Conceptual Change in Understanding the Nature of Science Learning:
An Interpretive Phenomenological Analysis

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Abstract

This study is the first of its kind to explore the thoughts, beliefs, attitudes and values of secondary educators as they experience conceptual change in their understanding of the nature of science learning vis a vis the Framework for K-12 Science Education published by the National Research Council. The study takes aim at the existing gap between the vision for science learning as an active process of inquiry and current pedagogical practices in K-12 science classrooms. For students to understand and explain everyday science ideas and succeed in science studies and careers, the means by which they learn science must change. Focusing on this change, the study explores the significance of educator attitudes, beliefs and values to science learning through interpretive phenomenological analysis around the central question, “In what ways do educators understand and articulate attitudes and beliefs toward the nature of science learning?” The study further explores the questions, “How do educators experience changes in their understanding of the nature of science learning?” and “How do educators believe these changes influence their pedagogical practice?” Study findings converge on four conceptions that science learning: is the action of inquiry; is a visible process initiated by both teacher and learner; values student voice and changing conceptions is science learning. These findings have implications for the primacy of educator beliefs, attitudes and values in reform efforts, science teacher leadership and the explicit instruction of both Nature of Science and conceptual change in educator preparation programs. This study supports the understanding that the nature of science learning is cognitive and affective conceptual change.

Keywords: conceptual change, educator attitudes and beliefs, framework for K-12 science education, interpretive phenomenological analysis, nature of science learning, next generation science standards, science professional development, secondary science education
Dedication

This Doctoral Thesis is dedicated to the life and memory of my mother, Margaret D. DiBenedetto, R.N.

from whom I learned loving, giving and caring.

We boast our light; but if we look not wisely on the run itself,
it smites us into darkness.

Who can discern those planets that are oft combust,
And those stars of brightest magnitude that rise and set with the sun,
until the opposite motion of their orbs
bring them to such a place in the firmament
where they may be seen evening or morning?

The light which we have gained was given us, not to be ever staring on,
but by it, to discover onward things more remote from our knowledge.

~ John Milton, Areopagitica
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Chapter One: The Research Problem

In order for students to effectively explain, use and communicate everyday science phenomena and be poised to succeed in careers in science and competitive global markets, their means of science learning must change (Duit and Treagust, 2003; Duschl, 2008; Michaels, Shouse, and Schweingruber, 2008; Prosser, Trigwell and Taylor, 1994; Schweingruber, Keller, and Quinn, 2012). For these successes to occur, educator understanding of the nature of science learning must also change.

Statement of the Problem

Over the last two decades, there has been a growing body of research on teaching and learning in science that promises to breathe new life into standards-based educational practices in science classrooms (Cicerone and Vest, 2008). From this research, The National Research Council compiled and released a document, *A Framework for K-12 Science Education: Practices, Cross-cutting concepts and Core ideas*, designed to help realize a vision for science education in the twenty-first century. The document (referred to as *Science Framework* in this paper) is predicated on the notion of science education as conceptual change (Carey, 2000; Duit and Treagust, 2003; Duschl, 2008; Hewson, 1981; Michaels et al., 2008; Posner, Strike, Hewson and Gertzog, 1982; Schweingruber et al., 2012).

The conception of science learning that underlies the Science Framework can best be understood by characteristics of what it is not (Frayer, Frederick and Klausmeier, 1969). Science learning is not driven by a narrow scope and sequence. It is not realized through direct instruction punctuated by unrelated classroom experiments. It is not student mastery of broad content standards or ideas. It is not cooperative learning. It is not scientific method practiced in isolation. It is not kit-based or textbook driven. It is not exclusive of social interaction.
This Science Framework presents a conceptual shift in thinking that moves away from the notion that science learning occurs through either content or process. It marries both by viewing the nature of science learning as considerations of how students learn to articulate the purposes and uses of research and models, the construction of relationships between argument and evidence and the value of learning from and communicating with classroom peers.

This conceptual shift in understanding the nature of science learning adopts the idea that science learning is a social as well as a cognitive practice (Duschl and Grandy, 2013). Participating in science and communicating ideas as well as analyzing the social and cultural undertones in misconceptions (alternative conceptions) all reveal an appreciation for social constructivist influences in this Science Framework.

Additionally, the Science Framework holds science as “both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines and revises knowledge” (Michaels et al., 2008, p.17). Epistemological considerations are outlined in the Science Framework’s four strands of science learning or ‘ways of knowing science’. These strands are: 1) understanding scientific explanations; 2) generating scientific evidence; 3) reflecting on scientific knowledge; 4) participating productively in science (Michaels et al., 2008). Undergirding these learning strands is an appreciation for the capacity of young children to understand science phenomena and construct theories of science. There exists as well, the appreciation that science content knowledge is inextricably linked to the process of inquiry and the context under which that process occurs (Carey, 2000; Duschl, 2008; Michaels, et al., 2008, Pintrich, Marx and Boyle, 1993).

In the practice of science teaching, however, there exists a gap between this conceptual vision of student learning of science phenomena and the current descriptive and observational
learning that is happening in science classrooms (Braaten and Windschitl, 2011; Michaels, et al., 2008). Science curricula that prescribe process and product pedagogy and is written within the constraints and tight structure of a scope and sequence contribute to widening this divide. So too does pedagogy that focuses only on the delivery of broad surveys of science content knowledge peppered by perfunctory experiments conducted in isolation from peer discussion.

This gap extends beyond classroom practice to the beliefs and attitudes of student learning that teachers and other educators espouse. Educator beliefs and attitudes can be traced to their own particular educational experiences. These experiences contributed to the ways in which educators evaluate their own abilities in comprehending science phenomenon and capacity to teach science. It is this self-efficacy in understanding nature of science as well as educator epistemological principles and cognitive processes that figure largely in the development of their attitudes and beliefs towards science learning (Driver, Asoko, Leach, Scott and Mortimer, 1994; Harwood, Hansen, and Lotter, 2006; Pajares, 1992). Educator attitudes and beliefs that spawn conceptions of learning markedly different from inquiry based learning, pose challenges to building student efficacy in understanding science or learning science through a process of inquiry that mirrors the practices in the scientific community.

To align classroom practice with the vision of the Science Framework, educator understanding of the nature of science learning must be rooted in methods of inquiry that call on specific practices. These practices target a progression of learning and understanding of science concepts and ideas and reflect the social interactions within the scientific community. Central organizing concepts ground teachers in the ways they think about science learning (Posner, et al., 1982). If these organizing concepts differ from those that define the Science Framework, adopting this new vision becomes problematic.
The Science Framework suggests a new ‘signature pedagogy’ for science learning (Shulman, 2005). This defining pedagogy is represented in eight practices of science learning valued for promoting student efficacy in understanding, using and communicating explanations of everyday science phenomena. These eight practices are: 1) asking questions; 2) developing and using models; 3) planning and carrying out investigations; 4) analyzing and interpreting data; 5) using mathematical and computational thinking; 6) constructing explanations; 7) engaging in argument from evidence; 8) obtaining, evaluating and communicating information (Schweingruber, et al., 2012). These practices are meant to define the future of science learning where students will be active participants in their own construction of science knowledge.

One problematic consideration in adopting this pedagogy is the current conception of research held by educators at the K-12 level. For most educators, research is viewed as a singular activity at the computer or library. It is reduced to its utility as a tool. Additionally, the reading, and sharing of scholarly research is limited to those pieces they receive at professional development sessions. Rarely is scholarly literature among the resources teachers reference for unit and lesson planning. When research is viewed in such a manner, it is highly likely that these conceptions will creep into educator pedagogical practice and ultimately be transferred to the ways students think about science learning. However, when educators consider research as part of the practices and processes in their science classrooms, they add communicative, social, exploratory, and evaluative significance to its application in learning (Michaels et al., 2008).

Problematic as well are conceptions held of the relationship between evidence and argument in science classrooms. When evidence is viewed strictly in the context of scientific method, its potential for affecting science understanding is restricted (Lederman, 1992; Michaels et al., 2008; Schweingruber et al., 2012). The Science Framework expressly links evidence to the
communicative and social interactions it creates in the scientific community (Michaels et al., 2008; Schweingruber et al., 2012). Evidence that is situated in the context of peer to peer interactions and in the dialogue of argument becomes a vehicle for understanding and communicating science phenomena. Learning from and sharing scientific information with peers add a social dimension to science learning (Duschl and Grandy, 2013); the attitudes and conceptions teachers hold of these social interactions in the classroom may prove additionally problematic if seen as disconnected to the construction of knowledge.

In order for students to think differently about and value research, argument and collegial learning, science educators must come to a different understanding about the ways of knowing science. At the crux of this problem of practice is the need to depart from the teaching and supervisory practices that support a narrow scope and sequence of descriptive and observational science learning. A new vision for science learning must include science practices, concepts and core ideas based in the active practice of inquiry (Schweingruber et al., 2012). Bringing this new vision of learning to students necessitates a conceptual change on the part of the educators who teach them.

The purpose of this study had a dualistic nature. The study first explored the problem of how educators understand their thinking, attitudes, values and beliefs toward the nature of science learning; the study further explored changes to these attitudes and beliefs and how these changes influenced pedagogical practice.

The national movement toward standardization of science learning embraces the vision for science learning outlined in the National Research Council’s Framework for K-12 Science Education (Schweingruber, et al., 2012). Considerations of the four strands of learning and other dimensions of the framework underscore the gap between the Framework’s vision for science
learning and what is currently practiced in science classrooms. This gap necessitates a shift in student ‘ways of knowing’ science in order for students to “appreciate the beauty and wonder of science… possess sufficient knowledge of science… and have skills to enter [science] careers of their choice” (Schweingruber, et al., 2012, p.1).

The Next Generation Science Standards (NGSS) (NRC, 2012) being implemented are predicated on the vision outlined in this Science Framework. This study explored the problem of how educators understood their thinking, attitudes, values and beliefs toward the nature of science learning and how changes to these attitudes, values, thinking and beliefs influenced science pedagogical practice.

**Justification for the Research Problem**

This study expanded upon the literature that explores science as conceptual change (Carey, 2000; Duit and Treagust, 2003; Duschl, 2008; Prosser et al, 1994). It built upon insights from literature on conceptual change (Posner et al., 1982), from research that expands the model for conceptual change (Beethe and Hewson, 1998; Carey, 2000; Dole and Sinatra, 1998; Pintrich, Marx and Boyle, 1993; Sinatra, 2005; Sinatra, Brem and Evans, 2008; Thorley and Sofflett 1996) and from literature on the explicit use of conceptual change and meta-cognition to affect science learning (Hennessey and Beethe, 1993; Beethe and Hewson, 1998).

Part of the justification for this study was rooted in a deficiency extant in the literature. The Science Framework was newly introduced to educators in the last two years as were the national Next Generation Science Standards (NGSS) predicated on it. There is substantial research on science teaching and learning as well as literature that expands conceptual change models. However, literature that explores educator understanding of the nature of science learning through the context of conceptual change is sparse; moreover, research conducted via an
interpretive phenomenological lens is negligible. Studies on educator experience with the vision of the Science Framework as well as research precipitating from its use in classrooms were, up to this point, non-existent.

This study was the first of its kind in this endeavor. This study focused on teacher articulations of the nature of science learning vis a vis the Science Framework. It explored interpretations and meaning of educator experiences as they attempted a conceptual change necessary to align their classroom practice with the Science Framework’s vision. This study yielded findings of value to furthering research on understanding the nature of science learning through an interpretive phenomenological lens.

**Significance of Research Problem**

This study held significance for both theory and research. It contributed to theories for understanding the nature of science learning by exploring educator attitudes and beliefs about science learning. It held significance as well for research that explores the meaning educators assign to conceptual shifts in understanding science learning when experiencing changes in these attitudes and beliefs.

The significance of this study extended to practice by offering insight into appropriate content and approaches for teacher preparation programs at the undergraduate level. Science training for new educators must be inclusive of the vision of the Science Framework and an understanding of how this vision is articulated through the Next Generation Science Standards. As states adopt the NGSS standards and districts begin to disseminate them, the underlying concepts that gird this Science Framework must be explicitly understood. If science educators at every level of schooling do not understand this new conception of science learning, their instructional, supervisory and evaluation practices will not change.
For science learning and teaching to mirror what is practiced in the scientific community, explicit discussion of the process of conceptual change must be part of professional development programs for both teachers and administrators at the school level. Any endeavor that seeks to further the understanding of the nature of science learning must be inclusive of an appreciation of science as conceptual change.

**Positionality Statement**

“I used to think that stars were angels, but now I know they’re gas and dust and light.” After reading this reflection in a science journal belonging to a fifteen year old eighth grader, I was at a loss for words. The stars were up there night and day, and underneath their mantle, this teenager lived his life on the streets. How could he not have known them? The hard realities of his existence were tempered by the loving care he gave his grandmother and the stories of family, home and angels she shared with him. Stunned, I thought, “For him, angels were up there night and day, and underneath them, his teacher taught students year after year. How could she not have known them?” In the context of that singular classroom reflection, my conception of science learning changed.

The idea for this study came to me as I read and thought about reflections graduate students wrote for a final assignment in a class I taught entitled *Stem in the 21st Century* (Taft, 2012). The syllabus was created to introduce the Science Framework and its practices, cross-cutting concepts and core ideas. Along with this new vision for science learning, the course explored the use of scholarly literature in K-12 learning and the value of reflection and critique to science educator pedagogy and practices in science (Taft, 2012).

As I reviewed the reflections, I was reminded of the boy and the stars ten years earlier. It occurred to me that like his view of angels, teacher views of science learning were changing. The teacher talk that dominated classrooms was giving way to student talk. Research was being
discussed as a classroom protocol not a singular activity at a computer. Reflection, argument and evidence were taking on different purposes. And teachers were talking about students’ questions.

Most striking was the emerging sense of value teachers began to assign to the perceptions about science that young children brought to class. This especially interested me knowing that visualizing this new understanding of the nature of science learning was not a concrete process. There were ideas toward change that persisted in their nebulosity for some, however, changes in thinking, beliefs, attitudes and values started to take place within these teachers.

Throughout the semester, I continued to witness educator struggles in conceptualizing the Science Framework. For some, the lack of a descriptive, curricular scope and sequence made them uncomfortable. Others were wrangling with new thoughts about the philosophy and history of science. It was evident that for most of these educators, reflecting on Nature of Science itself was not a huge part of their own learning experiences. Although ontological, epistemological and axiological connections were emerging, several teachers wrote of being overwhelmed with the material. These realities, I thought, had severe implications for the way these educators envision science teaching, and more importantly, for way they understood the nature of science learning.

Further, I noticed that educators had limited familiarity with scholarly literature in science education. However, as the course progressed, they became interested in the research that informed the vision of the Science Framework. Evolving too, was the value they placed on the use of this research for their own lesson planning. This use of research in practice was only one of the many elements they needed to incorporate in their thinking to shift their conceptions for science learning. I had the easy part of explicitly teaching conceptual change; they had the hard part- shouldering attempts to make sense of and draw meaning from their continuing experiences with this conceptual change.
I witnessed how complex the process was for them to take in all this new information, make sense of it and how they saw it fit into their practice. I wondered how these educators were drawing out this meaning for themselves. True, this course provided formal exposure to the many dimension for this conceptual change, but I reflected on the ways these teachers were making sense of their attitudes and beliefs they held about science. I wondered how they constructed this learning and about their assumptions and prior conceptions they operated under. I was interested to know when they first became aware of any shift in thinking about science learning. Moreover, I thought about how other educators, without the benefit of this formal engagement, would come to understand and make sense of this new vision of science learning. I was interested in knowing what struggles these educators would encounter in their shift in thinking about science learning and if their beliefs would change as well.

The design of this study was heavily influenced by these reflections. It was tempered by my musings of the purpose that stardust, we call human, has outside an ethereal existence. So too, did my appreciation for conceptual change learning imprint itself in this research. My belief is that the purpose of teaching is to provoke deeper thought; my attitude is that teaching and learning is a human relationship. Both were both reflected in this study. The values of compassion, care and service, which I feel ground education, were prisms through which I conducted my research.

It was my intent to come to know myself as scholar-practitioner through the filter of my own biases that enriched my research. This was a continual and iterative process throughout my study. I hoped that by mingling my own meaning of experiences with those significances drawn by participants, I could make a contribution to the body of literature that supports educators to
see a new conception for understanding science learning and affect their practice to teach their students to do the same.

**Research Questions**

The central question of this study was “In what ways do educators understand and articulate attitudes and beliefs toward the nature of science learning?” This question was supported by two sub-questions that further guided this research. The first of these was “How do educators experience changes in their understanding of the nature of science learning?” The second sub-question was “How do educators believe these changes influence their pedagogical practice?”

**Theoretical Framework**

This research study was informed by conceptual change theory. The theory addressed a central question of the nature of science learning by exploring the process of how central organizing concepts held by participants changed from one set of commitments to another in light of new information (Posner et al., 1982, p. 211). The theory of conceptual change is rooted in the constructivist school of thought and expands the idea that epistemological structures or paradigms exist and shape human understanding (Piaget, 1970). Conceptual change theory establishes an epistemological process that defines how shifts in these paradigm structures occur (Duschl, 2008; Kuhn, 1970; Posner et al., 1982). When these shifts occur in science learning, they result in a new conceptualization of scientific phenomena through a process of accommodation.

**Cold conceptual change.**

The conceptual change model is rooted in current philosophy of science epistemology where there exists two distinct phases of conceptual change. The first phase includes a grounding of inquiry against a set of central cognitive commitments. These organizing commitments help
define problems, indicate strategies to address them and specify criteria for possible solutions (Posner et al., 1982). The second phase is the modification that takes place to these central commitments yielding new conceptions about ideas (Posner et al, 1982). Conceptual change was earlier defined in terms of a scientific revolution (Kuhn, 1970). This revolution in thought occurs when new knowledge challenges prior assumptions. In the process of thinking or inquiry, a modification of these central commitments, or paradigms, occurs. A new conception about the idea forms and replaces the former central commitments (Kuhn, 1970; Posner et al, 1982).

Conceptual change in science learning was explained by proposing a variation to the model (Posner et al., 1982). This variation includes current concepts or conceptual ecologies held by the learner (Toulmin, 1972). This conceptual ecology plays an active role in influencing the processes of assimilation and accommodation in a cognitive, or cold, conceptual change (Posner et al, 1982; Toulmin, 1972).

In science learning, students use their existing concepts to understand new phenomena. If new concepts are adequately understood, these concepts are assimilated into the existing paradigm or central concepts held by the student. However, if the central concept base of the student does not allow for adequate understanding of new phenomena, then the student must replace or reorganize these central concepts to accommodate new information (Posner et al, 1982). This process is called the accommodation phase of conceptual change.

There are four conditions that need to be met for accommodation to occur. First, a student needs to experience dissatisfaction with the ability of currently held concepts to solve puzzles or anomalies that new information brings. Secondly, the new concept must appear intelligible to the cognitive set of concepts held by the student in order to explore new possibilities. Thirdly, the new conception must appear plausible in that it appears consistent with other knowledge held by
the learner. Finally, the learner must feel that the concept has the promise of fruitfulness to solve anomalies brought by new information (Posner et al, 1982).

The cultural ecology a learner possesses drives conceptual change or accommodation (Posner et al, 1982; Toulmin, 1972). Five different types of concepts determine the direction of change: 1) anomalies, 2) analogies and metaphors, 3) epistemological commitments i.e., explanatory ideas and general views on knowledge, 4) metaphysical beliefs and concepts of science, and 5) knowledge of other fields and competing concepts (Posner et al, 1982).

The conceptual change theory theoretical framework offers avenues to explore how these five features of cultural ecology relate to the four conditions of cognitive conceptual change (Posner et al, 1982). For example, one such relationship is the connection between intelligibility, plausibility and anomalies. In order for students to find an idea intelligible, they need to construct a coherent representation of its meaning (p.216). The representation must be internalized and function either passively as a format in which information fits or actively as a plan for directing reasonable searches. How one represents knowledge determines the ability to make sense of it and use new ideas (p.217). Likewise the epistemological commitments held by the student are significant in what they initially determine as plausible in shaping their conceptual change (p.218).

An example of this can be seen in presenting students with the question, “If, at the core of the sun, there are billions of nuclear explosions occurring, then why hasn’t it blown up yet?” Learners have organizing concepts that help them understand characteristics of the sun and nuclear explosions. They find both the sun and nuclear explosions intelligible. However, there is an anomaly between their knowledge of the sun and their current knowledge of the destructive capability of powerful nuclear explosions. What is asked of them is to reconcile the effects of an
explosion with the intact structure of the sun. To find this idea plausible, they must find ways to reconcile characteristics of nuclear power with its hazards and the things (like gravity and electromagnetism) that may affect both this power and potential disaster.

Science learning rooted in addressing these anomalies lead students in determining the new concepts or explanations as plausible. If these explanations or new concepts prove fruitful in solving the anomalies, students will change their conception about the core of the sun and nuclear power. The new information or concepts that were introduced substituted the old set of organizing concepts with new ones.

The researcher viewed the vision defined by the four strands for science learning and the eight science practices presented in the Science Framework analogous to new conceptions in conceptual change theory for these participants. Conceptual change therefore, as a theoretical framework, provided a useful lens in this study. It helped inform the researcher’s understanding of how participants with informal experiences with the Science Framework began to change their conceptions about the learning of science. Conceptual change theory also influenced the researcher’s understanding of how participants’ epistemological and ontological conceptions affect thinking about the four strands and eight science practices for science learning (Posner et al., 1982; Schweingruber et al, 2012).

Additionally, this framework was instrumental in exploring how participants navigated the complex network of images, propositions and ontological overlays of the process of conceptual change. Conceptual change theory was used as a filter in the process of data analysis and provided a valuable lens through which the researcher understood participant descriptions. It provided a backdrop for the methodology used in this study to understand how participants made
meaning of a conceptual shift in understanding the nature of science learning and its connection to their conceptions of science teaching.

**Hot conceptual change.**

The theoretical framework of conceptual change in this study included an additional dimension. This study adopted affective conceptual change in tandem with considerations of cognitive conceptual change. The framework is inclusive of learner goals, values, self efficacy and control factors as mediating aspects that further define and explain individual conceptual change (Pintrich et al., 1993).

Personal, motivational, social and historical processes contribute to the construction of the new knowledge that will be either assimilated or accommodated in the conceptual change process. This *hot* model of conceptual change appreciates both the prior knowledge and current conceptions a learner holds that may be used to interpret new conflicting information (Pintrich et al, 1993). The conceptual ecologies of learners are influenced by their commitments and beliefs about the nature of knowledge, self efficacy and motivating factors. The intrinsic goals and shifts in attitudes and beliefs can influence the cognitive engagement of learners; therefore, a wider range of factors in addition to epistemological or cognitive factors must be considered in descriptions of the conceptual ecology of the learner (Pintrich et al. 1993).

In addition to these mediating factors, hot conceptual change acknowledges classroom contexts as moderating factors of conceptual change (Pintrich et al., 1993). The human interactions between teachers and learner influence learning. Inquiry activities and science learning is not an isolated process. They occur in the social context of classrooms. The personal motivations, goals, self efficacy and control factors students and teachers possess are exchanged through these interactions and environments of learning (Pintrich et al, 1993). Classroom
contexts that support dialogue, argument and other peer interactions moderate learner conceptual ecologies. Hot conceptual change theory argues for examining both motivational beliefs as mediators and classroom contexts as moderators of conceptual change in understanding the nature of science learning (Pintrich et al, 1993). This study adopted this argument of hot conceptual change.

Dole and Sinatra (1998) discuss a model of conceptual change. Their cognitive reconstruction of knowledge model discusses change in terms of social and cognitive psychology and science education. They discuss strength, coherence and commitment as qualities that influence conceptual change. Additionally, they consider motivation in the willingness to change and the idea that dissatisfaction referenced in cognitive conceptual change is a factor of this motivation (Dole and Sinatra, 1998).

Sinatra (2005) discusses five models of conceptual change that are on the spectrum from cold cognitive models to hot affective models. She notes that cognitive factors map changes in organization of understanding knowledge; she presents a developmental model with the internal cognitive processes that mediate conceptual growth reconstruction; she acknowledges that conception change theory adds the design for instruction to foster conceptual change; she discusses the more emotional influences of an affective model and the motivational factors that mediate and moderate change (Carey, 1985; Gregoire, 2003; Pintrich et al., 1993; Posner et al., 1982; Vosnaidou and Brewer, 1987).

Sinatra (2005), in tribute to Paul Pintrich’s legacy, explained the new evolving warming trend or view of conceptual change he espoused as intentional conceptual change “We defined intentional conceptual change as goal-directed and conscious initiation and regulation of cognitive, meta-cognitive and motivational processes to bring about a change in knowledge”
(Sinatra, 2005, p.113). It is this view of conceptual change embracing the motivational, affective and cognitive factors that provided the complete theoretical framework used in this study.

**Chapter Two: Literature Review**

The singular enduring objective of science learning throughout the twentieth century has been for students to develop an “adequate understanding of the Nature of Science” (Lederman, 1992, p.331). Scientists and science educators have offered differing definitions of the nature of science. Some define it as a set of values and assumptions (Lederman and Zeidler, 1987). Professional associations think of it in terms of a systematic gathering and testing of information (NSTA, 2013). Einstein (1936) called it a refinement of everyday thinking. The Science Framework offers that it is collective understandings rooted in science practices and cross-cutting concepts (Schweingruber, et al., 2012). While no singular definition fully describes the Nature of Science, the objective to develop a deep understanding of it has had an impact over the years on research for both the learning and teaching of science.

In the current movement toward adoption of national science standards, this objective of building an adequate understanding of the Nature of Science finds itself at the heart of the Science Framework (Schweingruber et al., 2012). The Science Framework is a culmination of the research yield from the last two decades on the nature of science learning, the practices of science learning and conceptual frameworks for understanding scientific phenomena. This paper presents five themes surveyed in the literature. These themes are: 1) The Nature of Science (NOS); 2) behaviorism and constructivist thinking; 3) social constructivism and science learning; 4) student conceptions in science learning; 5) teacher beliefs, attitudes and conceptions, and 6) science classroom articulations of conceptual change.
This last theme is further broken down into subthemes. These subthemes are: a) inquiry; b) explicit teaching of conceptual change; c) representations; d) NOS as explicit pedagogy; e) argument and reflection, and f) teaching from multiple perspectives.

**The Nature of Science**

The purpose of this study was to explore the attitudes and beliefs teachers held as they experienced initial change in their understanding of the nature of science learning. At the outset, it was necessary to clarify what was meant by the phrase *nature of science learning* in this literature review. The objective of this study was epistemological- to explore *how* educators understand a change in their conception about the nature of *science learning*. This epistemological purpose is distinguished from explorations of the ontology of Nature of Science (NOS). In this study, NOS was treated as one of the crucial components of science learning examined against the cognitive, affective, and socio-cultural constructivist epistemology of the conceptual change model (Posner et al., 1982). The attitudes, values and beliefs educators held toward these components of science learning were subsequently analyzed through the lens of interpretive phenomenology to understand the nature of science learning.

At the turn of the century, science educators thought students should come to understand NOS by sharpening their mental faculties via the rigors of the scientific method (Hurd, 1960; Lederman, 1992). Science teachers reflected this positivist viewpoint in the delivery of instruction. In fact, this thinking assumed that student learning was dependent on teacher conceptual understanding of the nature of science. Science teachers were seen as dispensers of science ideas delivering and imparting knowledge through methods based on the scientific method (Gage, 1989; Lederman, 1992).
As research continued into the nineteen fifties however, studies found that teachers did not possess adequate conceptual understanding of NOS. More importantly, there was no concluding evidence to support the *direct effect* of this teacher conceptual ability on student understanding and student conceptual ability (Lederman, 1992).

Several research studies at mid century continued to advocate for understanding NOS. The focus now turned to the *relationship* between teacher understanding of NOS and student learning (Lederman, 1992). No definitive evidence from these studies pointed to a direct relationship between teacher conceptual ability and student learning; however, a new assumption arose. The assumption focused on the *impact* of teacher conceptions. It was assumed that the conceptions teachers held about the nature of science affected their classroom behaviors and environments (Lederman, 1992).

**Behaviorism and Constructivist Thinking**

As the focus of research shifted from what teachers *know* to what teachers *do*, research regarding student and teacher conceptions were overshadowed by a growing interest in behaviors during teaching and learning of science. Duit and Treagust (1998) cite Bruner’s (1960) *Processes of Education* as a seminal work that drove curriculum projects of the nineteen sixties. Exploring the NOS and science learning centered on the structure of subject matter (Duit and Treagust, 1998). Four themes tightly wove around research on both learner acquisition of science knowledge and the implementation of curriculum. These themes concentrated on structures for learning, student readiness for learning, analytical thinking and inquiry and student desire to learn. (Duit and Treagust, 1998)

The goal of this research was to discover whether changes in teaching behaviors or changes in curriculum led to changes in student performance (Duit and Treagust, 1998). The
research on student learning in the nineteen seventies revisited the earlier focus on student cognition in science learning. Part of the reason was that other areas of study, philosophy of science, cognitive psychology and pedagogy, were embracing constructivist theories of learning (Duit and Treagust, 1998). These related disciplines were faring well as science continued to produce poor outcomes. This comparison encouraged a more constructivist view of science learning (Duit and Treagust, 1998).

Student conceptions of science differed from those of the scientific community. These conceptions were persistent, and in some cases, were the basis of student misconceptions or alternate conceptions of science (Driver, et al., 1994; Duit and Treagust, 1998; Schweingruber et al., 2012). Misconceptions of science were considered deficits in student knowledge. However, these student beliefs were both intuitively and formally constructed.

While teaching around these beliefs was targeted individually, there were no successful effects on student understanding of science (Driver et al., 1994; Duit and Treagust, 1998). Student beliefs and misconceptions since this time have come to be regarded as a resource for teaching and not mistaken ideas that need to be corrected (Carey, 2000; Duit and Treagust, 1998; Michaels et al., 2008; Schweingruber et al., 2012; Trumper, 2003).

**Social Constructivists and Science Learning**

Applications of constructivist thinking to the content and context of learning grew from mid century into the research of the nineteen eighties and nineties. Gone were the perspectives that science learning was mere pursuits of inquiry. The views that tied curriculum and behaviors to learning, mastery of the scientific method or mastering facts within specific domains were replaced by new understandings of NOS. The view of understanding NOS through content and context was expanded to include learning processes, including constructing conceptual
frameworks as well. Learning science is related to teacher and student conceptions of science content, the nature of science conceptions, the aims of science instruction the purpose of teaching events and the nature of the learning process (Duschl, 2008; Schweingruber et al., 2012). The learning of science must be an active process where students construct knowledge through experiences and models for explaining science (Driver et al., 1994; Duit and Treagust, 1998; Michaels, et al, 2008; Schweingruber et al., 2012).

This philosophy is espoused in the four strands of science learning of the Science Framework (Schweingruber et al., 2012.) The vision outlines a shift from passive to active science learning. Through this active learning, students can engage in the practices of the scientific community where their beliefs and conceptions can be springboards for teaching. Constructing science knowledge requires an active process of interpretation within a social and cultural setting (Driver et al., 1994; Duit and Treagust, 1998; Michaels et al., 2008). The core commitment of a constructivist position is that knowledge is not transmitted directly from one knower to the next, but is actively built by the learner (Carey, Evans, Honda, Jay and Unger, 1988; Driver, et al., 1994). The Science Framework’s conception of science learning adopts this position.

Constructivist traditions vary in the way they look at the knowledge construction process. There are individual or personal constructions of meaning about phenomena and informal theories (Carey, 1985; Duit and Treagust, 1998). A classical tradition that focuses on learning by interactions with physical lives (Piaget, 1970). In this tradition, children come to the learning of science with deeply rooted conceptions that need to be challenged by classroom activities in order for students to make a shift to a new paradigm of knowledge (Driver, et al., 1994; Piaget, 1970). Intellectual development in understanding NOS is seen as a progressive adaptation of an
individual’s cognitive schemes to his or her physical environment (Piaget, 1970; Trumper, 2003). The idea of learning progressions outlined in the framework is aligned with Piaget’s thinking, but also implies a shift in thinking about science learning (Schweingruber et al., 2012).

In addition to constructivist traditions that focus on the individual, others view science as socially and culturally constructed (Abd-El-Khalick, Bell and Lederman, 1997; Carey, et al., 1988; Carey and Smith, 1993; Driver et al., 1994). This perspective focuses on classroom activities that create interaction between the informal learning children have and the ways of knowing practiced in the scientific community. Social constructivists see scientific knowledge as symbolic as well as socially negotiated (Driver, et al., 1994). They argue that the process of knowing the constructs and systems of science requires activities that involve dialogue and cultural appropriation of the tools of science. They acknowledge that scientific knowledge consists of concepts and constructs to help interpret nature (Driver et al., 1994). The ontology of science and its epistemological practices are grounded in the social and cultural interactions and institutions of science (Driver et al, 1994; Duit and Treagust, 1998; Duschl, 2008). This thinking is reflected in the four strands of learning outlined in the Science Framework (Michaels et al., 2008; Schweingruber et al., 2012).

There is a difference between science processes and epistemology. Epistemology is the attitudes, values and beliefs one has about the nature of science and is inherent in the development of science knowledge (Abd-El-Khalick, et al., 1997). Students have been exposed to an idea of science learning that is solely an empirical process based in observation and experimentation (Carey and Smith, 1993). Pedagogy that supports a deep understanding of the nature of science includes teaching awareness of the constructivist nature of science work (Carey et al, 1988; Carey and Smith, 1993; Driver et al, 1994).
Science epistemology encompasses the beliefs, attitudes and learning ecologies of scientists working from theoretical perspectives and conjecture (Carey and Smith, 1993; Driver et al., 1994). Students need to come to an understanding that “theories are large-scale intellectual constructions” that underpin their understandings and activities (Carey and Smith, 1993, p.236). Pedagogy supportive of navigating students through their common sense epistemology toward the epistemology of science may assist students in the constructive interactions between these beliefs and potential conceptual change in science learning (Carey and Smith, 1993).

**Student Conceptions in Science Learning**

The research since the constructivist movement includes new ideas on how young children learn. Literature acknowledges that students come to learning with predisposed conceptions and misconceptions of science (Duschl, 2008; Michaels et al., 2008; Posner et al., 1982; Schweingruber et al., 2012). This acknowledgement plays a major role in the Science Framework on which the Next Generation Science Standards have been culled. A view that values student alternative conceptions requires an appreciation for prior knowledge and the unique cultural and historical backgrounds learners bring to the classroom.

Young children have the capacity for abstract reasoning around core ideas of science such as change, form, function, interpretations and systems (Duschl, 2008). Young children also have the capacity for complex thinking such as constructing theories. When students are given opportunities to predict, test, measure, collaborate and communicate ideas, they, over time, develop a progression in learning (Duschl, 2008; Michaels et al., 2008; Schweingruber et al., 2012). These practices maximize student ability to think in a complex manner and engage in abstract thinking to construct knowledge in the context of social collaboration with peers.
Considerations of the everyday thinking student have about science ideas are valuable in understanding the nature of science learning (Cobern, Gibson and Underwood, 1999). Student understanding of everyday science or the beliefs and meanings of science are situated in their social and cultural life contexts. Science learning that acknowledges this provides the backdrop for meaningful dialogue to develop between students. Using student alternative conceptions in classroom practices requires changing the focus from looking at what students do not know to looking at what students do know. This consideration will help students fill the gaps as they continue to build their scientific knowledge (Carey, 2000).

Children have theoretical frameworks that are built from concepts that differ from those that underlie scientific theories; these concepts are representational complex structures of both peripheral and core concepts that change over time (Carey, 2000). Because children absorb concepts gradually into newly created ontological categories of existence, teachers have to shift their own thinking about these alternative conceptions to include this progressive process of conceptual change (Carey, 2000). Practices and strands of learning in the Science Framework acknowledge the potential these complex structures have for student understanding of science.

In the classroom, understanding the nature of science learning means that teachers must grapple with the analytical challenges rooted in the philosophy of science by showing students how to build explanatory understanding of phenomena through modeling and discourse. Educators must not only possess a deep science content knowledge base, but also embrace student alternative frameworks as a starting point in lesson planning and instruction. This understanding and the ability to know a wide range of alternative conceptual frameworks requires that teachers diagnose student understanding of science knowledge in both qualitative and quantitative ways (Carey, 2000).
Conceptual change therefore, is not an objective or strategy, but rather a pedagogical practice. The vision that sits at the heart of the Science Framework has implications for the ways educators see science learning. Contemporary science teachers must adopt the idea that science teaching is conceptual change. In doing so, they will bring pedagogy to students that affects a deeper understanding of the nature of science through the progressive conceptual changes students will experience that is science learning.

**Teacher Beliefs, Attitudes and Conceptions**

Educator beliefs and attitudes of their personal science efficacy and their beliefs about inquiry and models for learning affect their conceptual framework of NOS, science learning and pedagogy. The belief a teacher has about her own critical thinking efficacy impacts her ability to develop theories of science, create conceptual models and transfer these to practice (Wenner, 1993). This efficacy is crucial to the development of student efficacy in understanding the nature of science, developing explanations of science phenomena and communicating these explanations to peers. The development of teacher efficacy affects the abilities students have in participating in everyday science. Important to this efficacy is the beliefs, attitudes and values educators hold in understanding the nature of science learning.

The Science Framework asserts that asking questions, developing models and constructing explanations, among others, are fundamental practices for the learning of science (Schweingruber et al., 2012). The Science Framework underscores the importance of student ability to understand these explanations and reflect on science knowledge (Michaels, et al, 2008; Schweingruber et al., 2012). How a teacher feels about their efficacy level in the critical thinking skills needed to develop these models for understanding will impact how a teacher comes to the conceptual understanding of the nature of science and science learning. Most importantly, this
efficacy level will influence the ways in which educators experience a change in the conception of science learning.

The beliefs teachers hold about inquiry affect pedagogy and science learning (Harwood, et al., 2006). Teacher beliefs influenced by their own educational backgrounds and epistemological commitments influence both choices for inquiry models and conceptions of inquiry-based science teaching (Driver et al, 1994; Harwood, et al., 2006; Pajares, 1992). Engaging students in inquiry science, i.e., questioning, constructing explanations and reflecting on science knowledge, requires teacher understanding of how their beliefs about this internal model can change to reconcile it with sound external models of the scientific community (Harwood et al, 2006).

Promoting deeper thinking and student directed inquiry is dependent on the skill in posing substantial questions (Harwood et al., 2006). Teachers must balance their own internal skill and efficacy level with the development of internal models of inquiry that reflect those of the scientific community (Harwood et al., 2006). Teacher perceptions and abilities to probe and question affect student exploration, observation and dialogue. Teachers who perceive themselves as having this ability understand that the nature of science learning includes building environments where students take control of their own learning that mirror the real world practice of scientific inquiry (Harwood et al., 2006). Teachers who possess the ability to change beliefs about internal models support the shift in thinking that is consistent with the objectives of the Science Framework.

Beliefs and attitudes about students and learning shape the cultural models teachers have and use in science education (Bryan and Atwater, 2002; Ladson-Billings, 1995). The beliefs teachers hold about the characteristics of students and their learning environments outside of
school influence the ways in which they bring learning to the classroom. Science learning is affected by the models and decisions teacher make about the purposes for learning, the content they choose for lessons and the means of delivery and classroom interactions with students (Bryan and Atwater, 2002; Ladson-Billings, 1995).

The models teachers have for their own learning are shaped by political and cultural upbringing, contextual background knowledge and prior educational experience science (Bryan and Atwater, 2002). These models influence both the models teachers choose for science instruction and their overall conceptual framework for the learning and teaching of science (Bryan and Atwater, 2002). Part of the process in understanding conceptions about the nature of science learning is to uncover and critique the beliefs rooted in these cultural models. Exploring teacher beliefs about multicultural issues and making adjustments to shift this thinking is supports the Science Framework objective to make science learning happen for all students.

In consideration of support of the Science Framework, another conception of teacher beliefs and attitudes deserves mention. Reforming the ways students learn science necessitates acknowledgement of those closest to them in this process. Keys and Bryan (2001) offer a different view of teacher knowledge of inquiry based learning in these reforms. They argue that educator beliefs, attitudes, knowledge and practices of inquiry-based science should be the focal point in science education reform. In this way, the research agenda centers on teacher attitudes and beliefs of inquiry as a central strategy for science learning (Keys and Bryan, 2001). As this study aimed to understand the nature of science learning, it was most appropriate to explore the attitudes and beliefs of science educators and the changes to them that occurred as they experienced conceptual change.

**Science Classroom Articulations of Conceptual Change**
Articulations of understanding the nature of science through conceptual change in the classroom are extant in the literature of the past twenty years. The literature offers a spectrum of evidence from the concrete explicit strategies that facilitate conceptual change to the more abstract explorations of science education as conceptual change (Beethe and Hewson, 1998; Hennesy and Beethe, 1993; Posner et al., 2012). Shulman (2005) proposed the idea of *Signature Pedagogies* for professions. Signature pedagogies define the standards of a profession for the purpose of understanding and preparation for “accomplished and responsible practice in the service of others” (Shulman, 2005, p.53). These signature pedagogies have surface or operational structures, assumptions or deep structure and an implicit structure of moral dispositions. These pedagogies of practice are pervasive and routine, differ in purpose, are internalized, interactive, demanding of student performance and provide for both risk taking and excitement (Schulman, 2005).

Signature Pedagogies extant in the literature for science as conceptual change include the role and function of inquiry, explicit instruction of both the nature of science and conceptual change, reflection and meta-cognitive activities, the use of argument and representations and differing perspectives for learning in science classrooms. This research along with the body of literature that underlies the Science Framework exemplifies both the purpose and role of signature pedagogy to symbolize the values and shape the future practice of the science teaching profession (Shulman, 2005, p.53).

Classroom articulations of conceptual change embrace pedagogy reflective of teacher beliefs that inquiry is inclusive of the social construction of knowledge. Social interaction in inquiry-based learning provides opportunities for student and teacher reflection of science ideas. These articulations are dependent on the rich dialogue that results when students are engaged in
sharing evidence, ideas and explanation in classrooms; it also acknowledges that both current and prior learning occur in the contexts of culture and classroom alike (Keys and Bryan, 2001). These considerations are part of this new signature pedagogy for science learning.

Inquiry.

Articulations of conceptual change in the classroom are evident when educators have the attitude and belief that science inquiry is an active process. Science learning is meaningful when concepts are interconnected and students can understand and explain relationships among science ideas (Michaels et al, 2008; Sweingruber et al, 2012). Science inquiry is rooted in the role that questions play and in the actions that make questions meaningful to students. Inquiry based science learning is an active process where questions and the processes of finding out are put in the hands of students during investigation and exploration of science ideas (Michaels et al, 2008; Sweingruber et al, 2012). The ability for students to understand and explain everyday science phenomena is dependent on the use of questions in their own learning.

A study by Chin, Brown and Bruce (2002) on student-generated questions underscores the idea that “questioning lies at the heart of scientific inquiry and meaningful learning” (p. 521). Questions have many purposes - assessment, exploration, clarification of ideas and etcetera. However, the types of student questioning have impact on the ways in which they learn (Chin and Brown, 2002). For example, a deep and probing question may lead to further thinking about a science idea. Deep probing questions also affect the opportunities and abilities students have to reflect on their learning (Chin and Brown, 2002).

The level of student thinking and its effect on student reflection and questioning in science learning is affected by teacher efficacy in content knowledge and the ability to think at deeper levels. There is literature that explores the dynamics of pedagogy of teachers with low
efficacy who avoid or repress student questioning which probes at deeper levels in order to avoid problems in the classroom (Chin and Brown, 2002; Wenner, 1993).

Science learning that utilizes strategies for deep questioning supports students in their construction of knowledge. Science educators who encourage deep and probing questions not only provide scaffolding support for students in their learning, but also provide information about where students are in their understanding. In addition to this quick assessment, questions help inform instructional design and further science inquiry activities (Chin and Brown, 2002).

Inquiry and investigation envisioned by the Science Framework is meant to be student driven (Michaels et al., 2008; Schweingruber et al., 2012). In order for active inquiry to take place in classrooms, the questions that are part of learning need to originate with the student. Student generated questions that are representative of higher order thinking allow the learner to be active in inquiry by exploring, thinking and communicating ideas in science. Chin and Brown (2002) offer information on two types of student-generated questions: basic questions and wonderment questions. They also explore their relationship to other learning activities. Focusing on the production of wonderment questions in science learning facilitates both independent and peer construction of knowledge, deeper conceptual thinking and skill in understanding the choice, use and purpose of questioning in science learning (Chin and Brown, 2002).

Questions lay at the heart of inquiry learning. Inquiry-based learning includes an understanding about inquiry, not just doing inquiry (Abd-El-Khalick, Boujaoude, Duschl, Lederman, Hofstein, Niaz, Treagust and Tuan, 2004). Science learning that is based in inquiry necessitates explicit discussion of the ways in which students understand inquiry. Connections must be made between this understanding, conceptions of nature of science and classroom based practices (Abd-El-Khalick et al., 2004). In order to achieve this level of understanding, part of
the learning must include time spent on the ontology of inquiry in addition to the investigations in doing inquiry.

Explicit teaching of the understanding of inquiry in teacher preparation programs helps build educator attitudes, values and efficacy that can be translated to classroom practice (Abd-El-Khalick et al., 2004). The value educators hold for the understanding of inquiry is connected to their appreciation for building student understanding of the nature of science. Researchers have developed a Views of Nature of Science Questionnaire as a classroom intervention to enhance student understanding of nature of science (Lederman, Abd-El-Khalick, Bell and Schwartz, 2002). The idea behind the questionnaire was to provide data for research on nature of science and provide meaningful assessment of student NOS views (Lederman et al., 2002). Classroom routines that foster an understanding about inquiry as well as an understanding of NOS, help students articulate new conceptions for science learning.

A study on reform efforts in Detroit showed that educators who value and provide inquiry based- learning in their classrooms, transform the experiences students have in learning (Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier and Tal, 2004). Students come to deeper understandings of everyday phenomena through experiences of asking questions, designing investigations, gathering and analyzing data, making interpretations, creating explanations, drawing conclusions and reporting findings (Marx et al., 2004). The Science Framework embraces these experiences for science learning.

The Detroit study underscored the need for a technology infused curriculum, collaboration and the use of inquiry based pedagogy to affect deep understanding of science ideas. The findings support the vision in the Science Framework that conceptualizes science learning as an active and collaborative process based in inquiry. These practices provide students
with scientific experiences that occur in the scientific community (Michaels et al, 2008; Schweingruber et al., 2012).

**Explicit teaching of conceptual change.**

A longitudinal study on the explicit use of the conceptual change model in a sixth grade classroom, yielded evidence that meta-cognitive activities such as reflection and discourse support a deeper understanding of science learning (Hennessey and Beethe, 1993).

As a learning practice, reflection assisted in the monitoring of beliefs and assumptions held about science ideas. As the progression of instruction brought students to accommodation, they reflected on the changes in their beliefs and were able to isolate the causal factors of these changes. Through discourse that was an integral part of classroom learning, reflections were given voice, and the dialogue emergent from these reflections along with other meta-cognitive classroom routines and practices acted as vehicles by which students conceptions of science changed (Hennessey and Beethe, 1993).

A subsequent study examined the particular pedagogy and found that unique learning goals supported the implementation of the conceptual change model. Educator planning that considered these learning goals supported a continuing environment of exploration and deeper thinking (Beethe and Hewson, 1998). Additionally, consideration of student levels of understanding of science concepts as they were being taught, allowed instruction to target specific routines to promote this conceptual awareness. Applying the conceptual change model to planning and considerations of student performance in instruction affected conceptual change teaching (Beethe and Hewson, 1998).

Teaching meta-cognitive strategies help students come to a different understanding of the knowledge of science principles from those they already hold. Student conceptions are deeply
rooted before the early entry into science classrooms. In short, students already possess meta-conceptual views of science. For students to construct learning of new science concepts and principles, they must first be aware of this initial meta-conceptual view and a shift toward the meta-conceptual perspectives of science knowledge (Duit and Treagust, 2003; Vosnaidou, Ioannides, Dimitracopoulou and Papademitiou, 2001).

For students to come to an effective understanding of the nature of science, teachers need to build upon a progression of conceptual understanding. How students are taught to conceptualize at the elementary level affects learning and teaching in the higher grades (Trumper, 2003). These conceptions, however, may be learned from teachers whose own conceptions of science do not reflect those held by scientists (Michaels et al., 2008; Schweingruber et al, 2102; Trumper, 2003). Moreover, conceptual understanding and the changes to this understanding are dependent on the ontological categories that students assign to physical entities, ideas and events (Chi, Slotter, deLeeuw, 1994). In order for conceptual change to occur, concepts need to be re-assigned to an ontologically distinct category. In short, for students to understand the nature of science they must rely on the ontological distinctions they make about concepts and the understanding of the symbols of phenomena assigned by the scientific community (Chi et al., 1994; Driver et al, 1994). For students to undergo conceptual change, the re-categorization of ontology and a meta-conceptual awareness of a shift away from initial views via accommodation must occur (Posner et al, 1982; Vosnaidou et al., 2001).

**Representations.**

Models or representations of ideas through analogies, illustrations, examples, explanations and demonstrations help students understand new constructs and accommodate a new conceptual model (Shulman, 1986). Teachers who adopt the use of representational models
render key conceptions intelligible by students. Intelligibility of a concept depends on the model used to represent it mentally and through discourse. Linguistic expression, critical attributes, exemplars, action, analogies and metaphors for concepts can be used to help students discern the essence of concepts and make them intelligible (Shulman, 1986). Plausibility and fruitfulness in like manner can be decided as a student progresses in accommodating a different understanding (Posner et al., 1982; Shulman, 1986).

Moreover, to support this process of conceptual change oriented learning, teachers must use these representations to unpack the meaning of intelligibility, plausibility and fruitfulness of the conceptual change model itself (Thorley and Sofflett, 1996). Understanding the nature of science learning as conceptual change extends to a how teacher plan and think through new and difficult pedagogical conceptions.

Also, the manner in which teachers reflect on student performance can include representational models to assist in interpreting student talk, writing and evidence from class activities. Representations are keys to seeing the shifting views that build teacher conceptual efficacy in pedagogical practice. Teachers who use representations of the conceptual change model to understand and shift their own pedagogical conceptions can affect conceptual change learning in the science classroom (Thorley and Sofflett, 1996).

The literature offers other representations or visualization strategies that assist in the understanding of the nature of science learning. Although these specific strategies are meant to help students construct a conceptual understanding of phenomena, they can also be used to help students shift alternative conceptions that differ from those accepted in scientific practice. Examples are strategies that map concepts out for observation in the physical space of the classroom (Moher, 2005). By allowing students to engage in active learning within the context of
the phenomena itself, students can re-conceptualize the relationships between causes, events and the characteristics of these phenomena (Moher, 2005).

The way students observe natural phenomena and reflect on that phenomena affects the ability to understand that phenomena (Yair, Schur and Mintz, 2003). Through the use of three-dimensional visual models of phenomena, students can connect the process of observing with the process of thinking about scientific phenomena and reconstruct a view of phenomena in a scientifically correct way. By understanding how to integrate these visualization strategies in teaching, teachers can affect student understanding of abstract scientific concepts in ways that capture their imagination and innovation (Yair et al., 2003). This exposure at a young age would scaffold the skills students need for the progressive learning of science.

NOS as explicit pedagogy.

In the literature, there is call for NOS to be given explicit consideration in school classrooms, ontologically as a body of knowledge and epistemologically as a way of knowing (Abd-El- Khalick, et al., 1997; Carey and Smith, 1993; Cobern et al., 1999; Lederman, 1992; Michaels et al, 2008; Southerland, Johnston and Sowell, 2006; Schweingruber et al, 2012). While K-12 science students are not expected to engage in high philosophy about the nature of science, NOS should be regarded as a cognitive outcome and therefore should be embedded in science content. There must be explicit connections between NOS and science classroom activities (Abd-El-Khalick et al., 1997). Instruction therefore will be planned and intentionally focused on NOS as a way of knowing, along with lesson objectives for core ideas, processes, and science concepts (Abd-El-Khalick and Akerson, 2004).

Students must learn that the structure or content of science knowledge is tentative, ever changing with new discoveries. They need to come to know it as subjective, that it is based in
theories proffered from thinking beings (Abd-El-Khalick, et al, 1997). This awareness must be cultivated early at the classroom level. So too, students must be taught that there is a duality of science— that it is both empirically derived from observation and a product of human inference and creativity (Abd-El-Khalick, et al, 1997; Carey et al., 1988; Driver et al., 1994). There must also be the appreciation that science is empirically based yet socially and culturally embedded (Abd-El-Khalick, et al, 1997; Driver et al., 1994). Explicit instruction must target the differences between observation and inference and underscore the relationship between science theories and laws (Abd-El-Khalick, et al, 1997).

This explicit teaching of NOS allows students to think about and share their particular perspectives on the constructs and characteristics of science. Planning for this sharing should be inclusive of meta-cognitive discourse within the context of assessing their ideas in relation to those of the scientific community (Abd-El-Khalick and Akerson, 2004; Beeth and Hewson, 1999; Carey et al., 1988; Duit and Treagust, 2003; Hennessey and Beeth, 1993). This discourse of student perspectives necessitates time for reflection on NOS.

**Argument and Reflection.**

Pedagogy that appreciates multiple perspectives includes argument as a means to promote understanding of a situation and persuade peers regarding the validity of an idea. Becoming familiar with the ideas of their peers motivates students to think differently about their own conceptions as they consider the evidence and reasoning offered through discourse with others (Michaels et al., 2008). They are able to see issues of science through a different lens. Argument and student talk are vehicles which help students understand the connections between ideas and evidence and help them make science visible (Michaels et al., 2008).
The use of argument in science classrooms provides opportunities for students to critically analyze issues of science in everyday life; constructing an argument involves considering alternative positions (Driver, Newton and Osborne, 2000). Argument is dialogical; it helps students think about discrepancies between their thinking and that of the scientific community (Driver et al., 2000; Michaels et al., 2008). It provides a context for the development of reasoning skills and the use of evidence to support that reasoning via data, claims, warrants and backing (Driver et al., 2000; Michaels et al., 2008; Toulmin, 1958).

Furthermore, argument as a discursive activity supports the construction of knowledge by giving voice to the historical, philosophical and socio-cultural dimensions of the nature of science knowledge (Driver et al, 2000). Science classrooms that generate lively talk encourage students to participate in reasoning, theorizing and sharing of science ideas within a social context.

Argument is socially constructed around interactions and language, so students must be introduced to the social and cultural settings in which argument occurs (Driver et al, 2000). Science educators must familiarize themselves with and plan for argumentation in their classroom. In this way they can effect changes in science learning away from the positivist approach of science as a solely empirical process toward science as a socially constructed enterprise (Driver et al, 2000). By capitalizing on the resources that students possess—diverse life experiences, linguistic and ethnic backgrounds and their alternative conceptions of science, educators can support students in understanding their own reasoning and that of their peers (Michaels et al., 2008).

Debate and argumentation are mediums that stimulate the process of reflection through which students may acquire conceptual understanding. Educators who model the use of evidence
to construct, evaluate and revise arguments help students in explaining how they know and why they believe (Duschl and Osborne, 2002). Both student and teacher need time to reflect on their own understanding of NOS. For teachers, it is to build science literacy among their students; students gain deeper understanding around the complex relationship between all domains of science, technology, engineering and mathematics (Abd-El-Khalick and Akerson, 2004).

The focus of learning should be “to enable students to reason and reflect meta-cognitively on their own learning and on the construction and evaluation of scientific knowledge” (Duschl and Osborne, 2002, p. 39). Structured reflection should be modeled for students to show them how to assess their ideas across context and assign meaning to NOS ideas. Modeling reflection strategies helps students visually organize the structure and meaning of the nature of science (Abd-El-Khalick and Akerson, 2004). Planned activities for reflection of views of NOS done in consideration of the unique learning ecologies of students provide an analytical framework for students to connect classroom activity to that of the scientific community and think about science epistemology (Abd-El-Khalick and Akerson, 2004).

**Teaching from multiple perspectives.**

In order for science epistemology to take root in the minds of students, classroom environments must allow for differing perspectives in the discussion of science. The perspectives about science that students bring to the classroom can be religious, aesthetical, scientific and conservationist and etcetera (Cobern et al., 1999). While school science environments have traditionally excluded all other perspectives, a classroom that accommodates a breadth of perspectives allows students to think about the NOS in a way that finds a niche in their cognitive and cultural milieu (Cobern et al., 1999). The way teachers interact with students around these
perspectives provide access to or obstacles from ‘border crossing’ into school science from the initial conceptions, experiences and knowledge held prior to school years (Cobern et al., 1999).

The demarcation of science for school purposes of learning science exclusive of exploring perspectives grounded in religion, aesthetics, poetry art and etcetera, presents obstacles for students as they struggle to make their own accommodations of NOS (Cobern et al., 1999). Pedagogical practice needs to take into account the meaning students give experiences, that is, to respect the meaning students give to the events we share “…students are not scientifically literate until the conceptual knowledge they have of science is meaningfully integrated into a cognitive framework that includes their everyday thinking… educators need to come to know their students as persons” (Cobern et al., 1999, p. 558).

It has been suggested that classrooms that perpetuate a one sided view of NOS may contribute to student loss of interest in science. Science pedagogy must undergo enrichment and de-formalization and reconnect with everyday life in order for students to make meaning of their conceptions of NOS (Cobern et al., 1999; Michaels et al, 2008; Schweingruber et al., 2012). This belief supports a constructivist science classroom environment supportive of various meanings of NOS that are connected to unique perspectives “Meaning is not given to us in our encounters, but is given by us- constructed by us, each in our own way, according to how our understanding is currently organized” (Cobern et al., 1999; Duckworth, 1987).

Conclusion

In order for students to develop an adequate understanding of the nature of science, science educators must come to an awareness of the personal beliefs and attitudes they hold toward the nature of science learning. Science knowledge is a socially constructed enterprise- so too should be science learning. The nature of science learning is characterized by explicit
instruction of NOS and meta-cognitive activities around science knowledge. Reflection and argumentation are vehicles by which explanations of science phenomena evolve. Ideas and constructs of science are made visible through models and the fleshing out of alternative conceptions.

The practices of science, cross-cutting concepts and core ideas outlined in the Science Framework and the Next Generation Science Standards require a shift in thinking, beliefs and attitudes toward science learning. If students are to develop the scientific literacy needed to effectively participate in and explain every day science and succeed in studies and careers in science, educators must undergo a change in the conceptions they hold in understanding the nature of science learning.

Chapter Three: Research Design

Research Question

The question central to this study was, “In what ways do educators understand and articulate attitudes and beliefs toward the nature of science learning?” A related sub question to guide this study was, “How do educators experience a shift in their understanding of the nature of science learning?” Further inquiry was explored through the second sub-question, “How do educators believe these changes influence their pedagogical practice?”

Methodology

In order to explore the dimensions of this understanding, this study took a qualitative approach rooted in the Constructivist paradigm. A qualitative approach gave voice to the perspective of the researcher in the study as she considered how and what participants experience (Ponterotto, 2005). The focus was on isolating the ‘lived experiences’ teachers had through which they came to deeper conceptual knowledge. In order to explore the depth of these
experiences, the researcher looked for the *rich and thick* descriptions of their experiences (Geertz, 1973; Johnson and Onwuegbuzie, 2004). It was the interpretation of these experiences that provided a new understanding of how teachers came to a greater conceptual understanding of science learning.

The ways in which participants experience change in their conceptions of the nature of science learning was explored in detail from personal accounts. The qualitative lens was appropriate as it allowed the researcher to explore and map how these participants experienced this change. As they recounted experiences, they constructed meaning and a different level of conceptual awareness (Ponterotto, 2005). Exploring how the participants constructed this new awareness meant navigating their perceptions through the lens of the researcher as well.

Additionally, these perceptions and perspectives in constructing this awareness yielded a complex collection of significances and associations for these participants (Cresswell, 2013). It was this rich diversity of experiences that helped the researcher make sense of what it meant to come to a deeper understanding of these experiences. The researcher positioned her own philosophy of science learning and her own cultural, personal and social histories among participant experiences to construct meaning from this complex network of interpretations about what and how they came to deeper understanding of science learning.

**Interpretive Phenomenological Analysis**

The methodological approach chosen for this study was Interpretive Phenomenological Analysis (Smith, Flowers and Larkin, 2009). The purpose of this study was to give voice to science educator experiences of change to their beliefs, attitudes, thoughts and values toward understanding the nature of science learning and to then interpret the meaning of this voice in the context of this change. Interpretive phenomenological analysis was appropriately adopted,
because of the dualistic nature of this study; it supported both the descriptive and interpretive purposes of the study. This methodology honed the focus on understanding human experiences of change (Laverty, 2003).

In adopting double hermeneutics, the researcher acknowledged that participants interpret conceptual change within the context of their social, cultural and historical background understanding (Heidegger, 1927/1962). Filtering data situated in their particular contexts, interpretive phenomenology assisted the researcher in understanding how participants constructed meaning of conceptual changes in their thoughts, attitudes, beliefs and values of science learning.

Interpretive phenomenology has its roots in the movement of phenomenology founded by Edmond Husserl (Creswell, 2013; Moustakas, 1994; Reiners, 2012). The ideas Husserl espoused were influenced by Immanuel Kant as he considered the idea of the a priori or consciousness or lived experiences of people. He considered thoughts, perceptions, emotions and imagination as involving an intentionality or “…a person’s directed awareness of an object or event” (Reiners, 2012, p.1). The use of *epoche* or avoidance of the ordinary way of perceiving things, Husserl allowed a new perspective of understanding participant experiences that emerged through substantial description of that phenomenon (Moustakas, 1994).

Martin Heidegger, a student of Husserl, proposed that consciousness is not separate from the world of human existence (Dowling, 2007). He rejected an epistemological stance and believed that the ontology of *being in the world* is the primary phenomenon (Dowling, 2007; Reiners, 2012). His focus went beyond describing those experiences of everyday occurrences to finding and interpreting the *meaning* embedded in those experiences (Reiners, 2012). Therefore, understanding becomes a reciprocal activity between participant and researcher (Dowling, 2007).
Interpretive phenomenology allowed the researcher to substantially interpret the experiences participants had of the phenomenon of change in beliefs, attitudes, thoughts and values that underpinned their understanding of the nature of science learning.

Interpretive phenomenology is, in part, a flexible descriptive methodology that centers on the exploration, deep probing and communication of substantial details, subtleties and unique characteristics of a participant’s experiences of a phenomenon (Larkin, Watts and Clifton, 2006). To capture the experiences of participants being in the process of change, the researcher gave consideration to both micro and macro pieces of information offered by the participants. The collection and recording of this information was conducted through a casual interview atmosphere. This setting allowed participant thoughts, feelings and ideas to flow directly from their experiences of them which gave the researcher an accurate understanding of the phenomenon as they knew and understood it.

To come to the closest point of approximate knowing of participants’ experiences, the researcher observed gestures and participant affective demeanor recording and describing, in detail, the information they shared. Deep, rich and thick descriptions were inclusive of words, phrases, intonations, larger ideas, essences of meaning, relationships and connections heard and observed in the interviews (Cresswell, 2013; Crist and Tanner, 2003). This detailed description allowed the ‘voice’ of participants to be heard in the data in a manner that rendered the most close and approximate reflection of the experiences (Larkin et al., 2006). The voice speaks to the essence of the phenomenon as experienced, and it was recreated for study through an analytical interpretive lens.

The other purpose of this study distinguished it from a purely phenomenological endeavor in that its aim was to additionally understand the meaning the participants assigned to
this experience. Hence, interpretative methodology accompanied phenomenological description. The researcher scrutinized the substantial description of details in an effort to interpret how participants made meaning of their experiences.

There was an ontological influence that drove this analysis of data, as the researcher was situated within the context of both the participants’ world and the context of change (Reid, Flowers and Larkin, 2005). The dynamic was rooted in the belief Heidegger held that people are persons-in-context, that is, that people are located in and actively engaged within the context of the world around them (Larkin et al., 2006). Interpretive phenomenology is ontologically based, in that the realities of the participants, or what they are being in at the time, are the realities the researcher attempts to experience.

Therefore, a coming to know or understanding is not an epistemological journey, but an ontological interpretation of the existence of the experiences of the participants (Crist and Tanner, 2003; Larkin et al., 2006). We come to know the world, because we are in it; that understanding is not a way we know the world, but rather the way we are (Heidegger, 1927/1962; Laverty, 2003; Polkinghorne, 1983).

Because of this ontological nature of being in the participant’s world, the researcher and participant shared or co-existed in the same experience through the exchange of dialogue. While the participants attempted to make sense of their experiences, the researcher was, at the same time, making sense of the participants’ meanings they drew from those experiences (Smith, et al., 2009). This double hermeneutical approach did not require the researcher to bracket out her own thoughts, assumptions and conceptions. Instead, she brought her prior experiences, knowledge, bias, personality, philosophical understandings, social and cultural mores and personal lens to the
analysis in order to interpret meaning of the experience or to give voice to participants’ concerns (Crist and Tanner, 2003; Larkin, et al, 2006; Smith et al, 2009).

Heidegger believed that nothing can be known without understanding backgrounds or life experiences of being (Laverty, 2003). Gadamer (1963) extended this thinking by embracing preconceptions as part of linguistic experiences that make understanding possible (Dowling, 2007). Gadamer, like Marcel (1950), believed that universality between the person expressing themselves and those who understand are “connected by a common human consciousness” (Dowling, 2007, p. 134; Gadamer, 1963; Randall, 1995).

Interpretive phenomenology therefore, tied this consciousness or interpretation of these experiences to the research question and placed the researcher in context of the idea of change (Crist and Tanner, 2003; Reid, et al., 2005; Larkin et al., 2006; Reiners, 2012; Smith et al., 2009). While the researcher could never exactly know the phenomenon of change as experienced by participants, the researcher’s prior knowledge of and experience with change and living in the moment with the participant allowed her to know, in a manner that closely approximated the experience, how participants experienced this change.

The researcher focused on the experiential claims of the participants and adopted a third party narration and description in order to get as close as possible to understanding why the participants made these claims and shared the feelings associated with them. The research question engaged this search for meaning within the chosen conceptual change theoretical framework (Larkin et al., 2006). Understanding the nature of these claims, in terms of participant experiences, was dependent on the process of intellectual construction of meaning. The researcher gleaned this meaning through analysis of these claims and came to know about the participants as she saw the experience through their eyes (Larkin et al., 2006; Smith et al., 2009).
The researcher positioned herself in the analysis of collected data by virtue of her own interpretations of themes gleaned from previous description and narration. The idea that the knower and the known are interrelated allowed the researcher to make sense of the meaning that experiences had on participants (Larkin et al., 2006). The researcher analyzed educators’ claims and concerns in understanding of the nature of science learning within the hermeneutic circle.

As interpretive phenomenology is an iterative process, the researcher moved back and forth between the general body of data and the individual descriptions and nuances of experience and constructed meaning of these claims through engagement with the participants (Crist and Tanner, 2003; Heidegger, 1927/1962; Laverty, 2003; Polkinghorne, 1983). The participants made these claims by drawing upon familiar resources i.e., moral rules, expressions of conflict, insights into their life-world, social interactions, cultural resources and etcetera, to make sense of the conceptual change. The researcher interpreted these claims and concerns as something new deliberately revealed (Larkin et al., 2006). In short, understanding was gained from starting with a-priori categories and ending with emerging themes (Laverty, 2003; Reiners, 2012).

The use of interpretive phenomenological strategies helped the researcher reflect on new meanings that emerged in accounts of participant experiences. Thus the total process was one of meta-interpretation or double hermeneutics where participants made sense of their experience, and the researcher assigned meaning all the while aware of how her influences affected the study (Crist and Tanner, 2003; Smith et al., 2009; Smith and Osborn, 2007). By adopting reflexive processes that situated data analysis in both the context of the research question and the sense participants made of experiences, the researcher contributed to further understanding of the phenomenon of conceptual change in understanding the nature of science learning.

**Researcher Bias**
The researcher had two roles: first, to listen closely for descriptions of participant thoughts, attitudes, beliefs and values in their experiences in understanding the nature of science learning. The second role was to seek meaning of these experiences through an interpretive lens. As the researcher approached this study, much of what she heard resonated with some of her own values and experiences as a former science teacher, graduate professor and continual learner. Since she had some similar experiences in thinking about the ontology of science learning, she identified with some attitudes, beliefs, values participants experienced in the development of a conceptual understanding of science. She listened to their experiences and made meaning of the relationships between what and how they developed and perceived a new understanding of science learning and how participants envisioned incorporating this into their pedagogical practice.

As her relationship with the participants deepened during the course of the study, there emerged more substantial interactive researcher-participant dialogue that informed the findings (Ponterotto, 2005, p.129). Because of the interpretive approach, this dialogue enriched close approximate meaning of the experiences creating a common consciousness around it.

**Ensuring Protection**

**Honesty and legitimacy.**

The process of protecting subjects was multidimensional and started well before research interviews commenced and continued through to the end of the study. The researcher believed that an ethical approach in research goes beyond safeguarding participant rights and confidentiality. Protecting participants was inclusive of the rapport she built with participants, the dialogue with them and the way they were brought to the point of sharing ownership of this
study. This protection was also grounded in the ethical attitude brought to the interviews, the consideration of data and the subsequent reflexive process of this study.

Verbal consent of participants was secured. The researcher spoke openly with participants about the purpose of the study and assured them that at every step, they had the right to dismiss themselves from participating. She assured participants of confidentiality and how their responses will be treated. The researcher was straightforward with participants about the study to yield legitimacy to every part of the process. There were ethics that were supported by honesty, and the researcher believed that in disclosing the purpose and all other components of the study, participants could make their own decision to remain and participate. The researcher acknowledged the risk of sharing information that might have spurred participants to exit the study, but in the end, their assent was what provided the legitimacy to the research findings.

**Participant stake in the purpose of the study.**

In order for the interviews to be both participatory and responsive, the participants needed to feel that they had a stake in the study. They shared the enthusiasm for what was uncovered. Full disclosure was offered. The researcher assured them that her role was limited to the study and did not extend into any other capacity that may affect their employment or work performance.

Through the lens of responsive interviewing, the sharing of participants experiences of understanding science took place in true interactive dialogue (Rubin and Rubin, 2012). In addition to inviting subjects to own part of this work, the researcher sought out their acknowledgement of the purposes of the study. Having their consent to hear their stories is one thing, but knowing they acknowledge the value of these stories to this research authenticated the study.
The researcher further established participant comfort and protection by sharing with them the potential benefits of the study. It was important that participants knew what impact this study would have in furthering ideas and strengthening practice in education. It was important to the researcher to share potential benefits of the study to confirm her passion and rationale for pursuing their stories. She believed that by sharing these benefits and risks was an opportunity to further connections between herself as researcher and participants. This connection was an opportunity to determine how enthusiastic participants might be about the topic, purpose and their contribution to the study.

This dialogue around both risk and benefit became a vehicle for researcher presence and authenticity in the study (Starratt, 2004). The researcher made the commitment to know the depth of participant experiences and regarded them as partners in the study. The rapport she built began well before the actual interviews (Booth and Booth, 1994). The researcher felt that she could best afford participants protection, respect and comfort by taking the time to ground them in all facets of the study as she endeavored to uncover solid data.

**Vulnerable populations.**

The subjects of this study are not a vulnerable population (Cresswell, 2013). The participants were secondary educators serving in urban districts. The process of research and its implications were addressed as well as questions they had about their participation. Therefore, participants entered the study equitably in a assured frame of mind.

The researcher also took measures to protect the subjects by protecting the atmosphere in which they agreed to tell their story. The researcher felt it was important for participants to feel confident and comfortable with any dynamic that changed or introduced something new during the study. A change in the line of questioning or a shift in the mood was done with a level of
sensitivity to the participants. In this way, the rich and thick descriptions flowed from the stories my participants shared (Geertz, 1973; Johnson and Onwuegbuzie, 2004). To support the idea of partnership in constructing new knowledge, the researcher secured clarity and preciseness in a manner that respected the participants throughout all stages of the study (Cresswell, 2013).

Participants

This study was conducted through purposeful sampling by recruiting educators who had formal and informal experiences exploring the Science Framework (Cresswell, 2013). Within the population, homogeneity existed in the criterion that these were educators with formal or informal training in the Science Framework. There were heterogeneous ages between thirty-five and seventy and across the areas of science domain teaching. The years of service ranged from three to twenty; grade levels were nine to twelve. Gender was heterogeneous with one male and four females participating. The sample size was five secondary urban educators.

Recruitment and Access

Educators were approached through social recruitment and personal contacts. Access steps included offering a clear message of what was to be explored. It was explicitly stated that the study was unrelated in any way to anything external to their participation in the study.

The researcher sent a letter explaining the purpose, methods and approximate time investment required for interviews. She also secured verbal consent via an unsigned letter of consent that was submitted to them and read aloud and audio recorded during the first interview session. Included in this letter was notification that participants reserved the right to withdraw from the study at any time, that their confidentiality would be preserved and disclosed the risks and benefits of the study (Cresswell, 2013). The researcher met with participants before the study in order to make them more comfortable during the interviews (Rubin and Rubin, 2012).
During the interview process, participants were asked to share and narrate their experiences, successes and vulnerabilities as they attempted to grow their conceptual understanding of science. The researcher injected her own experiences within this phenomenon to create the dialogue between participant interpretations of experiences and her own that is critical to the quality of interpretive phenomenology approach of this study (Larkin, 2013).

**Data**

**Data collection and management.**

Semi-structured interviews were the primary sources of data, and two rounds of interviews were conducted. The interviews were recorded via two electronic means (Rubin and Rubin, 2012). Interviews were in person and held at a mutually agreed upon location. Each interview session lasted between sixty to ninety minutes were participants were prompted by the use of a finite set of themes or questions which they previewed beforehand. Handwritten notes and analytical memos accompanied the digital recording of the interviews. The interviews were manually transcribed and stored digitally on computer hard drive at the residence of the researcher. Data was stored in a locked cabinet. Access to data was limited to the primary and student researchers and made available to participants.

**Data analysis.**

Analysis of the data in this study was conducted via coding strategies in a heuristic manner- that is approaching the research problem without a set framework for exploration (Saldana, 2013). First and second cycle coding was applied to participant responses (Saldana, 2013). Throughout the coding process data was comparatively analyzed at various moments in order for conceptual similarities, categories and patterns to emerge from the information gathered through participant responses (Boeije, 2002).
Initial review of data included a first reading of each of the transcribed interviews to understand the descriptions of each participant in their total response. This close reading of each text allowed the researcher to hear the essence of each response (Thomas, 2006). First cycle coding included rereading the responses and splitting the data (Saldana, 2013). Key words were isolated through the use of both *in-vivo* coding and description coding capturing general ideas as the researcher reduced the data (Saldana, 2013). The researcher used comparison of the initial coding to yield categories in the data gathered from the interview session (Boeije, 2002).

Through second cycle coding, a thematic framework emerged around larger categories (Thomas, 2006). Through the iterative process of comparing individual transcriptions with the meanings and significances emergent in the whole, thick rich descriptions of participant experiences emerged. The researcher interpreted these experiences through her own bias as she continued to move from theme to theme, and she identified the super-ordinate and subordinate themes emerging in this analysis (Thomas, 2006).

**Validity.**

There were three strategies used in this study to ensure validity and credibility of the research: triangulation of data, member checking and substantial description (Cresswell, 2013). Data was collected from various sources—anecdotes, interviews, and reflections. This triangulation of data validated the study by offering different entry points to participant perspectives and experiences of the phenomenon of increasing conceptual ability (Cresswell, 2013).

Secondly, member checking was utilized to ensure that what participants said in interviews was accurately captured during the coding processes (Cresswell, 2013). This ensured
that the interpretation of participant responses was aligned with the meaning and intent of what they recounted as experiences with the phenomenon of conceptual change.

Lastly substantial description that was rich in texture and substance allowed the researcher to delve deep in the experiences of participants and capture the essence of what they had experienced in this process of change (Cresswell, 2013; Maxwell, 1992). This gave the researcher the context in which she could immerse herself in participant interpretations of experiences of the phenomenon of conceptual growth (Maxwell, 1992).

In this study, researcher bias strengthened validity (Cresswell, 2013). Because the researcher taught a formal course structured around the Science Framework, she acknowledged that her own assumptions about conceptual understanding and science learning were injected into the study. Additionally, she clarified and situated her own perspective on conceptual change, since she made meaning of the experiences as she analyzed the data. This also secured the reliability of the data for this study.

**Limitations of the Study**

One limitation of this study was the small sample size. Findings were limited to the experiences of these five participants. However, in interpretive phenomenology, a small sample size maximizes the intimacy needed for double hermeneutics as a defining process of this methodological analysis.

Another limitation of this study was that findings emerged from experiences of educators at the secondary level. These participants work in poor urban districts where the population includes many English Language learners and those with Individual Education Plans. The experiences of suburban educators, those who serve in more affluent communities or in different educational settings than these participants may produce different or additional contributions to
the findings in this study. However, given the contextual nature of participant responses, it is safe to say that any other participant group would most likely produce findings that would be varied and unique to these participants of the study.

**Chapter Four: Findings and Analysis**

The purpose of this study had a dualistic nature. The study explored how educators understand their thinking, attitudes, values and beliefs toward the nature of science learning. The study further explored changes to these attitudes and beliefs and how these changes may influence pedagogical practice.

The participants in this study were urban secondary school educators. They shared a common background of working with marginalized students at an alternative high school. These participants share the collective experience of transforming a credit recovery program into a school that embraced competency-based instruction and models for teacher leadership. Both Cheryl and Sherry have served on a teacher leadership team and have taught courses in science. Sherry currently teaches social studies; Cheryl teaches math to freshmen. John teaches math and science in a secure setting for adjudicated high school youth. Christine currently serves as the science curriculum coach in her building and works with science teachers across grade levels. Sheila has experience teaching both math and science and is the coordinator for English Language Learning services in her building. She is currently teaching a course in biology.

Participants all had limited informal experiences with the Science Framework. However, in her capacity as curriculum coach, Christine has had more exposure to the document due to curriculum planning that is ongoing in her building. In addition to their informal experiences with the Science Framework, participants were introduced to its vision three years ago through a building-based professional development session. The session was limited to a brief survey of
the framework, and it was conducted by the then principal of the school who is now the researcher of this study.

The analysis of data from participant interviews yielded super-ordinate themes and subthemes in dimensions of beliefs, values, thoughts and attitudes toward science learning. These dimensions centered on the meaning and significance of research, inquiry, argument, models and misconceptions in science learning. The meaning that participants made of any changes to these beliefs, attitudes, values and thoughts was filtered through the significance to pedagogical practice vis a vis the vision outlined in the Science Framework.

There were four super-ordinate themes that emerged from participant interviews on their thoughts, beliefs, attitudes and values of the nature of science learning. The first of these themes was the conception that science learning is the action of inquiry. The emergent sub-themes were: the origin, purpose and power of questions, network of connections and contextualizing science learning. The second overarching theme was the conception that science learning is a visible process, initiated by both teacher and learner. The three sub-themes that emerged were: experiences, exploration and representations. The third super-ordinate theme was the conception that science learning values student voice. The emergent subthemes were: peer talk and misconceptions. The last super-ordinate theme was changing conceptions for science learning with subthemes: hot conceptual change and organizational claustrophobia.

The Action of Inquiry

The origin, purpose and power of questions.

At the outset of interviews, participants shared their thoughts and beliefs about their considerations of inquiry in science learning. All participants offered that there is action associated with inquiry. There were beliefs for students as researchers to “just really get into it
the process to understand concepts”. Cheryl and John referenced inquiry as inclusive of the relationship between research and the processes of the brain “research and inquiry are tied… you know talking to each other and inquiring, ‘what did you do? How did you get that to look like that?’ - it changes the neuropathy of the brain; it all interrelates; nothing exists in a vacuum.”

Participant beliefs of inquiry also revolved around the engagement of students in various activities. Sherry offered, “…it gets minds reeling with visuals and gives students more access to information that interests and intrigues them”. John likes to “involve them in higher order thinking and questions about things they don’t understand”. Christine “inductively leads them through investigations of science concepts”. For Sheila she takes “the original thoughts students have and ask them questions to spark their curiosity”. For all participants, their responses revealed beliefs and thoughts that inquiry is both questions and the process by which you go about looking into these questions.

There was considerable convergence among participant thought around the idea that questions drive science learning. Participants all saw questions as a means to find answers during research, argument, constructing and using models, all as a part of inquiry. For all participants, questions were tied to hypotheses that they agreed should be student generated.

Interesting enough, however, it became evident that their beliefs and thoughts toward the origin, power and purpose of questions diverged as they spoke about science learning. One participant saw the origin of questions as seated in the mind of the learner. John predominantly felt that “listening to questions that come from students helps you see how students process information in their own way” and preserves inquiry as a learner initiated activity. His conception is that questions are learner-based and emanate from human desire to know about the universe and the place of humans in it.
...I would want to learn about how I could come up with answers to phenomenon in science - things that are unanswered presently, ...and as a learner, I would want to know how what I’m learning affects my life and ... the world, the universe...and where I fit into it...or understand it better.

In contrast, the other four participants often saw questions as powerful teacher tools to guide students, assess learning and ignite curiosity. Although John shares in the idea that questions initiated by the teacher engage students, he didn’t voice a teacher dominated perception of questions in science learning that appeared in other participant responses.

Cheryl, at first, saw questions just as means of assessing what students know about a concept “Questioning to me was, you ask a question- you get an answer.” Her conception shifted a bit after considering the discussion in the Science Framework of questions as having different purposes “… now I’m looking at it as a way to get a clue; and the question can come from me or anyone in the class to kind of chip away at the whole mystery of the concept. You get more clues with the broader based questions.”

This adjustment in her conception of what a question’s purpose can be made a significant impact on the way she now looks at the learning process, “As part of the learning process, rather than teach the concept up front, you start with something general and you say [to students] that through the questioning process, we are going to decide if we can figure out the answer.” What this meant to her was that now she learned to incorporate the opportunity to teach students the types of questions to ask in her class routines

I never really thought through the types of questions you ask. We’re trained as teachers to ask questions, but never really thinking, ‘what type of question am I asking’? And that’s what definitely opened my eyes as a teacher ... in science, and also how to teach my
students how to ask those questions and dialogue, because dialogue is critical; kids learn by talking to each other.

Sheila’s thoughts were similar, but for her, questions are tied to building students’ wonderment of science; the teacher’s role is, in part, to spark kids’ curiosity and provoke questions “…to develop a sense of curiosity about science…and also for the breadth of science; science is not just space or molecules, you know, there’s so much more”. She believes students have a natural curiosity that needs to be ignited in the classroom. “When kids are curious, they will ask questions- and they do it on their own”. Commenting further about sparking curiosity, Sheila stated, “…you know you’ve got them when they’re raising their hands saying- tell me about that- what about this-what about that?”

Her thoughts and conception of questions as conduits to spark curiosity shifted a bit as she experienced the power of questions that originate with the student. The experience occurred during a health class where clips of a movie were shown. Sheila initially believed the students would rebuff the clips, because they lacked all the bells and whistles of today’s film. Conversely, the students were taken by the images and social themes. It was the power of students’ deep questions around the connections between the science of how AIDS is transmitted and the social issues of discrimination that took Sheila by surprise

…the whole trial thing- that sparked incredible questions and I thought- Wow, how wrong I was; I was totally off base; the lawyer getting into his personal life… saying he had reckless behavior; and I think the science part…a woman who got aids through a blood transfusion …they [students] were all asking about how it is transmitted and that grabbed them, and they remembered that…and they were all asking about it. I wanted to fall on the floor! I was shocked at myself- you could have heard a pin drop.
For Sheila, an immediate spark, something as small as a picture ignites questions from students- “…cause they see it as wow! They need to ask a question; they’re not going to let it go with just that picture- they want to know, how the heck did that happen?- oh the questions!, but in that class- they were asking the best questions.” Although it was an eye opener to see deep questions coming from students’ curiosity, Sheila is consistent in her thoughts on what needs to be present for science learning to occur. “I think it’s important in the classroom to provide them [students] with all kinds of stimuli… whatever it is that will help a student become curious about science”. For her, that students could generate such deep questions endorsed the value she ascribes to science learning- “it’s a high value- the world is changing quickly.”

Christine was passionate in her description of the question why in her role as curriculum coach and classroom teacher. She speaks of the power of the question why as a model in teaching her sixth graders the purpose and value of research data

…this kid, oh my god…the stacks and stacks of papers [he printed] and I said, what are you going to do with all that, and he said, ‘I don’t know.’…I said to him, ‘let’s sit down’ and…we narrowed it [his topic] down…we found three things…I made t-charts with him…’find three quotes about it… I want you to answer the question’…he hated doing the t-charts you know why? Because he had to take the time to think…and tell me why he pulled those quotes [from his research] and wrote them on the t-chart.

The power of questions had an impact for Sherry as she considered their relationship to demonstration as a vehicle for inquiry. Sherry values the use of visuals especially to capture the attention of students that are hard to engage. She saw her conception of the use of visuals shift a bit after considering the impact of a teacher’s use of demonstration in the book, Ready, Set, Science!
Faulkner had an amazing way of capturing kids’ attention…with the bottles or glasses and lowering them in the water…these kids were absolutely [engaged]…I saw them even take part in the dialogue that preceded her demonstration…it was questions- they all had questions; they all had theories, before she took that demonstration to the next level…she reeled them back in and dug deeper and deeper…

This shift in conception of the power of questions was significant for Sherry as it resonated with her reflections on her own learning as a child and her pedagogical belief that visuals help students learn complex concepts

…it’s most kids, even if they are auditory learners, or reading to them- they can’t capture the true essence of [a concept] or form questions…without having some visual recognition…to be able to envision it in your head… I took a step back and said wow, if I was in a class and had actually seen this demonstration in action- I would be loaded with questions… there was a lot of student to student dialogue…because it just piqued their interest!

Network of connections.

Participants share the conception that inquiry is inclusive of a multi-leveled network of connections. Participant responses pointed to the thought and belief that students that actively make connections on many levels work towards understanding concepts and phenomena of science. The network of linkages participants identify as part of science learning includes the general connection between science classroom learning and the real world, the specific connection between concepts, visual representations and hands-on activities, personal connections between science learning and student ownership of this learning, the connection of
application to concept knowledge, pedagogical connections between various learning activities and connections between the abstract and physical science. Christine offered,

I think the nature of science learning is through real-life experiences and connections…so they [students] can physically see or handle things so they can connect with it especially with an abstract concept…the vocabulary may be really hard, so they need that connection especially with an ELL student.

Participant thoughts additionally included the connection between science classroom learning and the real world. Christine tries to “make a connection somehow to the world- to something to get them excited …and they can understand the world and how it works”. Sheila’s thoughts also include connections to the outside world, “I think that students should not be learning in a vacuum…they need to go out and see things…they need to broaden their horizons and appreciate what’s happening on the outside…”

Sherry and Sheila shared personal reflections on the pedagogy used in their own science learning where concepts were connected to visuals and hands-on activities. Sherry recalled the relationship of visuals to other learning, “I went to a really good public school…we were provided with a variety of visuals …I think it’s a great way to teach science…the foundation, the note taking, the visuals, the hands-on and the creating…”

Sheila shared a memory about a hands-on ninth grade science class where she went out to a stream to gather water samples to view under a microscope “…we’d go out and get water, and we actually did it…that left an impression in my mind. That was something I enjoyed and I remembered it!”

Christine, too, offered a personal reflection in consideration of the value of connections in science learning. Her own daughter’s language disability influenced her attitude toward
making science learning visible. An example is the value she places on the use of concept maps as a means for students to make visual connections between the science concept and vocabulary, higher order thinking and relationships to other ideas. For students with language disabilities, “it provides a concrete connection to understanding the dimensions of the concept itself”.

Participants also made connections between science learning and student ownership of their learning. Whether science learning is teacher actuated or student initiated, all participants offered that students must take ownership of their own learning for both understanding and application of science concepts. Sheila tied science learning and questions to the social applications students could make in their world

… in this society…when you think about the technology…with terrorism…and the things kids face today…it’s important that kids understand…biological terrorism- learn about them so they [students] are not afraid of them- that they can understand …connections

Sherry also shared the same thoughts about the connection between the student and their own learning for independence, a connection Christine feels strengthens student understanding

I think that if a student takes ownership of their own learning, they are able to think on their own; and by a teacher questioning them, they’ll understand it more… if they take ownership [they] can teach each other, cause when you teach it that’s when you learn the best.

All participants shared the belief that connections matter in science learning –science concepts and dimensions of science learning do not exist in a vacuum. Cheryl’s thoughts underscored this shared meaning of connections “The nature of science learning means that “students not only understand a concept, but the underlying principles of the concept; they need to know how it is applied and connected and how it relates.”
The meaning of connections includes purposes for science learning that affect human understanding of science as a whole. John adds, “I think that the nature of human beings is to try to figure out the why of everything…science is about where we are and why we’re alive … I would try to instill in the students the complexity of it [science] and how we can stay alive.”

**Contextualizing science learning.**

Participants converged in their thoughts and beliefs that science learning occurs in the contexts of students’ lives both in and out of the classroom. Contexts such as family, culture, prior schooling and the notions of science students possess early on, all color the learning. Their collective conception was that there is a necessity for science learning to meet the needs of the students where they are at. As John said, “…the students are so different; they come from different cultures and different backgrounds that they have different ways of thinking about things.

Cheryl described what this meant for her personally as she reflected on the discussion of culture she read about in the Science Framework and what it meant for her as a teacher,

There was an A-ha moment. When they talk about the culture of the individual, there are a couple of examples of how certain cultures learn differently. For example they use the Eskimo culture where they learn by seeing- not a lot of dialogue. For a student in that culture coming into a classroom where they want them to dialogue- they’re like I can’t do that; but you then talk about [our students from Latin American] countries where they are yelling at each other, and it sounds like utter chaos; but if you really listen, there’s a dialogue happening—but it’s done through this different approach. And I think that was an A-ha moment for me; we look at a class and say we want you to talk, but you have to fit this mold. If you look at this group of kids maybe the dialogue isn’t so much verbal as it
is through the modeling, the writing and different things they’re doing- a combination of words and actions…rather than saying it they’ll say look this is how you do it- watch what I do with my hands…

The researcher asked her to target the element of her own experience in the A-ha moment she described. She reflected on her relationship with her students and considered how she perceived learning would take place

Training my ear and my eyes to recognize by looking at my students and knowing their backgrounds- what might be the best approach… I’m going to get more learning with a group of kids with the same synergy than blend kids out of their comfort zone. There’s a time and place for that…you can always come together later and share what you’ve learned…. 

The researcher pressed again for her to isolate the nuances of her conception of this experience. To say that the A-ha moment was that kids have different cultures was not true; she already knew that. The researcher asked her to consider what the concept was that may have changed. She answered, “To utilize that knowledge in a different way. You can use this cultural difference to benefit them [students] in the classroom to grow- by speaking to the individual and the individual needs- as a group of individual needs.”

Participants also were aware of their own personal contexts they bring to learning. The professional backgrounds, particular educator training, cultures, philosophies and their own experiences as students, they agreed, all influence how science learning is situated in their classrooms. However, while sharing the significance of the teacher student contexts for science learning, participants offered a sub-conscious dichotomy in their responses. The dichotomy was around the context in which participants conceptualized science learning itself. John situated
science learning in the context of the learner’s pursuit of the why; Cheryl seated science learning in the context of the teacher-learner relationship.

These contextualized notions of science learning brought to light participant conceptions of with whom the process of science learning originates- with the learner or with the teacher. For participants, the significance of context in science learning transcended the socio-cultural dimensions in the classroom and took root in their pedagogical philosophies. John’s conception is that science learning is purely a learner initiated activity. Cheryl’s conception is that learning is a teacher prompted activity. The others flux between the two, conceiving learning as a quasi-guided process with Sherry and Christine in closer proximity to Cheryl and Sheila in closest proximity to John.

Of all the participants, Cheryl’s responses are consistent with her belief that science learning is a teacher activated exploration or experience that is brought to students to foster interest or joy of science. She used synonyms for the verb to present many times in responses …the material I’m presenting…I want to make it so that every student finds…how I approach the different topics…you have to do some direct instruction, you have to give them the basis…my job is to find the right way to present it or give them the material they need or opportunity for them to learn in their way.

In contrast, John consistently sits at the other end of the spectrum of belief as he conceives science learning as an inquirer initiated activity- the learner as the prime thinker. Learning is an active process initiated by the learner to “…figure out the why of everything.”

Inevitably, John responds from the viewpoint of a learner. He discusses the science learner in a quasi idealized sense but balanced with the real world applications of understanding the unknown. John’s attitude conveys the importance he places on understanding science for
itself, “I think it would be important for them to understand that what they are learning is part of life; [that] would make understanding more meaningful to them…”

Teacher presence figures largely in Cheryl’s psyche— for her, science learning is teacher activated “…how do I reach that student for the purpose of presenting opportunities for students to learn in their way?” The other three participants share Cheryl’s conception and respond to questions about their thought and beliefs of science learning along a spectrum of teacher driven ideas; Sherry conceives learning as encouraging students to the higher Bloom’s activity of creating, covering the essentials, using various models and representations. She outlined the teacher activated process for learning

…first, the mini lecture to lay the foundation [rigor] and build note-taking skills, then utilize visuals to get kids excited about exploring, next engage them in hands-on and use technology to build kids creativity- in that order.

For Christine, teacher questioning plays a major role in the multisensory approach she envisions is science learning; it develops student habits to justify evidence

…by doing, seeing, thinking, I can have them write about what they saw; and I could ask questions to make them think deeper and about things they never thought about; then they could express that in writing…I know the big thing is find the evidence…I don’t want just that- I want to know why you thought that evidence- why you put that there.

Sheila, too, believes that science learning is teacher initiated stating that “it is important in the classroom to provide them with all kinds of stimuli”. She reflects on her own science learning in seventh grade where the teacher involved the students in hands-on activities; she also recounted how meaningful the teacher’s presentation of Big Bang was for her
…she also did a lot about the Big-Bang theory; she did all that stuff- I got a hundred on the test – I was the only one, but I never heard of that stuff before; but she really presented in such a way that I remembered it- and that was in seventh grade!

In contrast, John’s conception of science learning is divergent from the other participants. His belief around science learning was expressed with the use of the word learn several times; he includes himself as a learner

Well, I believe that everyone is a learner; and we can learn- and everyone is a teacher, and everyone’s a learner… so I can teach students what I know about science, and I can learn things from them…so that’s where it’s very interesting-my belief is that everyone can learn something new every day, and everyone should.

Science is a process initiated by the learner’s desire to know why- “all the questions… that is what science is all about…and I think it is the nature of human beings to try to figure out the why of everything”. Unlike the four other participants who contextualize learning in the relationship of teacher and student, John conceptualizes science learning in the context of the learner pursuing the why.

Science as a Visible Process

Experiences.

Participants considered their attitudes toward science learning and offered many references to experiences and exploration. The attitudes converged on the fact that experiences are opportunities to learn and explore, analyze data and make predictions and to take part in guided demonstrations and hands-on activities. Resoundingly participants conveyed the attitude that experiences are elements of inquiry as a process within the learning of science. Experiences are significant to participants as they offer students opportunities to think, to tell why, to look
outside the box, to look at the topic from a different perspective, and to link ideas to model making.

While these experiences figured largely in the beliefs and attitudes of participants, their views diverged when it came to identifying how the nature of these experiences materializes for science learning. The subtlety lies in participant perceptions of the nature of experiences themselves. On one end is the attitude that learning happens through real-life experiences brought to students through a hands-on approach; on the other is the attitude that learning is an experience that yields knowledge. Cheryl’s attitude leans toward seeing science experiences more in a utilitarian way- getting questions answered by relating experiences to learning.

I think what it is- is you have to look at the real world; everything focuses on the real world around us. Everyone walks into a classroom with experiences they’ve had or can have or will have I think if you want a student to truly understand what they’re doing-link it to something they have as a frame of reference.

For John, it’s not so much bringing experiences to science learning as it is students exploring their experiences with science learning. John had a philosophical tone regarding the meaning of experiencing science and the unknown

…just to learn about science- my God -it’s learning about the way you live, earth, life-it’s about everything!… the universe and where I fit into it, and what I take away!”

The knowledge that comes from experiencing science phenomenon serves the purpose of answering the questions of the unknown “…or [to] understand better.

Experiencing science learning for all participants, including John, was viewed as a process where meaning is made if students can put their hands on something and create something and build it with their own hands. They also were unanimous in finding meaning in
the application of science knowledge. John offered, “the purpose of learning science is to find answers…studies are done on Alzheimer’s, heart disease, cancer and why do we study these things?…to find cures for things to help people…”

For Christine and John, they considered the Science Framework’s vision for connecting science and engineering. It broadened their conception that science learning now should fully embrace engineering as well as science experiences. John shared the value of this wider conception’s connection to his idea of experiencing science learning

…build a model and then construct it… for example there’s a field near a pond…and they fertilize it and the runoff of fertilizer into the pond… everything dies…it’s a dead pond. The scientists ask, ‘how come the pond died?’… now the engineers come in and say…we’ve got to fix it…so that’s what I think the new shift in science is- is to make the scientists connect more…there’s a connection between engineering and biology.

Personal experiences students bring to learning are acknowledged by all participants; however, Sheila was moved by the significance these experiences had on her own conception about the students in front of her. She came away with a new perspective of how powerful those personal experiences can be for the ways in which students make connections to and understand science ideas. During a health class, a student made a remark about people addicted to heroin

…he said something that really stuck in my head- he said they’re not human- he said they’re cutters- and he was saying it in his own little way- well- heroin addicts- they’re not human- like they’ve transformed into-… they’re not human any more- they steal, they do all these things to get their drugs- they’re cutters; isn’t that a powerful thing for a little kid to say? It hit me like a ton of bricks- and he said it without missing a beat.

Sheila reflected on the significance of his remark to his science learning,
…well, to me it says that this kid is pretty sharp; and I think he understands; he understands that deep down he probably wouldn’t do heroin; that he knows science and what it does to destroy a body- a person’s body- their mind, and I think not only from seeing it- but from outside the classroom- he experienced it; and when you’re talking about it, he knows…why they are getting a fix- because it’s an opiate, because it’s this and that, so he gets the science side of it, and he has the experience.

**Exploring the joy of science.**

Participants spoke a great deal about exploration as a valuable experiential process. Their attitudes toward science learning conveyed an earnest desire for their students to see the joy and wonderment of science. Sherry acknowledged the power exploring science has that allows students to “make predictions that are not so far- fetched”. John mused that exploring allows students to “witness how extremely exciting it is that one cell differentiates into many… how the complexities and simplicities of science are unbelievably amazing and there are things we don’t know.” Cheryl shared that her appreciation of the joy that she has found in her own science learning spurs her to “impart something that brings interest and joy to students… it’s the excitement of finding out… what you didn’t know or never really looked at… it’s how y connects to z.” She shared the joy she feels when her students are able to link something they understand to the concept they are exploring.

For participants, the meaning of exploring science was rooted in their attitude that everything in science can be questioned, and they wanted to tap into student capacities. Sheila acknowledged that because “science is ever changing, it should be on par in importance with math and English in schools”. Participants shared that science is taken for granted, and more poignantly, for John, the significance was an immediate tie to the future
…if the students that are in school today don’t embrace science, who are going to be the scientists of the future? There’s going to be a major shortage of scientists. Who’s going to be in biotech and who’s going to solve the cure for cancer…who’s going to be taking up these science experiments and research when these people get old and they’re gone…there’s jobs to be filled and there won’t be enough people to fill them; to me that’s scary…people should know about themselves and the universe…

There are societal implications of science that students need to understand. The example of biochemical weapons or bioterrorism- topics students should explore to temper fear through understanding. John remained committed to the philosophical significance of exploring science for its own sake as a continuing process in finding the purpose and nature of man- to understand human’s place in the universe, “I love science… there is so much to learn… and we may never understand …”

Although the descriptions and the meaning of exploring science were focused on generating enthusiasm for student pursuit of science, most participants offered little regarding the pursuit of the nature of science itself. Sherry acknowledged that nature of science should be taught for itself, but confessed that she didn’t think of science in those terms. To her, pure science was more the understanding of the scientific method and applications of science knowledge.

Christine referenced theories in science learning- having students come to see different theories and ways of thinking among their peers. She spoke mostly of theories, not in terms of their connection to laws or truths, but to the connections students make when they understand a scientific concept or develop and pursue their own hypotheses in science classes.
Cheryl mentioned she had some experience with meta-physical ideas of science while Sheila offered meta-physics should be included in a syllabus of a course on nature of science. Participants hinted at the nature of science being tentative via their reference that science was ever-changing. In their responses for argument, research or inquiry, however, there was not mention of the empirical nature of science itself.

Actually, for all participants, the conception that nature of science is ontologically distinct from its epistemological axiological and pedagogical considerations was absent in their responses. Nature of Science did not manifest itself in any great detail among any participant response or in any reference in their conception of science learning.

**Representations.**

One of the most common themes around which participant responses converged was that of the necessity of models and other visual representations in science learning. Representations of many types were offered by participants- concept maps, data tables, problems as models, videos, displays, step-by-step demonstrations, physical measurements, pictures. It was clear that for all participants, models and representations were a given component of science learning.

The significances of these representations to learning were varied- to help students get a picture of a concept- to visualize it and remember it; to show how everything is connected; to retain more; to internalize learning; to bring home the message needed by visual learners. While these representations held various meaning to participants, one common idea that was shared is that models get kids thinking and thinking gets kids making models.

Participants unanimously saw models and representations as active pieces of science learning. For John, “Models constructed by students help demonstrate what they learned”. Data charts, T- charts, modeling a problem and displays all go hand in hand with reading, writing and
talking about science. For Christine, they “get students thinking and questioning; they help students build on what others have done in the past and make it better”. Cheryl offers,

There are actual models you can do in science particularly for slope. We use textbooks and rulers and adjust the height of the textbooks to determine rise, or adjust the distance of the ruler from a spot on a piece of paper to adjust the run to get the kids thinking about the fact that if you change one parameter, what’s going to happen to the other?...everything is interdependent…you’re showing them by changing a parameter …that can change the whole outcome.

Sherry ties models with students’ engagement with aesthetics. She also feels that building models is more a lesson in self learning and reflection

…having students build a model- this is where the earth lies….this is the sun…I think you could have them build their model before you say anything…we all know that scientist, as brilliant as they are, fail or have a hypothesis or go through a process in order not to only learn, but I’ve said it’s the things that I get wrong that I never forget once I learned the right thing…those are the things that stay with me…seeing them it made me reflect that it was the things I really didn’t understand that I probed into more…you not only need to reflect in order to move forward, but reflecting on what’s wrong usually promotes other questions…it may lead to something more far reaching in terms of learning on your won- self learning- I think it promotes self-learning.

Christine shared her own personal bias for the use of models. She also tied models to experiences students can have with solving problems

I’m a multi-sensory learner and I wonder if I teach that way on purpose…you need visuals…we are building on what others have done in the past…look at a model and
come up with some ideas… trying to figure out genetics- that’s a problem-solving model. RNA synthesis that’s a problem- you have to match up the anti-codons… that’s a model, but there’s so much more to it, because they [students] have to get the right codon to match the right way or something is going to be wrong… so you can use it that way.

Cheryl had adjusted her conceptions of models in consideration of audience after looking at some of the discussion in the Science Framework.

“Students need to know that there might be things that just don’t fit if they look at them independently, but through research and modeling…they can blend concepts… [but], I think it changed my views a bit as to how you can model- does it have to be through someone touching it, or can it be someone modeling it through an explanation? I think that’s where it change for me- depending on the individual- the word model- the words as a modeling tool for one person may be more effective as the physical item…so I think with modeling, you need to look at your audience to see what will work best for each individual- it [modeling] is extremely important, regardless.

The Value of Student Voice

In addition to responses of thoughts, beliefs and attitudes toward science learning, participants answered questions about their axiological considerations of the nature of science learning. Emergent were two sub-themes: the value of peer talk in argument and research and the value of multiple perspectives for the learning of science.

Peer talk.

All participants offered an appreciation for peer conversation, sharing and exchanges in science learning. Participants unanimously considered research and argument as peer-based
activities. They placed high value on students talking with one another about a topic and minimizing teacher talk. John offers,

*I’ve seen them [other teachers] talk over the kids heads and they talk too much…they should get kids talking more…you have to know where they [students] are at first, and I think that’s a challenge because you don’t know what’s in their head…what they know…you have to find out where they are at…put something on the board and see if they respond…I’m open to anything they say and I’m appreciative when they come out with things I don’t know… I welcome that and I say it out loud- you know, I can learn from that and thank you that was really helpful…*

One of the dynamics participants value is when students engage themselves in conversations that pull in classroom concepts and student opinion. Participants see argument as a conduit to learning

*To me it’s [argument] when students actually start to debate among themselves…you actually have a conversation taking place where everybody’s ideas are coming out…it’s a great learning tool; I’ve heard students say, ‘Oh I didn’t think of it that way- I didn’t realize you could do it that way- so to me it’s a critical piece of learning*

There was an interesting response about student talk from both John and Sherry. They perceived argument, in part, as an opportunity to explore students’ ethics, morality and emotions. They described the meaning ethics, emotions and morals had in science learning. Their responses pointed to the consideration of what research calls hot conceptual change. Sherry offered her thoughts from a cross-curricular history class with science learning:

*Well, I think the atom bomb is a perfect example…we have this very powerful thing that we used to end the war…should we can we get into an ethics/ morality sort of thing I don’t*
know; I guess I’m going to say yes- you bring in the philosophical piece and ask the students…should we keep it to ourselves- what is our responsibility- there’s so much you can do with science and I would say a lot of students are science phobic…and I think a way to capture those students is to present them with an something they can argue or discuss.

John considered student voice and expression in science writing and he pondered the place of emotions in science learning. A student had shared with John a book of poems he had written. John thought about the significance of embracing this piece of student art in his science class

…Because he can express himself in writing. Written expression- you should be able to express yourself in science by writing; you should be able to express your thoughts and the more practice you have in writing poetry, the better you put words together, and - I don’t know if emotions come to play in science…

Pushed to decide, do they or don’t they, John thought aloud, “they didn’t…should emotions be part of it? I don’t know; I don’t think they play a part in science – when you think of science- emotions I don’t know.” This was a critical piece for John, as it prompted a soft conceptual shift in his thinking about student emotion and its place in science learning

Mmm, you know, I saw in that video yesterday…I showed them the development of the fetus inside the mother, and there wasn’t a peep in the room, because I told them, this is how you began your life. And I said some day you will be having children and it will be happening and it will be your children developing inside your mate. And I think that’s an emotional thing. But they paid attention, because I think that had an emotional connection to –that’s…it’s their brother, mother, father- it’s how everyone is born…look at the miracle of it…
John considered further the direct question, Do you think this emotional attachment these kids experienced played a part in what the outcome of learning will be for them in two, three or six months with you? And he answered, “Yes, because… all the things in the world have some connection to all of us.” He further offered more to this evolving conception that learning science is not exclusive of emotion,

I could show them a flower, a rose, and say, do you think that’s beautiful- it’s a living thing. There’s beauty in science. So that’s emotional. That’s not a factual thing; what I think is beautiful, may not be to someone else. So that’s an emotional thing…

Student talk manifested itself through research for most participants. Sheila valued student voice that came from “peers interviewing one another as a substitute for internet research”. Cheryl found value in student voice from in all manner of research that had students thinking independently about theories and sharing ideas about those theories

…give them a topic, have them come to the learning on their own…it makes them start to think…and form their own theories rather than me telling them what to think; so it builds that thought process and I think research is a very key part of that…it doesn’t have to be a research project, it could be research though and experiment or hands on or connection with a model; inquiry you know- talking to each other and inquiring…

During the second interview session, Cheryl too, had a slight shift in conception about peer talk after considering some of the case studies that exemplify the Science Framework’s vision for student talk. Her shift was not so much indicative of implications of student voice as it was of implications on her thinking that peer talk does not always have to be teacher initiated

I might look differently at my approaches now- meaning we are so caught up in we’ve got to give the information, give the information; now I take that step back and figure out
how to let the kids get to that information on their own…you have to abandon the traditional way…I think the thought process now is …let students work through it…

Peer talk is a very critical and valuable piece for Christine. Her motto is doing, seeing, thinking. She described her consistent expectation that students explain why helps build student confidence through justification of evidence. It also is tied to student accountability for learning. She described the significance of her students’ routine to justify and explain …cause they can use that anywhere…if they know how to break down data and pull out what’s important and the evidence- that helps them explain why…and it expands in terms of writing…they have to do the thinking…by doing an experiment and seeing it, they have to really think about it- so they’re reflecting on what they learned… it’s that kind of accountable talk- do you agree/disagree what else can you say? …and that really makes them feel good about themselves- they feel important… when they justify and explain…

Christine spoke more about the significance that peer talk had in her role working with other teachers as curriculum coach for her school. Her response shed further light on why doing, seeing, thinking was connected to the value of student talk to fulfill the ‘accountable talk requirement’ across subject areas in her particular school …cross curricular- the integrated studies; I mean they [administrators] are holding them [teachers and students] to ‘accountable talk’ for reading and writing; and now we can do accountable talk for science. And that’s what I would tell them; some of them seem very afraid to teach science, but you are already doing it in another discipline. But now you can integrate it; and you know what- they [students] will not only remember the writing, they will remember the science… you know how to do ‘accountable talk’ with dialogue-it’s the same thing and that’s what I try to tell them…
Participants shared the value of student talk for those who were English Language Learners. Shelia shared a lighthearted anecdote as an example

…in a biology class one of my students was able to repeat the four phases of mitosis; it was obvious the student was quite satisfied with himself- especially when he was able to point out to me that I was wrong about telophase and metaphase on an assignment. He was correct! He was also able to tell me where my thinking was incorrect. I believe his moment was a boost in confidence that he could do it- he could understand something complex [in English] even though his proficiency level was low.

**Misconceptions.**

One of the major conduits all participants believe give voice to student conceptions of science is the discussion of misconceptions. Participants offered a variety of responses. Cheryl said: “…a possibly misunderstood topic or preconceived notions that may not be correct; you think something is one way and when you look at the reality, you see it’s another.” Christine defined them as “a misunderstanding or a lack of knowledge or a lack of understanding.” John’s answer was unique and mirrored closely the Science Framework, “Misconceptions are possible truths.” Christine saw them as “myths passed down that are untrue; isolated experiences; you know something, but don’t know the full story- you learn something and it’s not right.”

Possible truth- John’s response flowed consistently from his student-centered perspective and echoed the vision of the Science Framework

… the first thing that came to my mind is- how do you know something is a misconception? How would you label something a misconception? It might be a misconception to one person- and someone else may say may understand- it’s not a misconception……because people have ideas of how things work and how things have
always worked and that may not necessarily be true, Because they are looking at it from one point of view…

Cheryl’s attitude mirrors the idea, as well, that misconceptions are alternate conceptions—“…they may have taken a diversion…they may have just listened with their limited knowledge formed an opinion, but by giving them a chance to take what they know and not necessarily fix it, but change the way they look at it.” Limited knowledge is something that Christine targeted as well,

They [students] only believe what they see on TV- kind of like myths being passed down that aren’t true- that’s their experience with science; or maybe they did a little experiment, but they never continued on a path to bring that experience up to the next level- it’s isolated, there’s no connection to anything else- it’s an isolated experience.

Participants saw opportunity in misconceptions- especially for connecting the value of student voice to evidence, inquiry, argument and models. Participant responses converged in their ideas that the role of misconceptions is a “great way to learn science”- “they make students question one another”; “they encourages expression via model making and the exchange of diverse perspectives”; “…you can learn from them and persevere- trial and error- persevere with an new hypothesis if you’re not right- just keep going”; “[encourage students to] consider contributions from others…data from other experiments”; “…they generates student engagement in discussion of evidence-. John gives voice to one student who argued evidence in a case for maggots spontaneously appearing

One student said to me, ‘if you pour Diet Coke on a piece of meat, maggots will appear’. I said… ‘Where do maggots come from’- ‘fly eggs’ he said. ‘So you can’t just pour Diet Coke on a piece of meat and have maggots appear suddenly’…and he’s telling me ‘no no
I seen it on a video and you can actually see the maggots appear’…and he’s adamant about it. So I said, ‘let’s pull this up on the computer this- let’s find out…’ he’s saying it’s true and I’m not saying it’s not, but that I believe differently… Let’s find out about it rather than just dismiss it saying that’s a misconception…I wouldn’t do that to a student; I wouldn’t shut him down no, no- ‘well let’s research this together…show the whole class…what do they think about it?’… I open it [video] up- ‘what do you guys think did maggots appear? Someone has a stick and they are touching another stick and it’s coming up with a little goopy thing and they say it’s moving. Is that a maggot…it may look like that but you have to understand that life comes from living things- there’s no spontaneous generation’- and we talked, and it opened up a lot of different things…conversations and controversies.

In the discussion, John demonstrates a shared attitude of all participants -to preserve the integrity of the student’s prior knowledge. Cheryl shared that prior student knowledge must be preserved for them to want to continue to learn and share ideas,

…and I think that by doing that- by taking the misconception- the prior learning rather than call it a misconception- call it prior learning…and these children take that as a foundation and use it as a springboard to move forward; don’t discount what they’ve done, don’t call it wrong- just show them where their knowledge was limited…

Participants value misconceptions for the dialogue they generate. John advocates, “…stir up controversy…throw out misconceptions- tell them [students] a blatant non-truth- and they’re going to sit there and take it in? No, they say it’s not true, and it opens up this dialogue; and, it’s fun to converse with them…”
Participants were asked the significance of misconceptions in science learning. The responses included “they get kids thinking deeper- asking questions”; students can “look outside the box and see things a different way”; “you have information and you can experience it differently”; “…reconcile two different results from experiments by talking about it”; “everyone’s ideas come out.”

For Christine, the meaning of misconceptions is that it allows students to dialogue about things that connect to science. Using her students’ misconception that an ant colony consisted of a single ant-hill led the class to a social connection about the value of working together. The dialogue was generated via a first grade picture book about ants with her third grade class. Tapping into their background knowledge and the interest, they came to a new conception in finding out about all the types of ants and work they do in the underground network of an ant colony. “And from that I said, ‘Ants are social, and they have to work together; and we are social; Why do we have to work together- to accomplish things. I brought up things in the world like building structures or…your family.”

Sherry’s response on the meaning of misconceptions in science learning brought the question of reflecting on science knowledge to challenge one’s thinking,

I think that sometimes students need to have that misconception in order to be interested in finding out whether or not their misconception is actual truth…maybe for them to delve into why it isn’t”… I think back…it was the things I didn’t really understand that I probed into more.

Changing Conceptions for Science Learning

Hot conceptual change.
One interesting offshoot of Sherry’s responses on the meaning and significance of misconceptions was present in all other participant responses— they all saw the value of misconceptions beyond their usefulness as cognitive teaching tools. Valuable connections to the meaning and significance of misconceptions were seen in other milieus beyond the cognitive. Participants spoke with feeling of many other changes that take place when misconceptions are considered in the learning process. For participants, misconceptions breed changes as part of the learning process; conceptual changes, for them, are crucial elements of science learning.

The meanings participants shared of experiences with conceptual change in and outside the classroom were personal and intimate change experiences. Their responses were rooted in the cultural, ethical, religious, emotional, attitudinal, and meta-cognitive natures of conceptual change; in short, participants affected, experienced or witness hot conceptual changes in science learning.

Sherry considered a comment used to make the point of conceptual change. “Miss, I used to think that stars were angels; now I know they’re gas and dust and light.” Sherry’s response touched on the cultural and ethical considerations in the process of changing conceptions in the science classroom,

…. what has really happened from a science perspective is this student now knows the makeup of a star. From an imaginative, creative or cultural perspective, where at a young age this child believed that –maybe had a fear of the dark or fear of something else- or abandonment- we all know that, depending on the student…if they believe that what was outlying was a guardian angel looking over and maybe protecting them, you’ve now taught them something, but now they are abandoning something just as important and you do run that risk…I’m not sure that we have the right to do that to young students. I
think we have a bigger responsibility to our students; if I just found out today that stars are not angels, I could process that, or handle that, or dismiss you altogether saying you’re full of ca ca, and I would still believe that. And I think in this day and age, what we have seen in classrooms, students, their history, their experiences, backgrounds and family lives or lack thereof …I’m not saying we don’t introduce, but we need to inform and educate on a realistic level; but I don’t know if we can, or have the right – or we actually think that we [teachers] are the people to- we are there to thought provoke not idea squash…you have to tread so carefully- if you had a child who had lost a [parent], you say your mom is watching over you- and who is going to take that away from a child?…we are not privy to all their backgrounds.

Cheryl mused about the significance of ‘finding out’ or changes in conceptions that students experience in science learning. A poignant piece of her personal response was the relationship teachers have with students when misconceptions arise. Cheryl not only alluded to the value of considering student voice, but how changes in science learning that connect to the religious, emotional and other hot conceptual changes affected her as a teacher of science,

…when children enter a classroom, they’ve already been learning science since birth; and we learn all through school; maybe we misunderstand when someone says something and that becomes our thought…by taking the kids misconception and having themselves look at it and evolve their thought process, kids can see how they learn and through that learning it cements it with the child…they’re not being told you’re wrong, their allowing their mind to process it- it becomes more of their own thought- so they’ve corrected their own misconception if you will… I was raised in a religious household where there is creation and we all believed that this is divine intervention …but I also had scientific
curiosity that led me down the evolutionary path; I heard my church say creation is it; I heard my teachers say evolution is it; but no one ever thought to take my misconceptions of how things worked and allow me to pull- use them as a springboard to meld the two things – or come to a deeper understanding of what was going on…I was always confused, because I have all this evidence here, and I have all the evidence in the bible that says this; but I could never get those gaps- it used to bug me; but what I learned was that you do not have to subscribe to just one train of thought, and it changed the way I felt about approaching two completely different subjects; it really,…allowed me to be more open-minded in teaching- I would say, let’s see this from a totally different perspective- there must be something I’m not seeing-how can these totally different things actually work together…I’m a puzzle person- that’s the scientist in me.

One interesting observation of participant responses on misconceptions and changing conceptions was the readiness and willingness for participants to identify with what their students experienced. They drew parallels between their students and themselves vis a vis the attitudinal changes that take place when misconceptions are part of science learning. Sheila likened herself to a student in a personal anecdote about a conceptual change in nutrition and weight loss. She ties the idea of student talk to her own experience with changes in conceptions about nutrients and proteins

… I went to that [nutrition center]; I have been struggling with my weight for some time. I’m eating basically the same things, but the weight is packing on…well, she was talking about when you don’t have enough muscle mass, you won’t burn fat efficiently…you step on this scale that reads your body mass..she was showing me the charts…that was an eye-opener…I didn’t think I could be that off…[my attitude was] thinking that eventually
I would be- that I could be the same as I was twenty years ago…that I really didn’t change physiologically- that at the core- I didn’t change- I can still do this, I can still do that, but the reality is, that’s not true. What I have been doing is—I have been reading a lot… my son’s personal trainer magazine, so in my mind I’m thinking maybe that would help me, but in my mind, I’m not convinced [about protein and whey]. I’ve heard it from the doctor- cut back on this… I went to weight watchers… and read about protein body-builders; My misconception is I can’t do it—it’s not going to happen for me; but when she showed me the data- the hard data…she explained about protein…and amino acids…and it reinforced what I had been reading…now I know why I can’t lose weight… I was gathering data. I heard about the chemistry…the heart-rate… information not from one magazine but from many magazines, now you hear it from a group……people have good results… that’s something that can change your conception. I’m thinking well, maybe I can do this--- and I think that when students that have misconceptions, …I think it’s a good eye-opener for a lot of kids… when they are presented with a topic…and they throw their ideas out … other students say you’re wrong and this is why I feel that way… and they state their case…they’re coming from two different experiences… the significance is that if you encourage students to talk something through and clarify it with fellow students- this may help dispel misconceptions.

Participants also identified and considered any conceptual changes they experienced after their informal experiences with the Science Framework. For Cheryl, the idea of learning progressions was a shift in thinking about science learning

I thought it was interesting that changing to [adopt] learning progressions is a result of disagreeing with the current way science is taught using standards with too many
disconnected topics. A better way is to start teaching -or rather -training students how to inquire about science topics by asking questions with no right or wrong answers and letting students come to some conclusions by themselves. Other students can agree or disagree but must be able to answer questions about their point of view….the new thinking is that beginning in the early grades, we begin to groom students for inquiry about science and to guide them in learning how to answer questions that lead to a deeper understanding…we need to capitalize on their prior knowledge and their already formed ‘theories’ to dispel misconceptions and reinforce what they know is true.

For Christine, it was a modification in conception about the idea that students as young as kindergarten can be engaged in inquiry. She sees they can use evidence as they share explanations with peers through argument and came to see the value of younger students’ alternative conceptions about science phenomena.

Another shift in conception that participants attribute to their experiences with the Science Framework is to look differently at the frames of reference from which students are coming to the learning first before taking the lead in teaching. Cheryl offers,

The question of ‘what did you think about it is something that I’m trying to really get into…have students do a brain dump around a word…or topic in science- just put a word up…in carousel style… a word association….take those associations and pull them into where you are going…again we all come in with stuff that we associate with those words…I think it’s something I took away from this…because it will be so much more effective and together we can work toward learning concepts.

Sherry took away the conception that meta-cognitive processes that help students see how their conceptions are changing are valuable in science learning,
I think that misconceptions- it would be so interesting and so much fun to pull out five- especially if I could demonstrate them- five science misconceptions throughout history and have students …say which one is the most interesting… it will show students well, so didn’t a lot of other people [have misconceptions]… we’re going to monitor how you come to a different- meta-cognitively-…I do see value in that.

She further considered the significance of doing that exercise,

It gives them [students] a feeling of- I accomplished this- god this was a misconception, because I have the proof here…they have to be able to recognize it and then they have to question it; then…say prove it…and I think that’s the teacher’s responsibility- to lead them in that direction.” The researcher verified that she thinks conceptual change should be explicitly taught- “I do… let them [students] higher order think…what we need to do is focus on the child instead of the curriculum.

**Organizational claustrophobia.**

One last theme was emergent from participant responses about the significance of changes in conceptions from experiences with the Science Framework. It was interesting how participants noted that other educators in their schools worked under misconceptions of science learning. Participants shared that, at times, their attitudes, beliefs and values for science learning that mirrored the Science Framework were at odds with those of supervisor, administrator, evaluator and other educator conceptions of science learning.

One of the most striking convergences was the use of emotionally charged words in participant descriptions. Changing conceptions for science teaching vis a vis the vision in the Science Framework had emotional overtones. Participants offered the emotions of nervousness, fear, frustration. They saw that conceptual change was not only cognitive, but affective as well.
Christine spoke about a teacher’s difficult change in conceptual attitude about the use of reading in science and the connection to evaluators.

…the light bulb that went on [for her] was the ease of teaching it and how excited the kids got using a first grade book…they [students] asked so many questions, and they were excited about it… [her class] is very structured- it’s ‘I do, we do, you do’ all the time; unfortunately, that’s how they [administrators] are making- almost manufactured- everyone has to fit in the same kind of bubble and that’s the way they teach all the time- ‘I do, we do, you do’… they are afraid to use it [inquiry science] because coming out of the colleges and coming into certain districts, they are told they have to teach a different way… when they come in …to be observed, there’s a checklist …they have to have certain things in place, and it’s unfortunate because it is making them nervous to do anything else…and they don’t want to move away from what they were told, because they are scared.

She further thought about how this affected science learning, “Actually, I think it’s hurting the education system, because it’s not letting them… it’s very frustrating for me, but it was exciting when she saw me do it [present a lesson]…they are so afraid that they are going to get scrutinized… I think it [the old conception of science learning] hinders it.”

Other participants spoke of the changes colleagues need to see in order for science learning to change. Christine focused especially on evaluators that lack exposure to the Science Frameworks vision, “…a lot of them have not been in the classroom that long; they only know the concepts, but I don’t think they experienced the concepts or teaching them; they know all the buzzwords, but they can’t- how would they know an effective way to do it, if they haven’t done it themselves?”
For Christine, evaluators and administrators who don’t share the Science Framework’s vision negatively impact the thinking of science in classrooms.

Creativity is gone cause the kids want to do so much- all they do is read and write all day- not so much the fun part- the thinking part- they even give them sentence starters- this is ridiculous they have four sentence starters…so they are only using those four sentences all the time- it’s limited…it [the Science Framework] is a guideline they are not telling you how to teach…and I think the evaluators need to be trained- they’re not, so it’s different.

She further voices what other participants feel, as they realize the attitudinal conceptual changes for science learning that are slow in taking place within their schools.

It’s going to go back to where they are now; there’s not going to be any change in science learning. Because again they’re stuck with ‘the objective, the standard… and they’re ‘ok, I’ve got to do this first, this second this third; and they’re- it’s like you’re claustrophobic- you can’t get out of this hole- you’re not allowed to be creative- it’s scary…we are frustrated, very frustrated- a couple of us were asked to create a scope and sequence out of it!… it’s taking us a long time; and the administration wants it by this date… it is very difficult because it [the Science Framework] is not a scope and sequence! …but they want it.

In consideration of the implementation of the Science Framework’s vision for science classrooms, John’s response captured the unanimous sentiments of all participants:

I don’t know who the people are that are developing this new curriculum- hopefully they are teachers- people who have been in front of students and know how the learners learn…and know the obstacles they have and …the backgrounds that they come
from…they should have more teachers’ input when they are thinking about the way
science is taught around the country.

Conclusion

For participants, the thinking about science learning and the attitudes, beliefs and values
they hold greatly mirror the vision of the Science Framework. Participants acknowledged the
necessity of their own conceptual changes for effective science learning. Most importantly, they
found great significance and meaning of these changes to their pedagogical practices that allow
students to come to deep understanding of the nature of their own science learning.
Chapter Five: Discussion of the Findings

Findings the Implications for Research

The purpose of this study had a dualistic nature. The study first explored the problem of how educators understand their thinking, attitudes, values and beliefs toward the nature of science learning. The study further explored changes to these attitudes and beliefs and how this change influenced pedagogical practice. The study was designed around the central research question: “In what ways do educators understand and articulate attitudes and beliefs toward the nature of science learning?”

Analysis of participant data yielded four super-ordinate themes regarding the dimensions of beliefs, values, thoughts and attitudes toward science learning. These dimensions centered on the meaning and significance of research, inquiry, argument, models and misconceptions in science learning. These four themes are: the conception that science learning is the action of inquiry; the conception that science learning is a visible process initiated by both teacher and learner; the conception that science learning values student voice; that conceptual change is necessary for science learning

**The conception that science learning is the action of inquiry.**

Current research suggests that science learning in schools must endeavor to mirror the actions of inquiry that take place in the scientific community (Michaels et al., 2008). The findings in this study supported this call, as they offered insight into beliefs, attitudes and value educators hold for inquiry in science learning.

Participants conveyed attitudes and beliefs that defined them as thinkers and doers. Just as scientists, they seemed to be constantly engaged in learning about science. They held beliefs, attitudes and values about science learning that affected the questions they asked, the
connections they made and the actions they took. All this was reflected in the context from which they made sense of the action of inquiry. Findings on participant attitudes and beliefs about science learning converged on the tenet that science learning is comprised of both questions themselves and a host of actions associated with the pursuit of inquiry and answers to those questions.

The significance of this finding supported research that suggests that teacher attitudes and beliefs matter; that they affect science learning by the questions they ask and those elicited from students; that they affect pedagogy in the choices teachers make for their own internal models of science inquiry (Driver et al, 1994; Harwood, et al., 2006; Pajares, 1992).

The attitudes toward inquiry shared by participants were grounded in the belief that students must be immersed in iterative steps of inquiry. These included formulating hypotheses, generating questions, participating in demonstrations and experiments, re-thinking at deeper levels, illustrating or making visual representations of their learning, as well as, engaging in argument with peers about their research, evidence and models. These findings supported the literature that calls for students to step into the role as researchers in order to understand both science concepts and the principles of science that underlie those concepts (Harwood et al., 2006; Michaels et al., 2008; Schweingruber et al, 2012).

Participant responses exposed deep beliefs that they had both the capacity and responsibility to bring science learning to students. They demonstrated how they brought this learning through inquiry models that met students where they were at, preserved the learner’s prior knowledge, sparked curiosity in science and served students in the contexts of their own individual backgrounds and learning styles. These findings were mirrored in the literature that marries teacher efficacy in their own beliefs with their ability to translate this ability to practice
(Driver et al., 1994; Wenner, 1993) and the literature that underscores how educator beliefs and attitudes toward science learning have cultural, social and epistemological affects on the models of inquiry they chose to bring to science learning (Bryan and Atwater, 2002; Ladson-Billings, 1995).

This study held significant implications for research that calls for teacher beliefs, knowledge and practices of inquiry based science to take center stage in reform processes (Keys and Bryan, 2001). Findings offered insight into the ways in which educators bring about learning by acting on the beliefs and attitudes grounded in student centered inquiry, experiences, dialogue and the pedagogical skill and ability to affect conceptual change for science understanding. This was evidenced in the ways in which participant’s epistemological attitudes toward the origin of questions drove the learning they designed for their students. Participant value for and attitude that science learning is about the questions students generate, supported literature that calls for educators to get to know the student by considering learning from their perspective, prior knowledge and current understanding (Abd-El Khalick et al., 1997; Carey and Smith, 1993; Michaels et al., 2008; Schweingruber et al., 2012).

The attitude that a teacher’s toolbox should include questions of various purpose supported research that values inquiry approaches that probe for prior knowledge and yield clues to students’ alternative conceptions (Carey and Smith, 1993; Driver et al., 1994). The value participants assigned to the dialogue and argument emerging from questions, as well as their belief that research and the use of models connected to inquiry, supported the research of the Science Framework (Schweingruber et al., 2012). The vision of this framework rests on the asking of questions, the development and use of models and the construction of explanations as
fundamental practices among others, for the learning of science (Michaels et al., 2008; Schweingruber et al., 2012).

Findings of the study pointed to the epistemological considerations participants had regarding the point of origin for science learning. Participant responses diverged around this issue and situated learning in either the students’ pursuit of answers or within the dynamics of the teacher/student relationship itself. However, whether learning is initiated by the teacher or learner, participants’ epistemological attitudes and beliefs were reflected in the literature that embraces the idea that science knowledge is socially negotiated, and students’ informal learning interacts with science classroom activities (Abd-el-Khalick et al., 1997; Carey and Smith, 1993; Driver et al., 1994).

Participants believed that the contexts of family, culture, prior schooling and early notions of science that students possess all color the way students construct science learning. This had significance for research that both recognizes these social connections to science and holds the learning of science in the context of an active process where students construct meaning from experiences and models of inquiry that promotes conceptual understanding from multiple perspectives (Cobern et al., 1999; Driver et al., 1994; Duit and Treagust, 1998; Duschl, 2008; Keys and Bryan, 2001; Michaels et al., 2008; Schweingruber et al., 2012).

Furthermore, the findings of this study had significant implications for specific questions raised in the literature regarding science inquiry as a conduit for conceptual change. Participant responses in this study shed some light on two questions. The first question addressed was, “How widespread is a conceptual change-inquiry approach as an approach to science learning?” The second was “What does conceptual change, inquiry-based learning look like in poor urban and ESL classrooms?” (Keys and Bryan, 2001).
Most importantly, the findings in this study added to the call in the research for inquiry-based learning to support conceptual understanding at the secondary level (Keys and Bryan, 2001). Participants shared their beliefs and attitudes for science learning at the secondary level offering partial insight into the impact that inquiry instruction within a conceptual change approach holds for science learning in general (Driver, et al., 1994).

**The conception of science learning as a visible process.**

One of the more resounding responses all participants offered was the attitude and belief that experiences are elements of inquiry as a process within the learning of science. They agreed that learning happens when thinking and understanding is affected through hands-on engagement and real-life experiences. This supported the literature that acknowledges that knowledge is actively built by the learner (Carey et al., 1988; Driver et al., 1994; Piaget, 1970; Trumper, 2003). Participants spoke of experiences as both mediums for science learning and tools for science learning.

The research of the Science Framework outlines four strands of learning, and two of the strands were reflected in participant attitudes that students need experiences where they can engage in generating scientific evidence and participate productively in science learning (Michaels et al., 2008). The scientific practices of this framework’s vision were supported through this study’s findings, as participants saw science learning as an active process of inquiry and experiences. This process was made visible by these experiences that involved students in planning and carrying out investigations, organizing and interpreting data and developing and using models (Schweingruber et al., 2012).

Participants spoke often about the value they placed on visual representations and models that help students understand science concepts and phenomena in science learning. Participants
viewed representations as a means for students to explore dimensions of a concept and to remember it. More importantly, they wanted students to be able to see that ideas in science do not exist in a vacuum. Participants saw models as teacher-created and student generated.

Through the use of photos, concept maps, videos, problem solving, physical models and etcetera, participants activated their thinking that when students build models, they are thinking deeper about science. These model building experiences that participants brought to their students are those experiences represented in the literature that advocates for making science visible (Carey et al., 1988; Michaels et al., 2008; Yair, et al., 2003; Moher, 2005; Schweingruber et al., 2012).

The attitude participants shared toward the nature of science itself held significance for how students chose to explore science. Participants conveyed the beliefs that everything in science can be questioned and that science encompasses life, nature and the universe. Participants exacted joy and wonderment of science from their own experiences and reflections of science and the human role and purpose within it. Participants wanted to bring this wonderment to the ways in which students explore science.

Despite this appreciation, however, participant responses reflected little in the literature that holds the conception of science as ontologically distinct from its epistemological, axiological and pedagogical considerations (Abd-El- Khalick et al, 1997; Abd-El-Khalick and Akerson, 2004; Cobern, et al., 1999; Lederman, 1992; Michaels et al., 2008; Southerland, et al., 2006; Schweingruber et al., 2012). Participants did acknowledge that science and technology change quickly and that students form and use hypotheses; however they did not expound on the tentativeness of science, its empirical nature or that it is based in laws that have relationships to theories.
The conception that science learning values student voice.

Participant responses demonstrated the value they placed on argument and research as conduits to learning science. Their values converged around the idea that both argument and research are peer-based activities and they linked both to student talk in the classroom. They offered many pedagogical strategies to get students talking about science: visuals that spark questions and hypotheses, required justifications for chosen pieces of evidence in investigations, demonstrations that evoke sharing thoughts and projects and activities that elicit student comments about science phenomena and their ties to ethics and society. The value that participants assigned to research and argument for promoting and sustaining student centered dialogue supported research that advocates for making science visible across all linguistic, cultural and experiential differences (Carey, 2000; Driver, et al., 2000; Duschl, 2008; Michaels et al, 2008; Schweingruber et al., 2012).

Participants saw argument and research as vehicles for students to share and learn from one another’s perspectives on science. The value participants placed on student sharing of connections between ideas and evidence and considering students’ alternative positions, supported research that argues that students can come to a greater understanding of science as they reflect on both their learning and the ways of learning chosen by their peers (Abd-El-Khalick and Akerson, 2004; Driver, et al., 2000; Duschl and Osborne, 2002; Michaels et al., 2008; Schweingruber et al., 2012).

The fact that participants placed a very high value on students’ alternative conceptions gave testament to support of the Science Framework which contends that students’ prior knowledge and alternative conceptions of science phenomena is a powerful teaching tool (Michaels et al., 2008; Schweingruber et al., 2012). Participants stated that exploring student
misconceptions is a “great way to learn science.” Participant voice is in harmony with the Science Framework’s vision to preserve the integrity of students’ prior knowledge allowing student to engage in abstract thinking and communicate these ideas with their peers (Duschl, 2008; Michaels et al., 2008; Schweingruber et al., 2012).

Participants gave voice to student alternative conceptions no matter the definition they assigned to them— a partially misunderstood concept, a preconceived notion that may be incorrect, a lack of understanding or a possible truth. Despite the various perceptions of student alternative conceptions, participants agreed that these alternative conceptions serve as springboards to stimulate and spark dialogue, argument and hypothesizing about science phenomena. These considerations supported the literature that espouses the idea that young children have the complex capacity to reason, offer theories and construct arguments about science phenomena (Carey, 2000; Driver, et al., 2000; Duschl, 2008; Michaels et al., 2008; Posner et al., 1982; Schweingruber et al., 2012)

**Conceptual change as science learning.**

This study had value for the body of research that calls for science learning as conceptual change (Beethe and Hewson, 1998; Carey, 2000; Hennessey and Beethe, 1993; Michaels et al, 2008; Schweingruber et al., 2012; Thorley and Sofflett, 1996). The vision of the Science Framework is a vision for science learning as conceptual change. Participants expressed beliefs, attitudes and values that support this vision of learning. Their practice had been affected by the considerations of change to their own conceptions of learning and they had the desire to affect that change in their students as well.

However, participants felt that their understanding and approaches of science learning were at times at odds with other educators, evaluators and administrators. Their attitudes and
beliefs that inquiry is an active process were constrained by scripted I do, we do, you do routines. Their value for student voice that they felt is paramount in learning science and their beliefs that students should visualize, experience and participate in science were constrained by established protocols and practices in their buildings. In short, the participants felt that their schools as organizations did not share the same conception they possessed for science learning.

The findings expressed participant considerations of the affective changes students experience as they come to understand science concepts. These changes were perceived to affect cultural, religious, attitudinal and ethical dimensions of students and those of participants themselves. These findings supported the literature that conceptual change is not only cognitive, but affective as well- that there are contextual and affective components to creating change in students’ conceptions of science learning (Dole and Sinatra, 1998; Pintrich et al., 1993; Sinatra, 2005).

One of the most interesting findings was the fact that these participants who have had very informal experiences with the Science Framework and no prior experiences with conceptual change theories, expressed beliefs that meta-cognitive activities are of value in learning science. While they did not explicitly teach meta-cognitive conceptual change, they did value the use of questions that helped students see the thinking behind changes they experienced in understanding while engaged in research, demonstrations and justifying evidence.

The importance of this finding was the support it provided for research on conceptual change models, the explicit teaching of conceptual change and research that supports the strands of science learning and scientific practices outlined in the Science Framework (Beethe and Hewson, 1998; Carey, 2000; Dole and Sinatra, 1998; Duit and Treagust, 2003; Duschl, 2008;
Hennessey and Beethe, 1993; Hewson, 1981; Michaels et al, 2008; Pintrich et al., 1993; Posner et al., 1982; Schweingruber et al., 2012; Sinatra, 2005; Thorley and Sofflett, 1996).

Findings also showed that participants considered learning progressions, the role of argument in kindergarten and the connection that engineering has with science as pieces of their own conceptual change in science learning. The findings directly supported the research in the Science Framework that calls for student learning to be in step with the developmental growth of the child and iterative in a manner of increasing complexity as the student advances from kindergarten to high school (Michaels et al, 2008; Schweingruber et al, 2012).

A last finding that concretely supported the vision of the Science Framework spoke to the frustration participants experienced with other educators who do not see science learning in a conceptually different way. Participants expressly shared that it was most frustrating for them to be required to offer science learning within the constraints of a scope and sequence. Their beliefs, attitudes and values for inquiry based science directly mirrored the research of the Science Framework; they recognized that the Science Framework is not at all a scope and sequence, but a vision for science learning that is conceptually different from that which has traditionally been practiced in science classrooms (Michaels et al, 2008; Schweingruber et al., 2012).

These findings showed that the participants viewed science learning as a process of inquiry that gives voice to student understanding of science. These findings supported the research that calls for students to participate in science learning in ways that are practiced within the scientific community (Michaels et al, 2008; Schweingruber et al., 2012).

Findings and the Implications for Practice

Explicit instruction.
The findings of this study held implications for practice in the area of expanding course content to be inclusive of both conceptual change and Nature of Science. The conceptual change that sits at the heart of the Science Framework and feeds the Next Generation Science Standards must be explicitly taught. The findings pointed to the value participants placed on meta-cognition that brings students to a deeper understanding of science ideas. The study showed that administrators, evaluators and classroom teachers must shift their conception of science to embrace the vision that learning is about changes in cognitive concepts, attitudes, beliefs and values via inquiry. Science education will not change unless educators let go of the notions of scope and sequence and mutually exclusive considerations of content, process and context which have for so long driven science learning.

Nature of Science also must be explicitly taught in both undergraduate and graduate teacher preparation programs and science classrooms at the K-12 level. The participants in this study had very limited experience with formal courses on Nature of Science. Yet, the attitudes, beliefs and values that they brought to the pedagogy of science learning were shown to be strengthened by these limited opportunities of exploring the ontology of science itself. Without exception, classroom teachers, science curriculum directors and educational administrators at every level should be exposed to the history and philosophy of science in order to align classroom instruction, programming and protocols with the ontological vision of the Science Framework.

**Teacher leadership.**

The findings of this study had strong implications for a second area of practice: teacher leadership in science education. Given that participants had limited experiences with the Science Framework, their attitudes, beliefs and values closely mirrored those in the research, scientific
practices and strands of learning outlined in the Science Framework itself. They valued argument, research and models as integral parts of the inquiry process and preserved and fostered student voice as they embraced pedagogical strategies that gave voice to students’ alternative conceptions, hypotheses and explanations of science phenomena.

Teacher leadership assumed by educators who have experienced changes in their conception of learning can model ways for other educators to actualize conceptual change in student learning in their own classrooms. Teacher to teacher coaching and practice sharing around the use of protocols for reflection can help set routines that isolate anomalies, ruminate sense making and future application of new information. When taught to students, these reflection routines help them map and take ownership of how their views in understanding phenomena change (Beethe and Hennessey, 1993). Educators that teach the beliefs, attitude and vision of the new Science Framework can bring this explicit learning of change to students.

This begs the question, why then, are teacher leadership and practice sharing opportunities in science education at such a premium in K-12 schools? With the Science Framework’s call for progressions of learning, it would make sense that strong teacher leadership practices of collegial coaching, program design, peer evaluation and sharing scholarly research would best affect science learning in our K-12 schools.

On a related note is the implication of these findings on teacher leadership at the state level. There should be significant working group representation by teachers whose attitudes and beliefs embrace the vision of the Science Framework. As curriculum standards are being distilled from the Next Generation Science Standards, science teacher -leaders should have significant roles in crafting state frameworks. These educators can best preserve the alignment of frameworks with the realities of classroom learning and focus on student centered objectives that
cut across domains of science and realistically embrace the practices outlined in the Science Framework.

**Curriculum design at the district level.**

The findings for this study held deep implications for the work of curriculum designers at the district level. In support of science practices, core ideas and cross cutting concepts that will be written into science curriculum, affective learning strategies should be writ large. Curricular guidelines should be inclusive of exploring students’ prior knowledge and alternative conceptions that help shape the goals and motivations for learning that students bring with them to school (Pintrich, 1993).

District level planning must consider these mediators of learning so that curriculum targets the building of student self-efficacy in ways of knowing science phenomena (Dole and Sinatra, 1998; Pintrich, 1993; Sinatra, 2005). Because Next Generation Science Standards emerge from a vision of science education as conceptual change and not a scripted format, curriculum design at the district level needs to substitute the old scope and sequence planning mentality with designs that infuse practice with the mediators of learning (Michaels et al., 2008; Pintrich, 1993; Schweingruber et al., 2012).

An example of these mediators of learning are classroom and assessment activities that build student efficacy through presentations, multi media portfolios of work, reflection and opportunities for students to ask more conceptually oriented probing questions (Chin and Brown, 2002). Affective strategies used in learning activities that elicit student commitments and beliefs about the nature of knowledge, influence changes in their conceptual ecologies as they build self-efficacy in inquiry skills. For districts to implement this new vision for standards-based inquiry instruction, their view of curriculum design necessitates a hot conceptual change. Maximizing
utility of mediating factors of learning at the district planning level will pave the way for a new conception of learning in science classrooms.

**Assessment planning.**

This study held implications for assessment practices as they align with instruction (Taylor and Nolen, 2005). Affective considerations of student goals, motivations and their level of self-efficacy should translate to the means and design of assessment. In this way, set indicators for meeting the standard take on a different meaning. Student outcomes morph from the production of knowledge to the demonstration and application of a progression of knowledge rooted in science practices, core ideas and cross cutting concepts (Michaels et al., 2008; Schweingruber et al., 2012). This progression of knowledge builds student efficacy in the ability to explain, apply and communicate science ideas. Assessment opportunities should mirror this progression of knowledge.

As classroom context moderates learning, so too does the context of assessment. The relationships and interactions of testing methods must be aligned to those affective instructional interactions. Assessments that target the beliefs, attitudes, alternate conceptions and efficacy levels of students will more closely measure the progression of knowledge in science classrooms. Examples of this type of assessment design include multiple and varied formative assessments and those that provide multiple dimensions of learning. Such means of assessment include student conferencing and semi-structured interviews that honor student voice as well as measure mastery of practices necessary for inquiry.

**Professional development.**

This study had significance for the scope and design of professional development content that will transfer the vision of the framework to classroom practice. In addition to the four
strands of science learning, scientific practices, cross cutting concepts and core ideas, the framework describes conceptual change (Michaels et al., 2008; Schweingruber et al., 2012). The conceptual change view of the Science Framework would best be taught in professional development modules by those educators who have experienced this change.

These educators, like the participants in this study, know the meaning and significance of their own changes in pedagogy. They came to change science learning by situating research, argument, inquiry and the use of representations within the learning in their own classrooms. The ability for students to initiate learning and own that learning comes from the self-efficacy these educators have within themselves and transferred to pedagogy (Wenner, 1993). Change became their pedagogy. Professional development needs to be conducted by these educators who understand that pedagogy brings students to an understanding of science, not just the doing of science.

Part of building student self-efficacy is to appreciate student voice. Educators honor this voice by considering students’ alternative conceptions. They build this efficacy by finding ways to create contexts for dialogue, research and evidence; encouraging student talk in all of these affects this self-efficacy (Driver, Asoko, Leach, Scott and Mortimer, 1994; Harwood et al., 2006; Pajares, 1992). Through teacher- to- teacher coaching, educators can lead one another in initiating the conceptual changes necessary to build this self- efficacy in their students.

A last implication is seated in the argument that interpretive phenomenological analysis has a place in classroom pedagogy. Student/ teacher conferencing could be modeled on the semi-structured interview format. Educators could identify specific areas for questioning, and the thick rich descriptions that result could offer valuable insight into how students experience learning in the science classroom (Reid et al, 2005; Larkin et al., 2006; Smith et al., 2009). This is valuable
assessment and planning data. Finding out where students are at and the overlay of teacher interpretation, yields a different view of the understanding of science ideas and science learning.

Additionally, educators could find entry points for this descriptive information in lesson planning. The lessons teachers design could include activities where students could reflect on how their attitudes and beliefs affect their understanding of science concepts. Educators could use the same conferencing strategies to help students identify their own goals and motivations for learning. These affective assessments, like rubrics, can be used to guide a student through metacognitive thinking. This explicit strategy would help students map the processes of their own conceptual change about individual concepts and larger ideas in science.

**Findings and the Implications for Theory**

There were two implications of this study on education theory. One was that interpretive phenomenological analysis (IPA) be more widely used as a method of research in educational thinking. The second implication was that affective as well as cognitive conceptual change theory be applied not only to science epistemology, but to the epistemological considerations of the arts and social sciences as well.

While IPA is not so much a theory as a methodology, the findings of this study pointed to the value IPA has for bringing participant attitudes, beliefs and experiences out through interpretations that elicit new clarity of these attitudes and experiences. From this, significant meanings and sense making informed current thinking and future practices for science learning. IPA brings the human side to uncovering the unique understanding and meaning that science had for these participants and their implications for science learning. How much more enriched would theories of learning be, if they considered the rich descriptions of experiences and the unique meanings made of the processes of learning that take place in classrooms every day?
Hot conceptual change figured largely in participant responses. The findings of this study pointed to the value of learning science from multiple perspectives. Moreover, the study determined that conceptual change needs to be an explicit part of science learning. As metacognitive thinking has value for science learning, so too does it have value for understand the ideas and connections of these ideas to other concepts in education theory as a whole. Thinking differently about the nature of education will yield new approaches to teaching pedagogy and content in undergraduate and graduate teacher education programs.

**Findings and Positionality Redux.**

A last implication of this study rested with the future growth of the researcher herself. There are avenues yet to be explored when one becomes a scholar-practitioner. The journey that transformed this Doctoral candidate to a scholar-practitioner has brought changes to her own thoughts, attitudes, values and beliefs about the role of research in practice and how practice informs research. The service to be rendered under this new conception is yet undefined. The surety is, that wherever that journey may lead, the traveler will remain humbled by the eternal magnificence of the stuff of things that are gas and dust and light.

**Limitations of the Findings**

One limitation endemic to Interpretive Phenomenological studies was the small number of participants. In this study, the number of participants was five. There may be other convergent or divergent themes coming through the findings if the number of participants was closer to eight or ten. However, given the interpretive nature of this study, it is probable that many unique meanings and significances would be forthcoming from additional participant responses.

Another limitation of this study is that findings reflected attitudes, beliefs and values of participants who were predominantly secondary teachers in poor urban schools. The
environmental contexts and experiences of these participants were reflected in their responses. Although two of the five participants had been educated themselves in suburban schools, the attitudes and beliefs they shared were centered on meeting the student where they were at and bringing science learning to students in the ways that accommodated them best.

A third limitation of this study was that findings reflected responses of participants who had very limited and informal experiences with the Science Framework, the philosophy and history of Nature of Science and Conceptual Change Theory. Although findings may be different from data from participants with formal experiences with the Science Framework, i.e., a formal course, the participant responses in this study represented more authentically the experiences of most educators, as the majority of them would not be enrolled in such a class.

**Conclusion**

The findings in this study held significance for research, practice and theory. Findings supported research that explores educator attitudes and beliefs about science learning. The study’s findings had implications for further research into the value of educator attitudes and beliefs as a central focus in processes and efforts for educational and pedagogical reform.

This study had implications for practice by offering insight into appropriate content and approaches for teacher preparation programs at the undergraduate level. Findings asserted that training for new science teachers must be inclusive of the vision of the Science Framework and an understanding of how this vision is articulated through the Next Generation Science Standards. The findings of this study also confirmed that as states adopt the NGSS standards and districts begin to disseminate them, clarity around the underlying concepts that gird this Science Framework must be explicit. Findings made clear the fact that if science educators are blind to this new conceptual idea, their practice will not change.
Finally, the findings of this study had implications for theory that explores the meaning educators assign to their conceptual understanding of science and the significance to and meanings for practice when these attitudes, beliefs and conceptions change. The study findings assert that for science learning to mirror what is practiced in the scientific community, explicit discussion of the process of conceptual change must be part of professional development programs for both teachers and administrators at every level. The findings support that any endeavor that seeks to further the understanding of the nature of science learning must be inclusive of an appreciation of science as conceptual change.
References


Crist, J & Tanner, C. (2003). Interpretation/analysis methods in hermeneutic interpretive


Larkin, Michael. (2013). Interpretative Phenomenological Analysis- An Introduction. as retrieved from http://prezi.com/dnprvc2nohjt/interpretative-phenomenological-analysis-introduction/?auth_key=3d2c098e0db0a31ea05f2d9f60148ed5144e6d06


of the research. *Journal of research in science teaching*, 29(4), 331-359.


Reiners, G.M. (2012). Understanding the Differences between Husserl’s (Descriptive) and
Heidegger’s (Interpretive) Phenomenological Research. *Journal of Nursing Care, 1*(5).


