics, and scientific inquiry, as well as his/her experiences with the PREP project. No other information will be requested from your child. Data will be shared with project staff to help improve the project. Evaluators will collect data at school with the teacher's and school administrator's permission.

III. Risks

There is no monetary cost to any participants for participation in this project. No participants will encounter any physical, psychological, or sociological risk as a result of their participation in this study. Your child's participation is completely voluntary; if your child does not participate, s/he will not be penalized in any way. Any information s/he provide will be kept confidential and/or anonymous.

IV. Benefits

There are no direct benefits to your child for participating in this study. His/her feedback, however, will be helpful in guiding our future efforts in developing and implementing science activities and curriculum.

V. Extent of Anonymity and Confidentiality

Evaluators will gather data and promise to keep this information confidential. Evaluators will code participants by random number, which will be used as an identifier on any written material. Names of participants are not required for completion of the research and thus will not be recorded. Evaluators will ensure that participants remain anonymous to the rest of the project staff. Findings from this research will be made available to project staff and possibly to leaders who have participated in the project. At no time

will the researchers release the results of the study to anyone other than individuals working on the project without your written consent.

Evaluators will occasionally need to make audio tapes of children’s interviews. Names of the participants being interviewed will not be recorded, and transcripts will be made of the tapes by the evaluators prior to use of data to avoid identification of participants. Tapes will be stored in a locked office (Room 304) in the Fralin Biotechnology Center at Virginia Tech, and only project staff will have access to the audio tapes. Data will be retained for a minimum of five years past the termination date of the grant (September 30, 2008). Video tapes will not be made.

VI. Compensation

Your child will not be compensated in any way for his/her participation in the study.

VII. Freedom to Withdraw

Your child is free to withdraw from this study at any time without penalty. S/he is free not to answer any questions or respond to experimental situations that s/he chooses without penalty.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Fralin Biotechnology Center.

IRB Approval Date

Approval Expiration Date

IX. Subject’s Permission

I have read and understand the Parent/Guardian Permission and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary permission for my child’s participation in this study:

Parent/Guardian signature

Date: _____

Should I have any pertinent questions about this research or its conduct, and research subjects’ rights, and whom to contact in the even of a research-related injury to the subject, I may contact:

- Investigators: Erin Dolan, Ph.D. (540) 231-2692 edolan@vt.edu
Amy Germuth (919) 484-2986 agermuth@hotmail.com
Compass Consulting Group, Carrboro, NC
- Department Head: Dennis Dean, Ph.D. (540) 231-6933 deandr@vt.edu
David M. Moore (540) 231-4991 moored@vt.edu
Chair, IRB
Office of Research Compliance
Research and Graduate Studies

This Informed Consent is valid for one year from the date of signing.

APPENDIX C4

MINOR SUBJECT'S ASSENT FORM

MINOR SUBJECT'S ASSENT FORM
Partnership for Research & Education in Plants (PREP) Study

Dear Student,

Your teacher is participating in a program called PREP, to help you learn about and participate in science research in genetics, genomics, and biotechnology. We are examining what effect this program has on your teacher and you. In order to do this, we will be examining what you learn during your science or agriculture class. We will ask you about what you learn about scientific research, biotechnology, genetics, and genomics.

If you give permission, you may be interviewed. A visiting project evaluator may ask you questions about the activities you are doing and about your science or agriculture class in general. **YOUR DECISION ABOUT WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH PROJECT WILL NOT AFFECT YOU IN ANY WAY**, and your responses will be kept anonymous. Your guardian has signed a form giving consent for you to participate in this project. Do you agree to participate in this project?

Subject's signature: _____

Subject's name: _____

Date: _____

This Assent Form is valid for one year from the date of signing.

**VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
INFORMED CONSENT FOR SCIENTIST PARTICIPANTS**

Title of Project: Partnership for Research & Education in Plants (PREP)
Investigators: Erin Dolan and Compass Consulting Group (Carrboro, NC)

I. Purpose of this Research/Project

You are being invited to participate voluntarily in the above titled research project. The purpose of this project is to examine the impact of the PREP program on all participants. As part of the PREP project, an educational evaluator (personnel from Compass Consulting Group) will determine the efficacy of different program components using standard educational assessments (pre- and post-tests, interviews, surveys, field observations, instructor notes, and student work). Data acquired from human subjects will be used for programmatic evaluation and for gaining insight into the implementation of inquiry-based instruction in science and agriculture classrooms. PREP staff may share the results of the research at future presentations or in professional publications.

The subject pool for PREP includes: high school science and agriculture teachers, high school students, and research scientists. In the five years of the project, we will collect data from approximately 100 teachers, 1,000 high school students, and 25 research scientists participating in PREP. Although we will be working with significantly larger numbers of participants, we will confine our data collection to these numbers to ensure reasonable and timely data management and analysis. The only criterion for selection will be that the participant falls into one of the categories of the subject pool (high school science or agriculture teacher, high school student, research scientist).

II. Procedures

This evaluation will make use of both quantitative and qualitative methodologies to gather data about the effects of the PREP project on all participants. You will be asked to complete surveys, and may be interviewed to examine your understanding of pre-college education issues and your attitudes toward outreach and scientist participation in pre-college education, as well as your experiences with the PREP project. No other information will be requested from you. Data will be shared with project staff to help improve the project.

If you participate in this study, you will spend some of your participation time completing questionnaires, surveys, and interviews. You may also spend up to five hours with observers if you visit a participating classroom or meet with participating high school students. Evaluators will collect data at Virginia Tech and other participating school sites. Onsite visits will only be performed with permission from you, the teacher, and the school's administration.

III. Risks

There is no monetary cost to any participants for participation in this project. No participants will encounter any physical, psychological, or sociological risk as a result of their participation in this study. Your participation is completely voluntary; if you do not participate, you will not be penalized in any way. Any information you provide will be kept confidential and/or anonymous.

IV. Benefits

You will learn about how participating in the PREP program is beneficial to you, as well as to other scientists and participating teachers and students. You may learn strategies for improving your own ability to teaching concepts in genetics, genomics, biotechnology, and scientific research.

V. Extent of Anonymity and Confidentiality

Evaluators will gather data and promise to keep this information confidential. Evaluators will code participants by random number, which will be used as an identifier on any written material. Names of participants are not required for completion of the research and thus will not be recorded. Evaluators will ensure that participants remain anonymous to the rest of the project staff. Findings from this research will be made available to project staff and possibly to leaders who have participated in the project. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent.

Evaluators will occasionally need to make audio tapes of participant interviews. Names of the participants being interviewed will not be recorded, and transcripts will be made of the tapes by the evaluators prior to use of data to avoid identification of participants. Tapes will be stored in a locked office (Room 304) in the Fralin Biotechnology Center at Virginia Tech, and only project staff will have access to the audio tapes. Data will be retained for a minimum of five years past the termination date of the grant (September 30, 2008). Video tapes will not be made.

VI. Compensation

You will not be compensated in any way for your participation in the study.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty. You are free not to answer any questions or respond to experimental situations that you choose without penalty.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Fralin Biotechnology Center.

IRB Approval Date

Approval Expiration Date

IX. Subject’s Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- I may have to complete a survey or questionnaire, or participate in an interview. My total time commitment to the study will be no more than four hours.

X. Subject’s Permission

I have read and understand the Informed Consent and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent:

Subject signature

Date: _____

Should I have any pertinent questions about this research or its conduct, and research subjects’ rights, and whom to contact in the even of a research-related injury, I may contact:

Investigators: Erin Dolan, Ph.D. (540) 231-2692 edolan@vt.edu
Amy Germuth (919) 484-2986 agermuth@hotmail.com
Compass Consulting Group, Carrboro, NC

Department Head: Dennis Dean, Ph.D. (540) 231-6933 deandr@vt.edu
David M. Moore (540) 231-4991 moored@vt.edu
Chair, IRB
Office of Research Compliance
Research and Graduate Studies

This Informed Consent is valid for one year from the date of signing.

APPENDIX C5

SCHOOL ADMINISTRATOR'S LETTER GRANTING APPROVAL FOR RESEARCH

February 15, 2006

Fralin Biotechnology Center
West Campus Drive (0346)
Virginia Tech
Blacksburg, VA 24061

Dear Ms. Grady:

I am writing this letter in regard to your recent request to involve one of Ms. [REDACTED] [REDACTED] Biology classes in your current study "An Investigation of the Implementation of Scientific Inquiry in Secondary Science and Agriculture Courses."

According to your summary of the proposed research, it is my understanding that you would like to observe and write field notes in the Biology class each class period (approximately five to six class sessions) that the students and teacher are involved with activities related to the Partnership for Research and Education in Plants (PREP). In addition, you have indicated that student, teacher, and school names will be replaced with pseudonyms in the field notes and future documents and that other identifying information will not be used.

Provided that Ms. [REDACTED] instruction and student learning are not negatively affected by your observations in the classroom, I approve your request. I understand that if the observational field work does interfere with the quality of the classroom instruction, Ms. [REDACTED] or I may withdraw permission for you to observe her class without any penalty for Ms. [REDACTED] with regard to her professional relationship with Fralin Biotechnology Center.

Sincerely,

