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An Examination of the Relationship Between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs

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An Examination of the Relationship Between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs

by

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Abstract

In the last twenty years in US science education, professional development has emphasized the need to change science instruction from a direct instruction model to a more participatory and constructivist learning model. The result of these reform efforts has seen an increase in science education professional development that is focused on providing teaching strategies that promote inquiry learning to learn science content. Given these reform efforts and teacher responses to professional development, research seems to indicate that whether teachers actually change their practice may depend on the teachers' basic epistemological beliefs about the nature of science. The person who builds the bridge between teacher beliefs and teacher practice is the designer and facilitator of science teacher professional development. Even though these designers and facilitators of professional development are critical to science teacher change, few have studied how these professionals approach their work and what influence their beliefs have on their professional development activities. Eight developers and designers of science education professional development participated in this study through interviews and the completion of an online questionnaire. To examine the relationship between professional development providers' science beliefs and their design, development, and implementation of professional development experiences for science teachers, this study used the Views on Science Education Questionnaire (VOSE), and interview transcripts as well as analysis of the documents from teacher professional development experiences.

Through a basic interpretive qualitative analysis, the predominant themes that emerged from this study suggest that the nature of science is often equated with the practice of science, personal beliefs about the nature of science have a minimal impact on the design of professional development experiences, current reform efforts in science education have a strong influence on the design of professional development, and those providing science education professional development have diverse views about epistemology and the nature of science. The results and conclusions from this study lead to a discussion of implications and recommendations for the planning and design of professional development for science teachers, including the need to making equity and social justice issues an integral part of inquiry and scientific practice.

Dedication

To my daughters, Isabel and Natalia who have served as an inspiration through their dedication, work ethic, positive attitude, and perseverance. It has been a wonderful journey to learn and grow alongside them these past few years. To Dr. Ron Narode, whom I will always remember as a great teacher, science education colleague, and friend. Ron motivated me and instilled in me the idea of entering the doctoral program and encouraged me along the way while teaching me invaluable lessons.

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CHAPTER 1: PROBLEM STATEMENT

Introduction

As a middle school science teacher over the past fifteen years I have participated in numerous professional development experiences including national, regional, and local conferences, workshops, and presentations. I have also had the opportunity to participate in summer institutes developed by organizations that include Oregon Health Science University (OHSU), Massachusetts Institute of Technology (MIT), the U.S. Space Rocket Center®, Discovery Education, and the Library of Congress. As a result of these experiences I have observed that teacher professional development is heavily focused on the transfer of content and primarily follows the dominant training-and-coaching model. According to Supovitz and Turner (2000), "staff development lies at the heart of nearly every educational effort to improve student achievement. Yet, paradoxically, the development of educators is a much maligned enterprise" (p. 963). Supovitz and Turner also indicate that "teachers ranked in-service training as their least effective source of learning" (p. 963).

In my experience of professional development I have also reflected on how the nature of science (NOS) is addressed as part of workshops and teacher trainings. Primarily, over the past 20 years, there has been a strong push to implement the inquiry process as part of teaching science and to move away from more traditional methods of instruction such as lectures (Kang, 2008). In the publication of the National Science Education Standards in 1996, "science is described as a way of knowing about natural phenomena and science teaching as facilitation of student learning through science inquiry" (Kang, p. 479). Teachers' epistemological and nature of science beliefs have not been addressed as part of the latest reform movement in science education (Lederman, 1999). Lederman (1999) states:

> There is not, and there has not been, a concerted professional development effort to clearly communicate, first, what is meant by the "NOS" [Nature of Science] and scientific inquiry and second, how a functional understanding of these valued aspects of science can be communicated to K-12 students. Perhaps the lack of professional development related to the NOS and scientific inquiry is a consequence of the misunderstanding that the NOS and scientific inquiry fall within the realm of affect and process as opposed to cognitive outcomes of equal, if not greater, importance than "traditional" subject matter. (para. 3)

Science education continues the endeavor of leading students towards an in-depth understanding of scientific concepts. Today, there is a clear understanding that students cannot learn science by simply memorizing a long list of facts and concepts (Gallagher, 1991). Teaching science through inquiry and promoting teacher understanding of the nature of science should be an essential component of professional development efforts that seek to change science teaching and learning (Capps & Crawford, 2013; Lederman & Abd-El-Khalick, 2002).

Background of the Problem

This section will provide a brief situational analysis around the issue of professional development in science education through its current social, cultural, and epistemological contexts. A historical context of the problem as well as a more detailed epistemological analysis will be addressed in chapter two of this proposal.

There are several factors that have contributed to the professional development hodgepodge that exists today. First, the absence of a clear mission for the professional development of science educators and the vast diversity of programs complicate the development of effective and exemplary programs. In describing this situation, Feiman-Nemser (2001) writes,

> The charge of fragmentation and conceptual impoverishment applies across the board. There is no connective tissue holding things together within or across the different phases of learning to teach…. Professional development consists of discrete and disconnected events. Nor do we have anything that resembles a coordinated system. Universities regard preservice preparation as their purview. Schools take responsibility for new teacher induction. Professional development is everybody's and nobody's responsibility. (p. 1049)

As Feiman-Nemser notes, the lack of infrastructure and coordination for professional development of teachers creates a chaotic system that is missing a vision and objectives.

Second, professional development activities designed to create changes in science education are largely ineffective as a result of ignoring science teachers' beliefs about science epistemology and the nature of scientific knowledge (Lederman & Abd-El-Khalick, 2002). Van Driel, Beijaard, and Verloop (2001) observe that past reform efforts have been unsuccessful because they fail to acknowledge teachers' existing knowledge, beliefs and attitudes. Additionally, in their review of the literature on science teacher attitudes and beliefs and their link to instructional practice, Jones and Carter (2007) found that teachers' beliefs and attitudes are deeply rooted and resistant to change as a result of the long-term construction of these beliefs through their formal and informal experiences in science as students. Jones and Carter cite various research studies where science teacher attitudes and beliefs remained unchanged after participation in pre-service programs or workshops. Based on their review of the research, Jones and Carter argue that "the process of making epistemological and personal beliefs explicit is critical for professional development" (p. 1082). The research shows that making beliefs and attitudes explicit as part of any program for science teachers is a necessary component because teachers and providers may not be aware of their beliefs and attitudes about the nature of science or the contradiction between these beliefs and their practice.

Third, and I believe this to be the leading factor for this professional development hodgepodge, is related to how the challenge to the notion of objectivity is handled in science and how we view knowledge, which in science education is now influenced by social constructivist theories regarding the curriculum (Elby & Hammer, 2001). I also believe one reason for ignoring beliefs about epistemology and the nature of science as part of a professional development experience is the result of the ongoing debate about how scientific knowledge is built. According to Loving (1997),

> An intense debate is occurring in educational research about the legitimacy and theoretical bases of various methods used to arrive at explanations for some of our most perplexing phenomena. It first involved the extent to which such research could be carried out as a kind of science. The debate has gone on, however, in recent years to address the very nature of science, now questioning whether science has any claim to a unique way of knowing. Arguments are particularly vigorous with those involved in science education research. The science education community has moved from ignoring the philosophical upheaval about the nature of science of the earlier part of the century, started by N.R. Hanson (1958) and Thomas Kuhn (1962), to developing distinct philosophical and methodological camps-often referred to as *positivists* or *postmoderns*. (p. 422)

As Loving notes above, there has been a lot of controversy over the nature of science over the years and the construction of scientific knowledge. She ends up describing the field as two paradigms: Positivists or postmoderns. Loving further notes that in the positivist paradigm, “Scientific knowledge is thought to be largely cumulative, each new theory which replaces the older coming closer to a truth. In fact, science might be defined here as a search for truth [with a capital T for some]” (p. 430). The goal of science then for positivists is a continuous search for truth. An additional tenet of the positivist paradigm describes “knowledge as deductive generalizations coming from pre-existing facts” (Loving, 1997, p. 430) and the “truth-seeking activity is often achieved by limiting sites on the rejection or acceptance of a hypothesis after its being proposed, empirically tested, and analyzed” (Loving, 1997, p. 430).

According to Loving (1997), science teaching based on positivist views can lead to science education that ignores the historical journey of theories being taught; in other words, students only focus on the final product of inquiry. Additionally, Loving claims that this kind of science education can lead to scientific explanations taught as truth, and laboratory activities that are designed like cookbooks where emphasis is placed on procedures that lead to one right answer. Finally, Loving maintains that in this framework, science is taught as bias free and scientists are often portrayed as lacking human qualities. Aikenhead (2003) makes a similar observation regarding how science textbooks typically portray science and scientists. He writes:

> An idealized heroic rationalism paints a picture of individual scientists discovering (revealing) truth by applying the scientific method; a picture that equates scientific knowledge of nature with nature itself. Most textbooks convey an ideology of indoctrination into positivistic realism endemic to the traditional science curriculum. (p. 31)

To put it succinctly, Aikenhead describes textbook science in a way that lacks a humanistic perspective. A humanistic perspective in science means that science takes place in a social context and is a human construct.

While textbooks may portray a positivistic, realist view of science, reform efforts in science education support a view of scientific knowledge as socially constructed, a position called relativism (Duncan & Cavera, 2015; Elby & Hammer, 2001). The most recent reform effort in science education calls for a constructivist approach to teaching and learning (National Research Council, 1996, 2012; Next Generation Science Standards Lead States, 2013). Educational leaders and reformers have developed a significant number of resources, including professional development activities, with the aim of changing science teaching and learning. Freeman, Marx and Cimellaro (2004) argue that "if teachers are to realize their roles as facilitators and guides of knowledge construction, professional development opportunities must address issues of conceptual change" (p. 112). In this context, conceptual change means thinking about learning more from a student centered perspective, as opposed to the traditional teacher centered view of learning. More importantly, Freeman, Marx and Cimellaro claim that "if teachers are to adopt teaching practices embodying a constructivist view of learning, the professional development must model strategies consistent with a constructivist view" (p. 112).

Further complicating matters, is the argument around epistemological development. Perry (1970) observed that college students gradually move from an absolutist to relativist stance toward knowledge. A current debate in science education centers on what is considered a sophisticated epistemological stance and how productive this stance may be in helping students learn science (Elby & Hammer, 2001). Elby and Hammer (2001) argue that "productive epistemological beliefs—ones that help students to learn—sometimes differ from 'correct' epistemological beliefs espoused by philosophers and social scientists" (p. 565). Elby and Hammer claim that "much of students' naïve knowledge consists not of articulate beliefs, but rather, of epistemological resources—often implicit, often inarticulate—that can be triggered in different combinations by different contexts" (p. 566). Elby and Hammer suggest an alternative to the idea that naïve epistemologies can simply be replaced with more sophisticated ones. Elby and Hammer suggest that a resources-based model of epistemologies is a better predictor for the context dependent learning process in science education. My conclusion, then, is that science teachers would not only need to be aware of their own epistemological stances toward scientific knowledge, they will need to understand how to identify "productive epistemological resources that students can build upon (with their teachers' help) to become better learners" (Elby and Hammer, 2001, p. 565).

In a different context, but one that has implications around the previous discussion of epistemological development, Seixas (1993) examines this issue of recognizing the distinctions that occur between a field of knowledge and education about such a field. Seixas (1993) writes about the community of historians and compares the knowledge generated by this community with the knowledge generated by a classroom community. Seixas makes the claim that we are trying to use historians' products as the basis for the school curriculum. Seixas states, "conceiving of the two in a simple hierarchical relationship with historians' knowledge-products being passed to the classroom misconstrues the nature of history" (p. 315). Additionally, Seixas rejects the idea of envisioning these communities as one entity based on the differences of their members. Seixas describes the role of the teacher as the person responsible for shaping the relationship between the scholarly community and the classroom community and as the person managing the knowledge produced in each. Seixas writes,

> History teachers' subject knowledge thus entails a bridge between communities, extending outward to historians in one direction and to students in another. That very outward extension makes a community of inquiry revolving around teachers' own historical knowledge an unlikely event—or, in any case, an extracurricular and avocational event. If knowledge and learning are based in the community of inquiry, then lack of support for teachers' participation in the historical community is a serious deficit. This deficit raises a crucial issue: on what basis to construct or extend communities of inquiry to include teachers in the creation of knowledge. The solution depends, in part, on our conception of the nature of teachers' knowledge. (p. 316)

Although Seixas writes about the discipline of history, a similar argument can be made in science education regarding the roles of scientists, educators and students. Russ (2014) suggests to "shift away from thinking about learners adopting epistemologies of science toward thinking about learners as adopting epistemologies for science" (p. 391). Russ provides the following model of science epistemology as a prevalent one that shows repeatedly throughout the research literature:

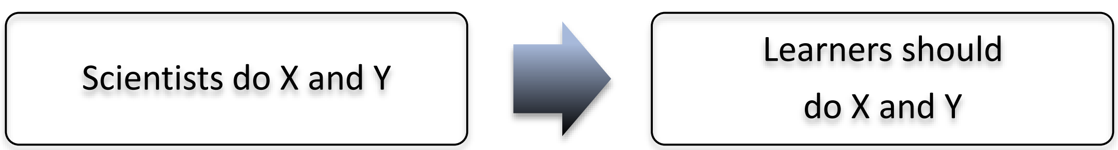

Figure 1. Form about the role of the epistemology of science for science education. From Russ, R. S. (2014). Epistemology of science vs. epistemology for science. *Science Education, 98*(3), 388-396.

In similar fashion to Seixas's reflections regarding knowledge in the school subject of history, Russ proposes a model in science education that "is grounded first in thinking about what practices and knowledge are useful for constructing knowledge of the natural world" (p. 392). According to Russ, the model shown in Fig. 2, could possibly lead to placing greater value on the productivity of particular science epistemologies "both for learners and from the perspective of learners—as they attempt to make sense of the physical and natural world" (p. 392). Thinking about science education in this manner would require educators to have a strong foundation in epistemology as they would, for example, “need to make the case for how and in what ways treating knowledge as tentative is productive for making sense of the world” (Russ, 2014, p. 392).

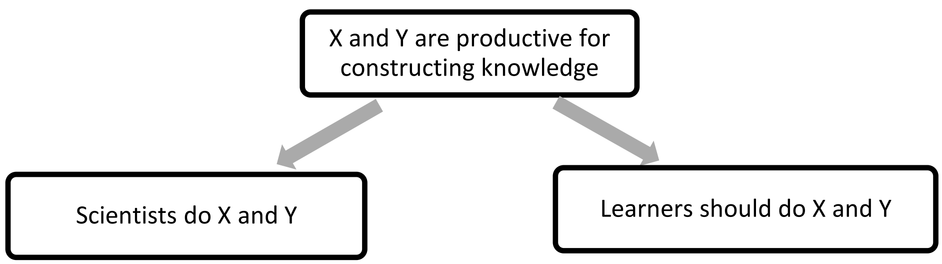

Figure 2. Proposed model focused on the utility of science epistemologies for knowledge construction. From Russ, R. S. (2014). Epistemology of science vs. epistemology for science. *Science Education, 98*(3), 388-396.

While the debates go on about the nature of science and epistemological development, the science education community continues to struggle with how best to prepare science teachers to address these issues. One problem is that science teachers lack preparation in the areas of history and philosophy of science (Loving, 1997). Aikenhead (2003) found that “teachers favour abstract decontextualized ‘pure science’…at the same time, a teacher’s loyalty to the academic science community, and to its myths, becomes well established and hence a teacher’s orientation to a traditional science curriculum is set” (pp. 36-37). This creates a challenge for those planning professional development designed to challenge teachers’ conceptions of the nature of science. The problem is further exacerbated when those planning and implementing professional development are unaware of their own beliefs regarding the nature of science and epistemology.

Statement of the Research Problem

In discussions of science teacher professional development design, one controversial issue has been the role that both epistemological and nature of science beliefs play in the design and development of such professional development experiences. On one hand, some researchers argue that these beliefs do not impact the design or the nature of the professional development experience (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). On the other hand, some researchers contend that these beliefs are at the heart of how the professional development experience is delivered to teachers and how it achieves its objectives (Aikenhead, 1997; Matthews, 1998). The purpose of this study was to examine the relationship between professional development providers' science beliefs and their design, development, and implementation of professional development experiences for science teachers. In particular, I sought to study the epistemological beliefs and the nature of science beliefs of those involved in the planning and implementation of these professional development experiences. The central research question for this study was, "What are the epistemological and nature of science beliefs of professional developers in science education and what is the relationship between the beliefs of the professional developers and their planning and implementation of professional development experiences for science teachers?"

Significance of the Research Problem

This section will discuss the implications of the research problem in terms of equity, inquiry teaching and the current reforms efforts in science education. One current area of concern in science education is the science achievement gap that exists by gender and race/ethnicity. Unfortunately, greater focus is placed on math and literacy gaps by researchers and policy makers (Quinn & Cooc, 2015). According to recent research studies of the science achievement gap, two explanations proposed for how these gaps develop are racial/ethnic differences in socioeconomic status and school quality. According to Quinn and Cooc (2015), Black and Hispanic students

> have less access (compared with White students) to school resources to promote science achievement…they are less likely to be taught by qualified science teachers, are less likely to have important science lab facilities and equipment and tend to be exposed to less rigorous curricula. (p. 337)

Furthermore, Quinn and Cooc state that Black and Hispanic students' teachers "place less emphasis on scientific inquiry and problem solving and are less likely to use techniques that promote active student involvement" (p. 337). The statement above refers to teachers' understanding of the nature of science. As we learn more about the gender and race/ethnicity achievement gaps, one important tool towards this challenge is professional development.

Additionally, my research is important because development of a strong science education professional development program that includes learning about scientific inquiry, requires a good understanding of the nature of science. According to Monk and Osborne (1997), "Epistemology does matter—because the answer to the question of 'how we know' is an important aspect of our account of science and the evidence for our ontological commitments" (p. 409). Understanding and making explicit the scientific epistemic beliefs that are part of the design of such professional development may lead to a more rewarding professional development experience for teachers. This in turn, may lead to improved science teaching. According to Waters-Adams (2006),

> the pursuit of science education is not the same as the pursuit of science…science education is different. It is not simply education in science, it is education about science (see Koulaidis & Ogborn, 1995, p. 274, in response to Wilson & Cowell, 1992). Koulaidis and Ogborn suggest that it is thus important that teachers have an adequate understanding of the nature of science, so that they can grasp the syntax of the subject that Shulman (1986) identifies. (pp. 940-941)

According to Sandoval (2005) sophisticated science epistemologies are instrumental towards improving students' understanding and practice of scientific inquiry and essential for full democratic participation in the 21st century. These are also the goals of current science education reform efforts. Professional development is a major tool in the process of implementing reform in education. If these efforts at changing science education are to be successful, it will be important for science teachers to examine, reflect on, and develop sophisticated science epistemologies. Therefore, one research area of study centers on those responsible for providing science professional development and their beliefs regarding epistemology and the nature of science.

The process of designing professional development experiences for teachers from the point of view that school science is different from the scientists' science, involves many factors with various levels of complexity. One starting point may be to write the goals and objectives for such an experience in light of teachers' views and beliefs about knowledge and teaching. This is important because a lack of attention to teachers' beliefs has the potential to render professional development experiences ineffective and result in minimally impacting classroom instruction. According to Korthagen (2004), "the beliefs teachers hold with regard to learning and teaching determine their actions" (p. 81). I believe that professional development that does not address or challenge beliefs will have little impact in terms of results. Korthagen provides the following example, "[teachers] may have developed the belief that teaching is transmission of knowledge, and most teacher educators find this belief not very beneficial to becoming a good teacher. However, in most cases, it is these old beliefs that prevail" (p. 81). Again, I believe that effective professional development programs address these beliefs. Hawley and Valli (1999) support this view and state, "professional development must engage teacher's beliefs, experiences, and habits" (p. 143). Feiman Nemser (1983) also shares a similar view regarding teacher preparation programs that do not address teacher beliefs about such things as the nature of knowledge. Feiman Nemser states, "The tendency of teachers to maintain their early preconceptions supports the argument that formal preparation does not challenge early informal influences" (p. 153).

Because we begin to develop our beliefs and values about knowledge and teaching much earlier than entering a teaching program, designers of professional development experiences that seek to address and impact teachers' beliefs should begin the process with a reflection on what beliefs teachers may bring to this experience and how they come to develop such beliefs. According to Feiman Nemser (1983), "learning to teach begins long before formal programs of teacher preparation. Its roots are personal experiences with parents and teachers and images and patterns of teaching shaped by the culture. Most preservice programs do not challenge these early influences" (pp. 166-67). Knowing about how learning to teach occurs within the subject matter in which one is interested in designing professional development experiences can facilitate the process of addressing the various beliefs participants may bring to this experience. Since our beliefs about knowledge and teaching develop over a long time, it is very difficult to change them (Hawley & Valli, 1999). That being said, a study conducted by Bencze and Elshof (2004) found that it is possible to change teacher beliefs that shift their perspectives toward a more postmodern view of science through participation in a field ecology research camp.

Hammerness et al. (2005) support the importance of learning to teach in different ways. Hammerness et al. state, "learning to teach requires that new teachers come to think about (and understand) teaching in ways quite different from what they have learned from their own experience as students" (p. 359). In this manner, teachers would address their beliefs about learning and teaching within the context of the inquiry community. It may also lead teachers to recognize the distinction between education in science versus education about science.

Presentation of Methods and Research Question

The purpose of this study was to examine the relationship between professional development providers' beliefs and their design, development, and implementation of professional development experiences for science teachers. This study will seek to accomplish this by providing a window into those who are responsible for designing such experiences. With that purpose in mind, the research questions this study seeks to answer are:

- What are the epistemological and nature of science beliefs of designers of professional development for science teachers?
- What is the relationship between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs?

This research study will use a basic interpretive qualitative methodology because qualitative research facilitates the understanding of phenomenon as well as the process of professional development experiences for science educators along with the perspectives and worldviews of the educational leaders involved in this process. Data for this study will include questionnaires and interviews with those responsible for the design of the professional development experience, drawings of a professional development event, as well as documents from the professional development experience.

Definitions of Key Concepts

Professional Development. The term *professional development* is an example of an experience for educating practicing teachers to improve their craft. According to Grant (1996), a large part of the early literature on professional development is focused on the paradigm of teacher training. As such, professional development tends to be described as "short-term, standardized sessions designed to impart discrete skills and techniques" (Grant, 1996, para. 1). For Grant (1996), professional development means:

> Professional development … goes beyond the term "training" with its implications of learning skills, and encompasses a definition that includes formal and informal means of helping teachers not only learn new skills, but also develop new insights into pedagogy and their own practice, and explore new or advanced understandings of content and resources. (Grant, para. 2)

Nature of Science. An additional concept that will be used throughout this paper and needs to be defined is the *nature of science*. According to a definition provided by Lederman (1992), the nature of science is:

> The values and assumptions inherent to the development of scientific knowledge. For example, an individual's beliefs concerning whether or not scientific knowledge is amoral, tentative, empirically based, a product of human creativity, or parsimonious reflect that individual's conception of the nature of science. (p.

331)

In other words, the nature of science refers to the principles and ideas that describe science as a way of knowing.

Epistemology. The term *epistemology*, as a branch of philosophy, refers to the nature of knowledge and knowing. In this dissertation, the term epistemology will be used more in accordance with how the field of psychology uses the term. Here epistemology has a more personal nature and refers to an individual's beliefs about the nature of knowledge and knowing (Borda, Burgess, Plog, Dekalb & Luce, 2009).

How the concepts of epistemology and nature of science are defined and used in the science education community have important implications that impact teaching and learning. The connection between these concepts and their implications will be more closely analyzed as part of the literature review of this proposal.

Epistemological beliefs. The terms educational beliefs and teacher beliefs have been widely used in educational research. Unfortunately, these terms are challenging to define because it is hard to distinguish belief from knowledge (Pajares, 1992). According to Pajares (1992), "teachers' attitudes about education—about schooling, teaching, learning, and students—have generally been referred to as teachers' beliefs. As it is clear that not only teachers have these beliefs, however, the label is inappropriate" (p. 316). Pajares also argues that the term educational beliefs is not appropriate, he states: "the construct of educational beliefs is itself broad and encompassing. For purposes of research, it is diffuse and ungainly, too difficult to operationalize, too context free" (p. 316). Pajares suggests that for research purposes, it is more appropriate to focus on what beliefs are about. In this dissertation, the term epistemological beliefs is used to refer to beliefs about the nature of knowledge.

Summary

In this chapter, I made a case for why it is important to examine our beliefs regarding epistemology and the nature of science as a part of a professional development experience in science education. In Chapter Two, I expand on the development of science epistemologies and their role on the professional development of science teachers.

CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter reviews the literature that applies to science education professional development. The chapter begins by presenting the theoretical framework for the study, its connection to the problem and its usefulness in analyzing the problem. The chapter then presents a historical background relevant to science epistemology and professional development efforts in science education with the goal of developing an understanding of how the intersection of the history of science, the philosophy of science and science education have framed this researcher's perspective and with the goal of aligning the topic and purpose of the study to the literature review. Next, the chapter identifies the larger themes in the literature and provides a critical examination of these themes. Finally, I will discuss the methodological literature and a justification for its selection.

The field of education is in a constant state of reform. Additionally, system wide reform efforts aside, individual teachers are also continuously seeking to improve their craft. Professional development is one of the methods that we have used with the aim of implementing education reform efforts or one of the methods teachers have used independently to improve their skills. Professional development involves many factors and variables. The study described here is focused on the design of professional development for science educators. More specifically, the purpose of this study is to examine the relationship between professional development providers' beliefs and their design, development, and implementation of professional development experiences for science teachers.

Theoretical Framework

As mentioned earlier, inquiry learning is a major focus of the current reform efforts in science education. The argument for inquiry is that it leads to a deeper understanding of science concepts and the development of skills necessary to do science, leading to a more experienced understanding of the nature of science (Sandoval, 2005). Within this context of science education reform and professional development being a key aspect of any reform efforts, I'm framing this research exploration from the perspective that one's beliefs are essential to developing and implementing science teacher professional development experiences. There are a number of learning theories that play a role in framing this research proposal, although some more strongly than others. I will first examine theories of social cognition and epistemological development and then transformative learning theory and social constructivism.

Social Cognitive Theory and Epistemological Development

As part of his social cognitive theory, Bandura (1978, 1983, & 1986) proposed a model of reciprocal determinism. According to Bandura's model, behavioral, personal, and environmental factors interact simultaneously to influence each other and help explain one's actions. Personal factors include cognition, attitudes and beliefs. Bandura's model indicates that educational leaders' beliefs will / may determine behavior and in turn behavior will / may influence educational leaders' beliefs. Bandura (1986) argues that one's "behavior is better predicted from their beliefs than from the actual consequences of their actions" (p. 129). Additionally, environmental factors such as the current political climate or the geographic location for professional development may influence educational leaders' beliefs on the design or purpose of professional development.

Since a major focus of this proposal involves epistemological and nature of science beliefs, it may also prove useful to explore theories of epistemological development. The research on personal epistemology is fairly new, and currently there is even an argument regarding how to define personal epistemology. Some researchers, Hofer and Pintrich (1997) and Sandoval (2005) define personal epistemology as "views about the nature of knowledge and knowing but not views about the nature of learning" (Elby, 2009, pp. 138-139). Chinn, Buckland, and Samarapungavan (2011) have expanded on the work by Hofer and Pintrich (1997) and proposed an epistemic cognition theory that includes five components:

- epistemic aims and epistemic value;
- the structure of knowledge and other epistemic achievements;
- the sources and justification of knowledge and other epistemic achievements, together with related epistemic structures;
- epistemic virtues and vices; and
- reliable and unreliable processes for achieving epistemic aims. (Chinn, Buckland, & Samarapungavan, 2011, p. 142)

The five components noted above provide an epistemic cognition theory that is more context and situation dependent. Chinn, Buckland, and Samarapungavan's work is important because epistemic beliefs can predict learning process and outcomes. A theory of epistemic cognition that is more context and situation dependent may shed light on why science teachers may switch between naïve and sophisticated science epistemologies. One limitation of this epistemic cognition theory is that it is primarily focused at the individual level and more research is needed to understand social epistemic practices for groups of students or learners (Chinn, Buckland, & Samarapungavan, 2011).

Other researchers such as Elby (2001) include views about the nature of learning in their research on personal epistemology. Hammer and Elby (2003) contend that "a constructive understanding of student epistemologies is often embedded in instructional practice" (p. 54). Elby (2009) acknowledges that regardless of the position one takes in defining personal epistemology, more research is required to come to an understanding on the connection between views about the nature of knowing and views about the nature of learning. Elby points out that "phenomenologically clear categories do not always align with the underlying mechanisms" (p. 148).

Sandoval (2014) argues that many current epistemic cognition theories do not have enough empirical support and calls for the development of a theory of epistemological development functional for science education. Sandoval states,

> A theory of epistemological development, by which I mean the ideas individuals develop about the nature of knowledge and knowing, ought to account for how people answer questions like What is knowledge?, Where does knowledge come from?, How do we know what we know?, and How do we evaluate knowledge claims? It includes related questions about evidence and other sources of justifications for knowledge. (p. 384)

If researchers are to develop a theory of epistemological development for science education, Sandoval (2014) argues there are a number of road blocks to clear. First, there needs to be a clear conception regarding how the nature of science and scientific inquiry are intertwined. Second, researchers need to distinguish between epistemic and epistemological. Third, research on epistemological development needs to examine the individual versus social component. Does science as a field and not scientists, have an epistemology? Or do scientists "develop their own ideas about what counts as a valid knowledge claim" (Sandoval, 2014, p. 385). Fourth, research on epistemological development also needs to resolve the issue of how to go about studying epistemic cognition. Should research focus on learners' practices, artifacts, or reflections? Or the combination of all? Should it focus on the individual or social component? (Sandoval, 2014).

Sandoval (2014) holds the view that a situated theory of epistemological development "grounded in efforts to promote particular forms of epistemic cognition in particular settings" (p. 387) would allow science teachers to be more successful in "helping students develop an understanding of scientific epistemology they can use in their own lives" (p. 387). My own personal question is, how do we first get teachers to understand their own scientific epistemology?

In this case, in addition to understanding professional development providers' epistemological and nature of science beliefs, I'm interested in exploring how these behavioral, cognitive, and environmental influences impact the design of a professional development experience.

In regards to teacher development, the work of Shulman (1986) towards a theory on knowledge growth in teaching is especially applicable here. Shulman seeks to answer the questions "What are the sources of teacher knowledge? What does a teacher know and when did he or she come to know it? How is new knowledge acquired, old knowledge retrieved, and both combined to form a new knowledge base?" (p. 8). In terms of teacher knowledge, Shulman believes that for teachers "to think properly about content knowledge requires going beyond knowledge of the facts or concepts of a domain. It requires understanding the structures of the subject matter" (p. 9). Furthermore, Shulman insists that teachers "need not only understand that something is so; the teacher must further understand why it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied" (p. 9). Shulman makes very clear what teachers must be able to do, Shulman states,

> The syntactic structure of a discipline is the set of ways in which truth or falsehood, validity or invalidity, are established.…A syntax is like a grammar. It is the set of rules for determining what is legitimate to say in a disciplinary domain and what "breaks" the rules.
>
> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice. (p. 9)

The quote above reflects the need for teachers to understand the history and philosophy of science to gain a better insight into how scientific knowledge is constructed.

Transformative Learning Theory and Social Constructivism

Mezirow (1996) introduced transformative learning theory as an adult learning theory. Transformative learning theory can be used to explore Shulman's work for teacher development. Mezirow defines learning as "the process of using a prior interpretation to construe a new or revised interpretation of the meaning of one's experience in order to guide future action" (p. 162). A main tenet of transformative learning theory contends that in addition to Bruner's four modes of making meaning, there is a fifth and essential mode that involves learners recognizing their own and others' implicit assumptions and expectations and evaluating these to develop a better understanding (Mezirow, 1996). Often, we have implicit assumptions about the nature of knowledge and the nature of science. Recognizing these implicit assumptions is important because the ability to explicitly communicate beliefs regarding the nature of knowledge and the nature of science can lead to better science teaching and learning.

It is also important to understand that a lot of professional development occurs in a social setting and not in isolation. More specifically, this idea of teachers collaborating to build common knowledge on one topic supports the theory of social constructivism where "knowledge construction is an active process – even a struggle – carried out by groups or communities, not by individuals" (Phillips, 1995, p. 9).

As a philosophy, constructivism traces its roots to the work of Piaget. The basic premise of constructivism holds that all knowledge is constructed and does not result from passive reception of information. One conflict that results from this premise is that if everything we come to know results from an active process, then even listening to lectures and memorizing science vocabulary is part of that active process that results in the acquisition of knowledge (Phillips, 1995).

Criticisms of Piaget's work result from Piaget's strong focus on the individual. Many science educators now use methods that are aligned with a more communal form of constructivism, commonly referred as social constructivism. Although Vygotsky is well known for his work on social constructivism, Thomas S. Kuhn has had a strong influence on social constructivist learning. Kuhn argued that much scientific knowledge is constructed through active participation within the scientific community (Phillips, 1995). In social constructivism, construction of knowledge occurs through our interactions with others and in community, a concept that brings us back to the model presented by Palmer in figure 2. Phillips highlights the work of the philosopher Longino as representative of the field in social constructivism. Longino (cited in Phillips, 1995) claims that knowledge is actively “constructed not by individuals but by an interactive dialogic community” (p. 112).

Another important figure in the realm of social constructivism is Vygotsky, and more specifically his development of the notion of a ‘zone of proximal development.’ According to Elliot (1995), this notion allows us to understand how learners move from learning with others to individual competency. Elliot claims that good teaching and I would add good professional development, can be defined on the basis of assisting teachers through Vygotsky’s zone of proximal development. Elliot argues that teacher development involves “movement from one social context to another via intrapersonal development” (p. 260). Addressing one’s beliefs about the nature of science and the nature of knowledge would be one way of assisting teachers through one development zone.

Based on the theories discussed above, those planning professional development should consider much more than the practical knowledge of educators. Mezirow (2000) argues that “in fostering transformative learning efforts, what counts is what the individual learner wants to learn” (p. 31). Trotter (2006) recommends the inclusion of reflection and journaling as part of the professional development experience to allow for the participants’ self-expression and the opportunity to create meaning. Especially if participants are to examine their own beliefs regarding epistemology and the nature of science. And as this may occur as part of a group, Mezirow also recommends "blocking out power relationships engendered in the structure of communication" (p. 31) to allow for a more democratic experience.

Before proceeding to examine some of the current literature on professional development in the context of the nature of science, it is helpful to take a short historical journey to learn about the links that exists between the history and philosophy of science, epistemology, science education, and professional development.

Review of the Research Literature through a Historical Lens

Analyzing the literature on science education professional development with a special focus on epistemological beliefs requires a look back at some important historical events. The reason for this historical context is to provide insight into how science educators have come to acquire various epistemological beliefs regarding the nature of science. This section of the chapter will present how the intersection of historical events from the fields of philosophy, science, and education has influenced science education and thus the perspectives of stakeholders in this field. While the entire history and philosophy of science cannot be examined here, particular attention is paid to persons and events as they pertain to science education. It may be helpful to organize this section around some of the more important periods of scientific thought. These periods include the scientific revolution, the Age of Enlightenment, science in the nineteenth century and science in the twentieth century.

The Scientific Revolution

The scientific revolution, beginning around the time of publication of Nicolaus Copernicus's *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Heavenly Spheres), marks the transition between the medieval world view and a more modern understanding of science. There was also a shift from a deductive reasoning approach to a more inductive approach. In his *Novum Organon*, Francis Bacon concluded that "natural knowledge could be built only through the inductive method, which entailed the painstaking accumulation of the observable facts of nature as a prelude to extremely cautious generalization" (Rudolph, 2005, p. 345). This was also the beginning of the scientific method. Creating a well-defined process to produce knowledge allowed for greater support for the scientific community. As a result, we see the beginning of institutions created to support science, such as the establishment of the Royal Society of London in 1660 with the purpose of promoting knowledge (Johnston, 2009).

During the time of the scientific revolution, Johnston (2009) reports that "the broad and entwined understandings of alchemy and astrology were replaced by a narrower focus to pursue more restricted goals. The new philosophers traded an inefficient but satisfying holism for a tailored assault on knowledge" (p. 57). Furthermore, Johnston adds that the "scientific revolution altered notions about machines, instruments, technology and scientific knowledge" (p. 60). The scientific revolution can be described as a thrust to apply rational methods of investigation to better understand the natural world (Johnston, 2009).

Prior to the scientific revolution the dominant philosophical view was an Aristotelian view, primarily because of its inclusion in Catholic doctrine (Ladyman, 2002). The scientific revolution brought a break with the theories of Aristotle and thus an important distinction regarding scientific theories, namely "that scientific theories seem to describe a reality distinct from the appearance of things" (Ladyman, 2002, p. 17). One argument that resulted from the publication of Copernicus' book can be seen as an early example of the debate between instrumentalists and realists (Ladyman, 2002). In the philosophy of science, realism is defined as "the philosophical view that explanations can be refined to accurately describe the true nature of physical reality" (Johnston, 2009, p. 46). In contrast, instrumentalism is defined as "the philosophical approach of treating any accepted fact or theory as a working hypothesis or provisional truth, i.e. as merely an instrument or tool in order to discover further knowledge" (Johnston, 2009, p. 47).

It is important to begin to understand how the scientific revolution and the realism versus instrumentalism debate has had an impact on science education. According to Milne and Taylor (1998) a realist perspective that goes unrecognized and uncontested remains in contemporary school. This perspective creates "an illusion of the certainty of knowledge" (p. 31) that is part of the teaching and learning of science. Milne and Taylor claim,

> the disempowering spell of the myth of realism is wholly captivating when students believe that they can see scientific facts by looking ever outwards (at Nature, the textbook, the blackboard, the teacher, the experimental equipment) rather than inwards (at their own conceptions). (p. 31)

One could also ask the question, why examine the realism versus instrumentalism debate in the context of science teacher professional development? As stated earlier, recent reform efforts in science education call for a constructivist approach to science education and according to Waters-Adams (2006), "there is a potential tension between a realist position and the idea that children can be generating their own knowledge" (p. 937). One of my arguments is that understanding the essential aspects of the debate between instrumentalists and realists can better prepare science educators to teach the nature of science.

The Age of Enlightenment

The Age of Enlightenment brought with it a different perspective to science. Immanuel Kant argued that just like science could be used to understand the natural world, it could also be used to understand the social world and applied to improve people's living conditions. Through science, Kant insisted on looking at the world rationally and scientifically. Similarly, the chemist Joseph Priestley advocated for directly relating science to human society (Johnston, 2009). Johnston believes that the "optimistic intellectual methods and social aims of Enlightenment ideas have been closely associated with science in wider culture, and continue to influence Western societies today" (p. 65).

Other academics of the time went even further in terms of relating science and human society. David Hume, developed a 'science of man' and applied scientific methods to study past human cultures. According to Johnston (2009), "[Hume's] definition of reliable knowledge, based on factors such as experience, evidence, and causation, were important in developing a philosophically grounded scientific method" (p. 67).

At about the same time, John Locke was developing the theory of Empiricism. Locke insisted that all human knowledge of reality is the result of sensory experience (Robinson & Groves, 2013; Ladyman, 2002). One aspect of John Locke's ideas and empiricism that had a significant impact on education was the idea that the human mind at birth is a blank slate, leading science educators through different times to see teaching as filling a receptacle with science facts and ideas. More importantly, in the context of constructivist reforms in science education, is to discuss Locke's ideas in relation to the various forms of constructivism.

Analyzing different forms of constructivism allows one to more fully comprehend the question "is new knowledge—whether it be individual knowledge, or public discipline—*made* or *discovered*?" (Phillips, 1995, p. 7). According to Phillips, Locke's ideas place him near the knowledge is discovered end of the spectrum and opposite from the end of humans as creators of knowledge. Phillips emphasizes that Locke believed that "the mind is not able to produce simple ideas of its own…it is the object in the external realm of nature…which is causally responsible (via experience) for producing our knowledge" (p. 7). Furthermore, Phillips reports that Locke believed that although complex ideas could be constructed by the human mind (which would put him in the humans as creators of knowledge end of the spectrum), this ability was established before birth or occurred automatically (Phillips, 1995).

As a response to the arguments posed by Hume and Locke, Kant was trying to resolve the conflict between empiricism and rationalism and figure out how it is that we acquire knowledge of the world. Unlike Locke, Kant did not see the human mind as a passive recipient of information, he saw it as actively engaged in the process of knowing. From Kant's point of view,

> when we look at the world we 'constitute' it in order to make sense of it. Some of the concepts that we apply to our present experiences do indeed come from our past ones, but the most important ones **precede** experience. They are **a priori** – prior to our experiences. (Robinson and Groves, 2013, p. 74)

Phillips (1995), in describing Kant as a quintessential constructivist, states, “The human cognitive apparatus…was responsible for shaping our experience, and giving it causal, temporal, and spatial features” (p. 6). With regards to science, Kant argued against empiricism and limited science to knowing about the phenomenal world (Robinson and Groves, 2013). According to Loving (1997), “Kant's transcendental idealism added a new kind of absolutist tradition” (p. 428) to science.

Again, it is my position that creating awareness of the arguments developed during this time period and learning about the impact different historical individuals had on how knowledge is generated, can have an influence in science educators’ perspectives on epistemology and the nature of science.

Science, Philosophy and Education in the 19th Century

In the middle of the nineteenth century, the school curriculum in the elementary grades primarily focused on the basic “R’s.” In the latter grades of primary education history and geography were also offered. The few high schools in existence during this time placed an emphasis on the college preparatory curriculum and primarily served the upper class. Latin, literature, philosophy, and algebra were the popular subjects (Pulliam & Patten, 1995). A strong critic of this classic curriculum and a supporter of science was Herbert Spencer. In 1855, Spencer published *What Knowledge Is of Most Worth?* advocating the importance of science and mathematics in the curriculum. Spencer recognized scientific knowledge as essential for leading a healthy life and as necessary for improving productivity in an industrial society through a strong knowledge base on the use of natural resources (Gutek, 1991).

During this time, the American public increasingly demanded using scientific thinking to solve problems faced in everyday life (Rudolph, 2005). According to Rudolph (2005), "one eminent scientist in 1884 argued for a thorough reorganization of higher education around the teaching of the scientific method" (p. 346). Rudolph goes on to state, "with 'truth' as the primary aim of higher learning, there was no choice, he went on, but to let the scientific method be the 'fundamental object in every scheme of a liberal education'" (p. 346). However, even though there was increased interest in science, the teaching of science placed minimum importance on teaching how scientists conducted their work (Rudolph, 2005).

By the turn of the century, science education became increasingly popular with the new technological advances of the era. Francis Parker, Wilbur Jackman, Williams T. Harris and E. G. Howe are recognized as leaders for their contributions to elementary science education. A common factor among the science programs developed by these educators was the mastery of scientific knowledge as the primary aim of science education. A different model of science education was developed by Liberty Hyde Bailey in an attempt to slow emigration from rural communities to urban centers occurring in the late nineteenth century. The primary aims for Nature study were to foster an appreciation for nature, create an interest in farming and assist the personal development of the student (Bybee, 1993).

For the most part, teaching methods in the nineteenth century consisted of memorization and recitation. Most teachers lacked training and were unaware of any current philosophies of education. The work of Johann F. Herbart strongly influenced teaching practices in the latter part of the century. Herbart developed a highly structured program of education called the Five Formal Steps of Teaching and Learning. These steps were: preparation, presentation, association, generalization, and application. Herbart's program led education into a "lock-step" system; teachers taught all subjects in the same way using the same textbooks (Pulliam & Patten, 1995).

In the latter part of the nineteenth century there was also an increased growth in the number of high schools in the nation. This growth created confusion over standards and curriculum. Additionally, "modernists" and "traditionalists" argued over what subjects to include in the curriculum and the purpose of secondary education, that is, whether education should provide vocational training or concentrate on the liberal arts (Pulliam & Patten, 1995). The tension between modernists and traditionalists was evident in a high school science survey, according to Rudolph (2005), the survey "asked teachers whether a high school biology course should place more emphasis on 'training in science method' or 'the utility value of the science' a phrasing which itself betrayed the assumption that such goals were somehow incompatible" (p. 362).

In science education, the laboratory method of instruction was widely adopted to expose students to the methods of science (Rudolph, 2005). In an effort to address these issues and give order and structure to secondary education, the National Education Association (NEA) created the Committee of Ten in 1892. The committee included as members the U.S. Commissioner of Education, five university presidents, one college professor, two headmasters and one high school administrator. The task of the committee was to examine the high school curriculum and make recommendations about methods, standards, and programs. The Committee of Ten took a strong stance on educational equality. The committee maintained that the purpose of secondary schools was to prepare students for a productive life regardless of their vocation. Members of the committee believed that all students had the aptitude to successfully perform on the educational program endorsed by the committee. In the committee's report, labeled as "a bastion of educational conservatism" (Pulliam & Patten, 1995, p. 91) college interests dominated, traditional subjects were supported, vocational and commercial courses were largely ignored, and the creation of new or innovative high school programs was discouraged (Pulliam & Patten, 1995; Ravitch, 1995; Rudolph, 2005).

The Committee of Ten also examined each academic subject individually and issued recommendations as to what the content of study should consist of, how should it be assessed, when should it be introduced, for how long should it studied, how should it be taught and how teachers should be prepared (Ravitch, 1995). Although the work done by the committee could not be enforced by the federal government, it had much influence over secondary education. One outcome of this reform movement was the creation of the College Entrance Examination Board; its purpose was to establish a common examination for college admission and the creation of admission standards in different subject areas. This board allowed colleges to maintain their power in the admissions process. Secondary schools began to use these subject standards to prepare students for the College Board's examinations and as a result the schools received criticism for teaching to the test (Ravitch, 1995).

In regards to science education, the Committee of Ten developed college entrance requirements that prioritized laboratory preparation in the high school. These requirements, titled *Harvard University Descriptive List of Elementary Physical Experiments*, were published in 1886. Rudolph (2005) describes these exercises as "highly quantitative, requiring careful observations and precise measurement, all to be dutifully recorded in a laboratory notebook and submitted for inspection to the examiners in the physics department" (p. 349). Furthermore, Rudolph claims "the inductive method of empiricist philosophy lay at the heart of the laboratory experience, and introductory textbooks as well as prominent scientists of the day reinforced this mode of learning" (p. 352). Empiricism is the theory that all knowledge is derived from experience only. Rudolph goes on to say, "the commitment to the inductivist approach was so complete that scientists and educators thoroughly denigrated anything that hinted at theoretical speculation" (p. 352). During this period of time, the scientific method in school science was synonymous with the laboratory method of instruction (Rudolph, 2005).

Science and Science Education in the Early 20th Century

The influence of the Committee of Ten over secondary education was highly criticized by professional educators who objected to the college and university member domination in the committee. As a result, the NEA created the Commission on the Reorganization of Secondary Education (CRSE) in 1918. The CRSE opposed the Committee of Ten's position that all children have the potential to succeed in the academic subjects required for college admission. In its Cardinal Principles of Secondary Education the CRSE concluded that the secondary curriculum "should be tailored and differentiated to meet the needs of society and of children" (Ravitch, 1995, p. 43). The CRSE advocated for a comprehensive high school offering a wide range of subjects and ultimately held that a liberal education was not for everyone. The work of the CRSE led to the tracking of students into an academic curriculum or a vocational one (Pulliam & Patten, 1995; Ravitch, 1995).

A period of radical school reform began to take shape with the work of the CRSE. In 1919, the Progressive Education Association was formed. This association supported experimental schools, sponsored annual public conferences on educational reform and published the journal Progressive Education (Pulliam & Patten, 1995). More specifically, reformers of this era intended to change high school physics instruction to be more personally and socially relevant (Rudolph, 2005). A major influence in this period of reform was John Dewey. Dewey attacked the curriculum of the time for being too subject centered and knowledge oriented. According to Dewey, education should be centered on the process of problem solving using the scientific method. Dewey rejected the idea of education as the study and mastery of knowledge organized into subjects. In addition to advocating "learning by doing," Dewey stressed the importance of relating instruction to current social, economic and political issues and problems (Gutek, 1991). Throughout this period of reform there was a definite antagonism to Dewey's ideas and the progressive education movement. The criticism was based on the fear that academic standards were suffering at the expense of progressive education programs (Pulliam & Patten, 1995).

The influence of John Dewey and the Progressive Education Association did not completely change teaching practices in science. According to reports published by the federal Office of Education (Instruction in Science, 1932) and the National Association of Research in Science Teaching (Report of the Committee on Secondary School Science Teaching, 1938), the knowledge model of science teaching continued to dominate the secondary school curriculum. The instruction of scientific methods remained a secondary goal of science education (Bybee, 1993).

Rudolph (2005) however, argues during this period of time "understanding the scientific process became an explicit goal of science instruction (p. 344). Rudolph contends that there was a conceptual shift regarding the teaching of the scientific method in schools. According to Rudolph, John Dewey's book How We Think "laid out the familiar steps of what became the popular view of the scientific method and contributed to the redefinition of science as an everyday problem-solving activity (p. 344). What is interesting, Rudolph indicates, is that

> Dewey did not try to provide a stepwise account of how scientists went about their work. He aimed rather to describe reflective thought in the most general sense-to detail the way people used thinking as an effective guide to practical action. (p. 367)

Similarly, Illinois biologist Stephen Forbes aimed to separate scientific reasoning from the laboratory method of instruction. Forbes saw the scientific method as a mental method and to study it meant to study how a scientist's mind operated while searching for scientific truth (Rudolph, 2005).

The engineer Dexter Kimball appropriately summarized the impact Dewey had on science education, stating in 1913, "the term 'scientific method' has come to mean a somewhat definite way of approaching the solution to all problems as opposed to older and so-called empirical methods" (Kimball, 1913, as cited in Rudolph, 2005). In subsequent years, lists of Dewey's steps of the scientific method became fairly common in the educational literature of the time, along with lists of projects for students to solve. This can almost be seen as a return to the laboratory method of instruction promoted by the Committee of ten that the progressive movement fought against and attempted to leave behind.

Science and Science Education in the Late 20th Century

After the Second World War, math and science education received increased attention, primarily to insure national security. In 1945, Vannevar Bush was commissioned by President Roosevelt to write a report on a program for postwar scientific research. In the report, Science the Endless Frontier, Bush identified scientific progress as an essential means to fight disease and as a need for national security. To address these issues, Bush called for the search of talented youth and the provision of scholarships by the federal government to attract students into scientific careers. However, Bush also warned against attracting too much talent towards science, he saw the educational structure as a pyramid, and concluded that there are only a limited number of students with the ability for science study (Bush, 1945). Bush's influence became evident when James Killian, in a speech to the White House Conference on Education, stressed the importance of science education and its role in national security (Dow, 1991).

Throughout the 1950s, the criticism of low academic standards in American education continued. The unresolved issue of an academic liberal arts curriculum versus vocational training in the schools was also in the middle of this postwar debate about education. In Educational Wastelands: A Retreat from Learning in Our Public Schools, Arthur Bestor held that American schools had become too concerned with vocational training and forgotten their primary purpose of teaching students how to think and how to learn. As a result of this criticism, the Progressive Education Association closed its doors in 1955. The last issue of the journal Progressive Education was published in 1957 (Dow, 1991; Pulliam & Patten, 1995; Ravitch, 1995). The dominant view within science education during this time was the logical empiricist view of science which had a direct impact on the pedagogical and curricular changes that would come as a result of Sputnik (Matthews, 2003).

The launch of the Russian spacecraft Sputnik in 1957 alarmed the American public and brought attention to American global competitiveness making science education a national priority (Duschl, 1990). After World War II and prior to the launch of Sputnik, the National Science Foundation (NSF) was petitioning for increased funding from Congress based on reports that the Soviet Union was aggressively developing an educational pipeline of scientists and engineers. Congress dismissed these requests stating these reports were simple propaganda. Not until the launch of Sputnik that Congress paid attention and approved an emergency budget allocation of $9 million for the purpose of creating science education institutes (Duschl, 1990).

In response to the Sputnik event, the federal government initiated its involvement in formulating policy to affect teacher education and preparation. In 1958 Congress passed the National Defense Education Act (NDEA). As the name implies, the goal of this policy was to increase the nation's security and global competitiveness by improving math and science education.

The policy instruments of teacher education and professional development provisions in federal legislation included for the most part inducements in the form of federal funds for teacher training institutes, fellowships, partnerships between K-12 and institutes with schools, colleges and departments of education, and expanded pre-service and professional development service providers (Cohen-Vogel, 2005). To comply with policy mandates, I would argue that often the focus of those developing and planning science teacher professional development is the method, content, and effectiveness of their programs and addressing science teacher beliefs was not a priority.

In terms of teacher preparation and professional development, the National Science Foundation (NSF) was the major government organization leading the effort to improve science education beginning with grants to fund summer institute programs for teachers under the direction of scientists. As an example, in 1958, there were 120 institutes and 6,000 stipends with a total cost of $6,400,000. In 1959 and 1960, there were 320 institutes and 16,000 stipends for high school teachers. In addition to funding summer institutes, the NSF also became involved in the development of high school science curricula as well as the teacher training that went along with its implementation (Duschl, 1990).

During the next three decades, the NSF was a major leader in science education. There is one major shift affecting teacher professional development that should be noted here. Duschl (1990) indicates that in the early 60s the NSF took the position that "summer institutes would not have an impact on the teaching that occurred in schools if the teachers were using outdated textbooks and curricula" (p. 21-22). As a result, the implementation of policy changed and the NSF's priority became the development of new curriculum materials. In turn, this shift led to teacher training in how to use the new curricula and a greater separation between science teachers and scientists (Duschl, 1990). Duschl states,

> By 1964 it was clear that curriculum implementation and not teacher training was the focus, and Congress raised questions about whether the shift of funds from institutes to the ccss program meant that teachers were selected differently for the summer programs. Indeed they were. But more important, teachers were participating in sessions in which the science taught to them was the science they would teach to children. It was a watered down approach and often quite insulting to a person with a background in science. The instructors of the programs were also more often than not faculty from colleges of education, rather than scientists. (p. 26)

According to Duschl (1990), this shift resulted in the focus of professional development moving away from teachers and towards entire school systems and control of programs away from scientists and toward teacher educators. The training program funded by the NSF increased eightfold during the period of 1962 to 1972, while the funding for the teacher institutes was cut in half. During this period, professional development was about how to teach rather than what was needed to know to teach.

The positivist paradigm was the predominant philosophy of science through much of the 1950s (Loving, 1997). Duschl (1985) illustrates the power of the positivist paradigm by claiming that this truth-seeking philosophy dominated most writing in science textbooks and classroom presentations of science. Duschl further claims that during this time of curriculum development, the scientific community "effectively ignored relevant developments in the history and philosophy of science" (p. 27). Challenges to the empiricist view of science were apparent in the 1950's by theorists such as Thomas Kuhn. Kuhn's *The Structure of Scientific Revolutions* was a major influence in the development of the postmodernist paradigm. Postmodernism "concentrates on how the natural sciences are *actually* carried out (rather than how they *should* be carried out) in the context of social, political, or psychological dimensions" (Loving, 1997, p. 433). Loving argues that science education ignored the challenges brought about by Kuhn and other postmodern scholars and continued to support a positivistic view of science.

Matthews (2003) offers a slightly different perspective. According to Matthews, the science education community was easily swayed by the most popular position regarding the nature of science. After the second edition of Kuhn's book appeared in 1970, Kuhnianism became a more popular view in science education. Furthermore, Matthews reports that Kuhn's views "certainly reinforced a lot of constructivist-inspired relativism and subjectivism in the science education community" (p. 113).

The new curricula designed during the 1960s was developed with the intent that "students would discover conceptual knowledge through activities designed to mimic scientific inquiry (Hodson, 1996, p. 115). According to Hodson, the reason for developing curricula in such a way was "the 'progressive', child centered notion that that inquiry-oriented learning is close to children's 'natural forms of learning' (p. 116). The crisis created by the Sputnik event led to promoting scientific inquiry as both content and method, as Schwab (1962) described in his influential essay 'The teaching of science as enquiry'. Hodson (1996) claims that further exacerbating the challenge of teaching science through inquiry, was the notion that "rote learning was falsely equated with transmission/reception methods, and meaningful learning with discovery methods" (p. 116). Finally, Hodson claims that creating more confusion was the result of failing to distinguish "how (existing) knowledge is learned by students (what I have called *learning science*) from considerations of how (new) scientific knowledge is generated and validated within the scientific community" (p. 116). Hodson believes that the idea that the best way to learn science through activities that model scientific inquiry is nothing more than an assumption and states, "what had started out as a psychological justification of learning by discovery had slipped over into an epistemological one" (p. 117).

Through this epistemological viewpoint, Hodson (1996) observes that "you cannot discover something that you are conceptually unprepared for. You don't know where to look, how to look, or how to recognize it when you have found it" (p. 118). As a middle school science teacher, I have found that, at times, students may not always find the conceptual significance of a science activity, and tend to agree with Hodson that if as an educator, one does not prepare carefully, students may be "distracted by all the clutter and 'noise' of hands-on activity" (Hodson, 1996, p. 118).

In summary, Matthews (1997) argues that in the 1960s two issues developed that could have an impact on science education today. The first issue was "equating the nature of science with the logical-empiricist nature of science" (p. 306) and the second issue was "to assume that, whatever view one adopted about the nature of science, the educational objective was to have students believe that view" (p. 306). In this case, Matthews refers to the logical-empiricist view or the constructivist view of the nature of science. Either way, Matthews (2003) claims that "the science education community is as guilty as any other of the charge of misunderstanding Kuhn, and drawing relativistic and subjectivistic epistemological conclusions" (p. 112). Matthews suggests "the science education community should more effectively engage with on-going debates and analyses in the history and philosophy of science" (p. 112).

Contemporary Issues in Science Education

An additional but different conflict that can surface as we analyze the planning and development of professional development involves the standards movement. In writing about economics and inequality in schools, Apple (2001) maintains that after the publication of A Nation at Risk, economic interests through the development of standards increasingly dominated education. During the decade after the publication of A Nation at Risk, nearly 1,000 mandates were legislated and close to 400 national reports were published with the goal of transforming and improving education (Hurd, 1993). According to Cohen-Vogel (2005), after 1992 teacher education policy shifted towards "heavier reliance on professional standards in the form of accreditation, licensing, and certification" (pg. 29). As a result, "summer institutes and training centers have largely fallen away to mechanisms that hold states, districts, schools, and institutions that prepare teachers accountable for ensuring their teachers are highly qualified" (p. 38). Webster-Wright (2009) argues that implied in the standards movement is a view on professional development "that focuses on the professional as deficient and in need of developing and directing rather than on a professional engaged in self-directed learning" (p. 712).

One strong interest group supporting the development of standards is the business community. Businesses see standards as a means for a well-educated, institutionalized and socially regulated workforce. Businesses also look to greater costs in training and remediation programs (Goldberg & Traiman, 2001).

According to Apple (2001), this is an attempt to make education itself an economic product; as a result he describes the following effects:

> The tendency for the curriculum to be rationalized at a central level and largely focused on competencies measured by standardized tests (and more and more dependent on predesigned commercial materials and texts) is resulting in the deskilling of teachers. (p. 284)

In making this comment, Apple argues that through standardization of education, teachers are losing the skills to set relevant curriculum goals, establish content and design lessons and instructional strategies. I believe this also tends to turn professional development into pure training. And, specifically pertaining to science education, I believe that addressing teachers' beliefs about the nature of science and/or placing a greater focus on the history and philosophy of science as part of a teacher's professional development and can remain a distant priority.

In light of recent standards based education reform efforts, Giroux (1985) perceives a risk for public school teachers, one that has implications for their professional development. According to Giroux "teachers do not count when it comes to critically examining the nature and process of educational reform" (p. 376) and so, teachers now run the risk of being demoted to "specialized technicians within the school bureaucracy, whose function then becomes one of managing and implementing curricula programs" (p. 376). I believe this view of teachers reinforces the paradigm of professional development as teacher training. Giroux does offer a possible solution against this challenge teachers confront. Giroux proposes to change how we view teachers, from specialized technicians to transformative intellectuals. As transformative intellectuals, teachers are "actively involved in producing curricula materials suited to the cultural and social contexts in which they teach" (p. 378). I would argue that in many professional development programs, teachers are passive recipients of information and do not actively produce curricula materials. Giroux goes on to state: transformative intellectuals take seriously the need to give students an active voice in their learning experiences" (p. 379).

Giroux (1985) argues the following:

> Schools should do more than pass on in an objective fashion a common set of values and knowledge. On the contrary, schools are places that represent forms of knowledge, language practices, social relations, and values that are representative of a particular selection and exclusion from the wider culture. (p. 379)

I would also contend that the arguments posed by Giroux must apply to professional development programs for science teachers. Such programs must go beyond the paradigm of teacher training and do more that pass on a set of skills or concepts. Professional development should not only be about acquiring more content or improving pedagogical skills, I contend that it should include a critical introspective into the nature of knowledge, the nature of science and a critical examination of one's beliefs.

Furthermore, as we have seen in this exploration into the history and philosophy of science, these fields are essential to learning science. Matthews (1997) argues

> the recognition that science was intimately tied up with philosophy, or more generally with world views, and that the learning of science also required the explicit or implicit learning of philosophy, was of course widely recognized among historians and philosophers of science, and among many top-rank scientists (Einstein, Planck, Eddington, Jeans, Schrödinger, Bohr, etc.), but it was mostly overlooked by science educators. (p. 300)

Research into Scientific Epistemic Beliefs and Professional Development

A number of studies regarding science teacher beliefs have focused on preservice teachers and how their beliefs change as a result of a science methods course that specifically addressed the nature of science. Borda et al. (2009) report that "college undergraduates consistently hold, and sometimes leave college with naïve epistemologies" (p. 162). Abell, Martini and George (2001) found that students in a science methods course recognize practices scientists engage in, such as making observations and generating patterns, but failed to recognize the role of this practice in theory building. Abell et al. developed the following set of recommendations to make the nature of science more explicit within the methods course:

- prompt students to distinguish what one can come to know from: a) observation alone; b) invention; or c) sources such as teachers and texts
- help students focus on how incoming ideas influence observations
- focus on the role of discrepant data by asking questions such as: 'Are all data equally important?' 'What do we do with data that do not fit our predictions or theories?'
- emphasize the role of the scientific community in constructing and evaluating knowledge, and
- ask students to reflect more about their evolving nature of science conceptions (Abell et al. 2001).

Abd-El-Khalick (2005) similarly found that preservice teachers hold naïve views on several aspects of the nature of science and even after explicit instruction on the nature of science (NOS), preservice teachers' views may remain unchanged or they may develop conflicting views. Abd-El-Khalick (2005) states,

> little change was evident in students' views of the tentative and theory-laden NOS, and the social and cultural embeddedness of science. By comparison, changes were pronounced regarding the inferential nature of scientific entities, the distinction and relationship between theories and laws, and the empirical NOS (p. 26)

Further, Abd-El-Khalick (2005) reports,

> Inconsistencies and compartmentalization were evident in the views of many participants. For instance, it was not unusual for some participants to note that scientists use creativity in developing scientific knowledge and then ascertain that science is distinguished by a prescriptive universal 'Scientific Method' that guarantees valid knowledge. Similarly, some participants still indicated that scientific knowledge is tentative and subject to change only to indicate later in their questionnaires that laws are different from theories because they are proven 'true' (p. 26)

The idea that science teachers can switch between naïve and sophisticated science epistemologies provides support for a theory of epistemological development that is context and situation dependent. In a different study, Akerson, Morrison, and McDuffie (2006) found that while preservice teachers' views of the nature of science improved as a result of a science methods course, these improved views were not retained past 5 months and in some cases, the participating preservice teachers reverted to their original views on the nature of science.

Windschitl and Thompsom (2006) collected data from 21 students enrolled in a teacher education program to engage in an independent scientific inquiry project. To learn about the participants beliefs about the nature of science and the role of models in science, Windschitl and Thompson developed a questionnaire about the nature of science models, the function of these models, and their use in instruction. Windschitl and

Thompson also examined the participants' inquiry journals, unit lesson plans, videotapes of participants' presentations, responses to the model-based technology assignment, transcripts of conversation, and a questionnaire given at the end of the course. Windschitl and Thompson found that thinking about science from a models perspective and creating a scientific model provided a challenge to all participants. Windschitl and Thompson argue that investigating scientific models is a task "rarely practiced in science education at any level" (p. 823). As a result of the difficulty in teaching and learning science from a models based perspective, Windschitl and Thompson claim that teachers often fall back and rely on the traditional and oversimplified approach of the scientific method as a way to implement a hands-on science approach; Windschitl and Thompson state, "even though it encourages naïve empiricism and often dispenses with the need for deep content knowledge to inform the inquiry process, it provides the only structure within which many teachers feel comfortable engaging their students in hands-on work" (p. 825). Although this conclusion is about pre-service science teachers, it supports the point made earlier by Loving (1997) and Aikenhead (2003) that laboratory activities designed like cookbooks where emphasis is placed on procedures that lead to one right answer leads to a science education that is abstract and decontextualized.

In another study of preservice teachers engaged in a fieldwork experience, Crawford (2007) found that within the framework of teaching science as inquiry, the interns teaching strategies varied widely from the traditional lecture to full, open inquiry where students generate their own research questions. According to Crawford, "the most critical factor influencing a prospective teacher's intentions and abilities to teach science as inquiry, is the prospective teachers' complex set of personal beliefs about teaching and views of science" (p. 636).

Kang (2008) and Yerrick, Parke, and Nugent (1997) had similar findings as Crawford (2007), they also found that preservice teachers' instructional goals were linked to their personal epistemologies. However, Kang found much inconsistency between science teacher beliefs and actions. Kang attributed changes in science teaching practices to the introduction of new perspectives on science teaching and learning as opposed to changes in beliefs regarding the nature of science. In their study of two-week summer institute for science teachers, Yerrick, Parke, and Nugent (1997) revealed that teachers maintained their initial fundamental beliefs about the nature of scientific knowledge. Yerrick, Parke, and Nugent believe "that an intricate set of resolving and rationalizing mechanisms allowed our participants to assimilate the messages of reform institutes without changing fundamental views of science and teaching" (p. 154).

A research study that delved deeper into the relationship between a teacher's science epistemological beliefs and their practice and also sought to focus more on experienced teachers was conducted by Brickhouse (1990). Brickhouse explored the relationship between teachers' beliefs about the growth of scientific knowledge and the methods used in their classroom instruction. Brickhouse conducted case studies of three science teachers. Case study interviews covered the teachers' conceptions of the nature of science, their roles as teachers, and their students' roles as learners. The case studies also included 35 hours of classroom observation and examination of the teachers' curriculum materials such as textbooks, tests, worksheets, and laboratory activities. One case study in Brickhouse's (1990) research involved a middle school science teacher with 26 years of experience and a master's degree in science education. This teacher, according to Brickhouse, viewed theories as truths that had been uncovered through rigorous experimentation. This view of science is more aligned with logical positivism and logical empiricism. Brickhouse found that the goal of instruction in this classroom was for students to know what the scientific theories are and student performance was based on a student's ability to memorize such truths. Brickhouse also found this teacher to have a view of the scientific method as a linear, rational process that leads to unequivocal scientific truth. Brickhouse found that a major part of classroom laboratory activity was focused on properly following procedures to get the correct answer. Finally, Brickhouse determined that the teacher in this case study considered science to progress by the accumulation of science facts and concepts. Brickhouse also observed a beginning teacher and found that as a result of inexperience, the textbook was the source of authority in this classroom and therefore, Brickhouse found this teacher to believe in a linear, stepwise scientific method as it is often described in science textbooks. One major conclusion that Brickhouse made from this case study was that "teacher education will make little impact on practice if beginning teachers are unable to implement instruction consistent with their beliefs about science" (p. 60).

Research into professional development has also been conducted through large scale quantitative methods. In one example of quantitative research analyzing the effectiveness of professional development, Garet, Porter, Desimone, Birman, and Suk Yook (2001) provide a large-scale empirical comparison of effects of different characteristics of professional development on teacher learning. Garet et al. gathered data from 1027 math and science teachers participating in Eisenhower professional development programs. Garet at al. used a teacher activity survey to look at three core features of professional development: content knowledge, opportunities for active learning, and coherence with other learning activities. Additionally, Garet et al. analyzed the type of professional development activity, duration, and collective nature. Garet et al. used an ordinary least squares regression to analyze survey data. According to Garet et al. their results indicate that "professional development that focuses on academic subject matter (content), gives teachers opportunities for 'hands-on' work (active learning), and is integrated into the daily life of the school (coherence) is more likely to produce enhanced knowledge and skills" (p. 395). Garet et al. also report "sustained and intensive professional development is more likely to have an impact, as reported by teachers, than is shorter professional development" (p. 395).

Allchin, Andersen, and Nielsen (2014) designed a professional development project with 20 Danish secondary science teachers where they explicitly introduced the NOS tenets and asked the teachers to plan and test classroom activities on the NOS. Allchin et al. found that teachers did not find anything wrong with the NOS tenets. Allchin et al. state, "while they [teachers] perceived the NOS tenets as informative, helping them to sharpen their own understanding of NOS, none regarded the 'consensus list' operationally as an entry into NOS teaching. The teachers preferred to teach NOS in context" (p. 463). Allchin et al. argue "the focus of research needs to shift from "how" to teach NOS to how to help teachers make best use of the knowledge about NOS teaching that now exists" (p. 481). In my own view, research into how professional development is designed and the role of science beliefs in this design may increase our understanding about how to best assist teachers how to move from teaching about the NOS to how better integrate the NOS into their teaching and use different approaches to teach about the NOS.

Other studies regarding the nature of science and professional development have focused on the effects of creating authentic science research experiences for teachers and the relationship between scientists and science teachers. Blanchard, Southerland, and Granger (2009) found that teachers with sophisticated, theory-based understandings of teaching and learning prior to the research experience were more likely to have classrooms supporting scientific inquiry. Caton, Brewer, and Brown (2000) found that the professional development research experience increased the participants' appreciation, understanding, and use of inquiry in the classroom. Caton et al. also found that successful collaborations between teachers and scientists occur when equal status between them is emphasized and there is opportunity to collaborate. However, it is also possible that power imbalances can have a negative effect on the professional development experience. When teachers and scientists come together a potential exists for segregation based on academic status. Narode (1993) found that when mathematics teachers and professional mathematicians came together during a summer institute there was clear system regarding social status based on a person's academic standing. Individuals with doctorate degrees presenting in the conference were given the highest status and K-12 mathematics teachers were given a lower status.

Dresner (2002) found that teachers participating in a summer forest research experience led to changes in the teachers' approach to teaching and also increased motivation, confidence, knowledge and skills in science teaching in the areas of biology and environmental science. Similarly, Houseal, Abd-El-Khalick, and Destefano (2014) found that a similar field research professional development experience in Yellowstone showed positive shifts in teachers' attitudes and also resulted in changes in pedagogical choices. In their study of a science teacher professional development summer institute, Capps and Crawford (2013) found that a summer institute provides a good way to supporting teachers in enhancing their views of the NOS. Capps and Crawford also found that not all teachers equally made gains in their views about the NOS and that extended support that allows for reflection may be needed for some teachers.

On the other hand, Drayton and Falk (2006) found that "most teacher professional development efforts that connect the scientist with the science teacher have focused on the transfer of knowledge, structured to make efficient use of the time of both teacher and scientist" (p. 737). Palmer (2007) offers a rationale for how gaining or possessing knowledge can lead to rivalry and segregation. In describing his vision of a typical educational community based on an objectivist stand, Palmer states,

> In the objectivist myth, truth flows from the top down, from experts who are qualified to know truth…to amateurs who are qualified only to receive truth. In this myth, truth is a set of propositions about objects; education is a system for delivering those propositions to students; and an educated person is one who can remember and repeat the experts' propositions. The image is hierarchical, linear, and compulsive–hygienic, as if truth came down an antiseptic conveyer belt to be deposited as pure product at the end. (p. 103-4)

In some cases, science teachers' professional development can represent Palmer's model where scientists are the experts and teachers are the amateur scientists.

Palmer (2007) also offers a different model where truth is no longer an object; instead what is to be learned and taught exists in relationship with the participants of a community. Palmer states,

> In the community of truth, as in real life, there are no pristine objects of knowledge and no ultimate authorities. In the community of truth, as in real life, truth does not reside primarily in propositions, and education is more than delivering propositions about objects to passive auditors. (p. 104).

With this model of learning, the goal of professional development is the creation of a broader learning community. As teachers enter into a dialogue with scientists, the teachers are given a glimpse of the scientific community and how it operates. Teachers participate in this scientific community by making observations, asking questions, submitting work samples for revision, and designing scientific investigations. By implementing this different goal, teacher learning has now moved from an acquisition model of learning to a participatory model. Sfard (1998) suggests that in the participatory metaphor "learning should be viewed as a process of becoming a part of a greater whole" (p. 6). Drayton and Falk (2006) found positive results in their professional development program by placing an "emphasis on teachers' learning as adults, with no specific classroom application" (p. 759), and focusing on the teachers' "mentorship or collaborative relationship with working ecologists" (p. 759).

I believe these findings have important consequences for researchers examining professional development experiences for science teachers in the context of how the professional development experience addresses teacher beliefs about epistemology and the nature of science.

Synthesis

A majority of the research literature I reviewed regarding epistemological and nature of science beliefs focused on preservice or in-service teachers. Webster-Wright (2009) conducted a detailed review of the literature on professional development and found that about three fourths of the literature is focused on the evaluation of professional development programs and a small portion is focused on examining the delivery of the professional development experience. Additionally, the majority of the literature on professional development is anecdotal. Webster-Wright concludes, “despite decades of research into effective PL, little has changed in PD research and practice across most professions” (p. 712). More concerning however, is that Webster-Wright’s review of the professional development literature “reveals that the discourse of PD is focused on the development of professionals through delivering programs rather than understanding more about the experience of PL to support it more effectively” (p. 712).

In my review of the literature, I found that few studies focused on those responsible for designing and providing professional development. Although research has been done on educational leaders around what constitutes effective professional development, the research did not focus on the beliefs of those individuals who have designed the professional development experiences.

However, one influential study in the development of the research question for this dissertation proposal, did peek into the beliefs of individuals responsible for providing professional development in the process of trying to determine what makes professional development effective. Astor-Jack, Balcerzak, and McCallie (2006) interviewed providers of professional development at four informal science institutions: a zoo, a science centre, a botanical garden, and an ecological field science outreach centre. Although the focus of their study was to identify the design components of professional development, the instructional strategies that support implementation, and the role of comfort in professional development, one surprising result of the study was the different definitions of inquiry provided by the participants. Some considered inquiry a teaching strategy while others saw it as a learning strategy (Astor-Jack, Balcerzak, & McCallie, 2006). Inquiry learning refers to the active learning process of students, often compared to constructivist forms of learning while inquiry teaching refers more to the activities a teacher engages in to create student inquiry in the classroom. It is important to reflect on this distinction to determine how research participants for this study approach inquiry as part of their professional development activities. The results of Astor-Jack, Balcerzak, and McCallie's (2006) study shows that the professional development providers' thoughts on scientific inquiry seems to impact the professional development experience and its eventual impact in the classroom.

Critique

Historically speaking, reviewing the history of science education shows there have been numerous efforts at reforming science education and part of these efforts show a concern by science teachers and curriculum developers at understanding what is meant by the nature of science (Matthews, 1998). While much of the research discussed in this literature review seeks to explore teachers' understanding of the nature of science, a study by Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) used a Delphi questionnaire to determine what consensus exists among science education experts (including scientists, historians, philosophers and teachers) regarding the nature of science within the framework of the contemporary school science curriculum. The research identified nine themes with high consensus considered to be essential elements of the curriculum. This research is important because it brings in an important perspective, one that is different from research seeking to evaluate professional development programs. The study by Osborne et al. focused on science experts as opposed to participants of a professional development program. Osborne et al. argue, "although there clearly is an ongoing debate within the academic community about the nature of science, we feel that the essence of this debate is about the extent to which cultural and subjective factors impinge on the practice of science" (p. 714). Therefore, Osborne et al. suggest that this debate has "few insights to offer into the practices, methods, and processes of science that any school science curriculum would seek to expose and communicate to students" (p. 714). I disagree with Osborne at al. in their suggestion that this debate has little to offer to science education because the postmodernist thought movement is increasingly questioning the validity of scientific claims (Kuntz, 2012).

According to Matthews (1998) the debate over the nature of science has intensified over that past few decades. Matthews describes a view of science in the past as

> there was general agreement that science was a good thing, that it was a cognitive enterprise abiding by intellectual standards, that it valued objectivity, that it

> sought to find truths about the world, and that it gave us the best possible understanding of nature and reality. Merton's characterization of science as open-minded, universalist, disinterested, and communal (Merton, 1942) summed up professional and lay opinion on the matter. (p. 162)

This view of science is in contrast to the way Aikenhead (1997) describes contemporary science: "mechanistic, materialistic, reductionist, empirical, rational, decontextualized, mathematically idealized, communal, ideological, masculine, elitist, competitive, exploitive, impersonal, and violent" (p. 220). Matthews (1998) argues that as a result of this debate, teachers "need to understand and evaluate the postmodern challenges of orthodoxy" (p. 163) in addition to the traditional pedagogical content knowledge. However, Matthews contends that a potential danger of urging for the inclusion of the history and philosophy of science as part of science teacher education is that epistemological development will be defined as "believing what I believe about epistemology" (p. 167) and thus teachers can potentially cross the line from education into indoctrination. Matthews believes that

> Most positions in the philosophy of science, including both constructivism and realism, are contested. Bringing epistemology and philosophy into focus in science education and putting the nature of science into curriculum documents will be to no great avail if it merely becomes the occasion for students repeating the opinions of their teachers. If epistemology becomes a catechism—like dimat in the former Soviet Union—then it defeats its educative purpose. (p. 168)

Matthews suggests that while we cannot expect teachers of science to also be philosophers of science, teachers should have some basic knowledge regarding the history and philosophy of science, "Philosophy begins when students and teachers slow down the science lesson and ask what the above terms mean and what the conditions are for their correct use" (Matthews, 1998, p. 169).

Review of the Methodological Literature

Research on professional development is a fairly recent issue. According to Joyce and Calhoun (2010), formal research on the topic commenced about 30 years ago. Furthermore, Joyce and Calhoun claim that during that period the discipline has not drawn the attention of programmatic researchers. Joyce and Calhoun define programmatic researchers as “those who pick up a model and conduct a series of studies to generate precise information about its effects and how to reshape it for greater effect” (p. 2). Joyce and Calhoun cite the following challenges in conducting research on professional development:

- The variance of implementation of a particular professional development model across settings
- Variations on the part of what teachers learn
- The fact that professional development may be designed to lead individual teacher growth in different directions
- The different objectives of various professional development models and the lack of a single dependent variable.

The challenges noted above are often found in research involving human activities since it is difficult to control all the variables. It is important to recognize these challenges in an attempt to improve the research on professional development and produce valid findings.

Similarly, Wilson and Berne (1999) observe, “what the field ‘knows’ about teacher learning is rather puzzling…due to the scattered and serendipitous nature of teacher’s learning” (p. 173). Wilson and Berne describe the field of professional development as an “incoherent and cobbled-together nonsystem, structured and unstructured, formal and informal” (p. 174) and as a result, Wilson and Berne argue that we have a limited sense of “what exactly it is that teachers learn and by what mechanism that learning takes place” (p. 174).

Recently there has been a call to make educational research more scientifically based, that is, research that uses methods such as randomized trials and other processes that one may find in clinical-like studies (Shavelson, Phillips, Towne, & Feuer, 2003; Zaritsky, Kelly, Flowers, Rogers, & O’Neill, 2003). Furthermore, I would argue that researchers have primarily approached research on professional development through the constructivist research paradigm as opposed to the positivist or postpositivist paradigms. In the constructivist research paradigm the aim of inquiry is understanding and reconstruction while in positivism and postpositivism the aim of inquiry is explanation (Guba & Lincoln, 2005). Furthermore, in the constructivist view, the researcher takes the role of “passionate participant”, there is greater interaction with the subjects of study and, as a result truth derives from the relationships among the members of the research community. These views are in contrast to the positivist and postpositivist views where the researcher takes on a “disinterested scientist” role, the subject of study is independent of researchers, and findings that result from direct observation and measurement are regarded as true or probably true (Guba & Lincoln, 2005).

Summary of the Research Literature and Application to the Study

Given the complex historical nature of the fields of science, philosophy and education and given their complex intersectionality, it is no wonder that science teachers have faced difficulties in comprehending epistemology in science education, in defining the nature of science, defining scientific inquiry, and implementing science education reforms, especially those based on constructivist pedagogies. The next chapter of this dissertation proposal will define and describe the research methods including data collection procedures and data analysis, that will be used to study the epistemological and nature of science beliefs of individuals responsible for the design and implementation of science teacher professional development.

CHAPTER 3: METHODS

Introduction

The purpose of this study was to examine the relationship between professional development providers' science beliefs and their design, development, and implementation of professional development experiences for science teachers. With that purpose in mind, the research questions this study attempted to answer are:

- What are the epistemological and nature of science beliefs of providers of professional development for science teachers?
- What is the relationship between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs?

A research question matrix matching data sources to the research questions above can be found in Appendix A.

Research Methods

In discussing teacher professional development, Wilson and Berne (1999) suggest that the questions "what knowledge do teachers acquire across these experiences? How does that knowledge improve their practice?" (p. 174) have remained largely unanswered. Attempts to answer these questions have been primarily conducted through a qualitative research approach.

Berg (2004) states, "the purpose of research is to discover answers to questions through the application of systemic procedures' (p. 7). In defining qualitative research, Berg (2004) writes, "qualitative research properly seeks answers to questions by examining various social settings and the individuals who inhabit these settings" (p. 7).

This research study used a basic interpretive qualitative methodology because qualitative research facilitates the understanding of the process of designing professional development experiences for science educators along with the perspectives and worldviews of those involved in providing such professional development experiences. According to Merriam (2002), a basic interpretive qualitative study will use inductive analysis of the data to “identify the recurring patterns of common themes that cut across the data” (pg. 7).

Participants

To select study participants, this study used a purposeful sampling method since the goal was to learn about a group of people who possess similar traits or characteristics (Cresswell, 2005). According to Patton (2005), “purposeful sampling involves selecting information rich cases for study in depth, cases that offer insights into issues of central importance to the purpose of an evaluation” (p. 344). Patton claims that “small purposeful samples yield in-depth understanding and insights rather than empirical generalizations” (p. 344). Because I’m interested in the design of science education professional development and how science beliefs may impact this design, studying in depth a small number of strategically selected providers can yield rich data.

In this case, the intended population for this study involved individuals who are responsible for the design and implementation of professional development programs for science educators. These individuals may fulfill this role in a variety of professional settings. Some may serve in public or private K-12 school settings while others serve in a higher education setting or a science research organization. Additionally, this study considered individuals who perform the function of designing and implementing science education professional development from more informal science education settings such as science museums and zoos. Regardless of the setting where the participants in this study operate, it is also important to consider that these individuals will have a wide diversity of backgrounds, some have a background in K-12 education, some have a background mostly focused in higher education and are scientists or teacher educators. Some of the participants' backgrounds may solely come from informal science education training. A description of the research participants for this study, their backgrounds and other pertinent information is found in chapter 4.

Procedures

This qualitative research dissertation used a cross-sectional study design. A cross-sectional study design collects data at one point in time as opposed to collecting data over time where the goal is to measure the effects of an intervention. One objective of a cross-sectional study design is to describe trends in the data to learn more about a group of people. In this case, I was interested in learning about the group of people that designs and implements professional development in science education. According to Cresswell (2005) the intent here should not be to generalize to the larger population but rather to "develop an in-depth exploration of a central phenomenon" (p. 203). More importantly, according to Cresswell, a cross-sectional study allows for the exploration of "current attitudes, beliefs, opinions, or practices" (p. 356).

This dissertation gathered data through the use of a questionnaire, one-on-one semi-structured interviews, and gathering documents related to the design of the professional development experience.

Participants received a questionnaire (Appendix B) to assess their beliefs about the nature of science. This questionnaire was sent electronically to the study participants. Once participants completed the questionnaire, a semi-structured interview was arranged with the purpose of following up on any questions regarding the nature of science questionnaire and to gain greater insight into the design process of professional development activities. A copy of the interview protocol can be found in Appendix C. According to Creswell (2005) “one-on-one interviews are ideal for interviewing participants who are not hesitant to speak, are articulate, and who can share ideas comfortably” (p. 215). Since many of the participants intended to participate in this study are in positions of leadership or have experience leading professional development, and since there were no potential power imbalances between researcher and participants, the participants were able to feel more comfortable discussing their beliefs regarding knowledge and the nature of science. According to Gibson and Hugh-Jones (2012), semi-structured interviews provide “a balance in the process between researcher-led questions (based on topics relevant to theory) and participant-led issues (that may help the researcher identify important issues that they would not otherwise have considered)” (p. 104).

Finally, documents related to the design of science teacher professional development activities created by the research participants were another source of data.

These documents may include print and online advertisements of the professional development activity as well as grant proposals that describe the professional development activity.

Instruments and Measures

One instrument that I used to collect data was the Views on Science and Education Questionnaire (VOSE) developed originally by Chen (2006) from the Graduate School of Technological and Vocational Education and Education Center at the National Taiwan University of Science and Technology. According to Chen, VOSE was developed "for creating in-depth profiles of the views of college students or adults, including pre-/in-service teachers about the nature of science (NOS), and NOS instruction" (p. 903). VOSE examines the following seven aspects of the nature of science:

- Tentativeness of scientific knowledge. This refers to the fact that scientific knowledge is both reliable and tentative based on new evidence. Kuhn and Popper proposed different ways for how scientific knowledge can change.
- Nature of observation. The observer's theoretical presuppositions affect their observations, in other words, observations are theory laden.
- Scientific methods. There is no single step-by-step, universal scientific method. There are various ways in which scientists go about doing research.
- Laws, and theories. Laws are relationships between two variables and theories are inferred explanations. Theories do not become laws.
- Imagination. While imagination is a more personal trait, it is still an integral part of problem solving and generating new scientific knowledge. Creativity is often used interchangeably with imagination to refer to this quality in science, however, VOSE focuses on imagination to avoid mixed results.
- Validation of scientific knowledge. The acceptance of a theory by the scientific community may be based on various factors such as empirical results, simplicity and the authority of the scientists proposing such theory.
- Objectivity and subjectivity in science. This issue examines the extent to which things such as personal beliefs and society or culture may impact a scientists' work (Chen, 2006).

VOSE was developed first through a pilot study with college students. After the pilot study, "two panels of experts reviewed the items for content validity and examined the philosophical meaning of each item" (p. 805). Finally, validity and reliability was established through a third stage that included a final test, a retest, interviews and data analysis. In terms of validity and reliability, "the developer of VOSE focused on the quality and meaningfulness of the items instead of pursuing a high internal consistency" (p. 815). The reason for this is based on the argument that "an empirically based instrument is developed from a qualitative perspective, which stresses the trustworthiness and authenticity of data" (p. 815).

Role of the Researcher

My approach to this dissertation study involved my experience as a science educator for 17 years and therefore, my participation in numerous professional development experiences. It was my involvement as a participant in science professional development that generated my interest in this research topic. As a participant, I noticed that professional development for science teachers is heavily focused on acquiring new knowledge or improving pedagogical skills and rarely included any mention regarding epistemology or the history and philosophy of science. As a result of my role as a participant or consumer of professional development I have developed a set of beliefs about what constitutes effective professional development as well as biases towards certain types of professional development experiences.

Data Collection and Analysis

The overall analysis method used for this study is a thematic analysis approach as I'm interested in what key themes are apparent as participants discussed their views on the nature of science, epistemological beliefs, and approaches to professional development design. A qualitative analysis involved the development of categories or themes to represent recurring patterns present in the data (Creswell, 2005).

Questionnaire Data Analysis

To analyze the data resulting from the questionnaire on the nature of science, participants' responses were assorted according to nature of science issues and philosophical positions. Participants' answers were compared using this assortment. Because there are a number of items that represent each issue of the NOS, all answers for each issue were placed in one cell of the table. Because the sample size is small, the results are descriptive and no statistical measures were employed.

Interview Data Analysis

I used a thematic content analysis to examine the interview transcripts. The tool that I used to conduct the thematic analysis is a Computer Assisted Data Analysis Software (CAQDAS) called ATLAS/ti. According to Barry (1998), some advantages of using CAQDAS include providing "a more complex way of looking at the relationships in the data" (para. 2.1) and aiding with "more conceptual and theoretical thinking about the data" (para. 2.1). Barry (1998) suggest the ATLAS/ti software is a good choice for straightforward, simple sample, one time point projects. Lewis (2004) also recommends ATLAS/ti for its "ability to work with a wide range of qualitative data (p. 460) and "the facility with which one can directly code, query, and analyze text" (p. 460). As a data analysis tool, ATLAS/ti allows for coding and retrieving, memoing and the creation of secondary texts. Coding refers to marking text passages the researcher is interested in and assigning a code to the selected text (Muhr, 1991). According to Muhr (1991) assigning codes is insufficient for data analysis. Memoing refers to annotating documents, selected text passages, and codes. Muhr states, "Without this memoing activity there is a chance that coding becomes reduced to a mere classification procedure. Coding and commenting are considered the central basic activities in the process of text interpretation"

Analysis of Existing Documents Describing Professional Development Activities

Copies of grant proposals describing the professional development activity, as well as copies of advertisements and descriptions of the professional development activity were obtained from the institutions offering professional development activities for science educators. These documents were explored using content analysis. Commonalities and themes between the content analysis data and the other data sources were identified and compared to the characteristics of science epistemic beliefs. These documents were read to identify themes or linkages related to science epistemic beliefs. Results obtained for the NOS questionnaire and interview data were compared to the wording of the documents describing the professional development experiences to determine any possible relationships between the epistemological and nature of science beliefs of the providers and the professional development activities offered by their institutions.

CHAPTER 4: RESULTS / ANALYSIS

Introduction

The purpose of this study was to examine the relationship between professional development providers' science beliefs and the ways in which they implement or provide professional development for science teachers. In particular, I sought to study the epistemological beliefs and the nature of science beliefs of those involved in the planning and implementation of these professional development experiences. The central research questions for this study were, "What are the epistemological and nature of science beliefs of professional developers in science education and what is the relationship between the beliefs of the professional developers and their planning and implementation of professional development experiences for science teachers?" The central themes that emerged from analysis of interviews, survey data, and professional development documents include:

- the nature of science is often equated with doing science;
- design of professional development experiences are influenced by education reform efforts and / or the mission of the sponsoring organization;
- research participants designing or providing science education professional development have diverse epistemological and nature of science beliefs.

Research Participant Information

All eight participants in this study have designed, conducted, or provided science education professional development for pre-service and in-service science teachers either as a member of a K-12 school district or an organization associated with science education. Following is a brief information about each participant.

Research Participant One

Research participant one has been formally involved in designing and providing science education professional development for the past four years. Research participant one has a master's degree in education and studied biology as an undergraduate. Currently, research participant one is serving as a Teacher on Special Assignment (TOSA) for a large urban school district. As one of their responsibilities as a district TOSA, research participant one designed, developed, and provided a course called "Biology for the Next Generation," designed for HS biology teachers implementing the NGSS. It is a 30 hour workshop. Research participant one has also facilitated monthly PLC meetings around problems of practice in implementing the NGSS in life science. Additionally, research participant one has science research experience having worked in a lab for eight summers. Research participant one participated in interviews and completed a survey.

Research Participant Two

Research participant two has been involved in designing and providing science education professional development for the last three years as part of an urban's school district STEM initiative. Research participant two has a master's degree in science education and studied chemistry and biology as an undergraduate. Research participant two is also currently teaching chemistry. In addition to providing short professional development events during the academic year to elementary and secondary teachers, research participant two also provides a week-long summer workshop for high-school chemistry teachers that aims at creating a student centered three dimensional learning environment. Research participant two participated in interviews and completed a survey.

Research Participant Three

Research participant three has been involved in designing and providing a week-long summer science education professional development for high school physics teachers for the past six years, also as part of an urban school district's STEM initiative. Research participant three also indicated they design, develop, and provide science education professional development to the following groups: 70 elementary teachers through a three year MSP grant, pre-service students who plan on being elementary teachers and general education teachers through university graduate courses, secondary science teachers in a large urban school district, and members of a professional organization of science teachers through courses and other professional development opportunities. Research participant three has a Master of Science in Physics and a Master of Science in Science Education. Research participant three is also currently teaching high school physics on a part time basis and serving as Teacher on Special Assignment. Research participant three participated in interviews and completed a survey.

Research Participant Four

Research participant four provides professional development for Advanced Placement programs and is associated with a college or university. Research participant four submitted a survey but did not participate in interviews.

Research Participant Five

Research participant five designs, delivers and evaluates science education professional development as part of their role as an education outreach specialist working for a zoo in a medium size metropolitan city. Research participant five has been in the field of informal environmental education for about 25 and has been conducting teacher professional development throughout that entire time. Research participant five has a bachelor's in Wildlife Biology, a bachelor's in Science Education, and a master's in Psychology. Research participant five participated in interviews and completed a survey.

Research Participant Six

Research participant six was active for many years on the committee of their local science teachers association in Australia (SEA*ACT/ branch of ASTA). Research participant six was also trained (2 days) as a Primary Connections in-school leader (Primary Connections are units developed by the Australian Academy of Science) and in 2015 lectured part time at the Australian Catholic University in Canberra - students of senior secondary science and curriculum. Research participant six submitted a survey but did not participate in interviews.

Research Participant Seven

Research participant seven began doing teacher in-service workshops for Wild Goose Company around 1994. Later, research participant seven designed and performed their own workshops, and currently do them around the country for K-12 teachers. The focus of the workshops is on Learning Cycle pedagogy and basic science content in all areas. They range from 1 hour breakout sessions to 3-week in-depth professional development. Research participant four submitted a survey but did not participate in interviews.

Research Participant Eight

Research participant eight has been involved in designing and providing a summer science education professional development for secondary science teachers for the past 23 years. Research participant eight currently is an Associate Professor in the department of Oceanography in a university in the United States where the summer professional development experience for teachers takes place. Research participant eight participated in interviews but did not submit a survey.

Analysis of Data and Presentation of Results

The data for this research study consists of survey data, interviews, and documents from professional development experiences. I will first provide an analysis of the survey data followed by an analysis of interview transcripts and documents from the professional development experiences provided by the research participants.

Survey Data Analysis

Surveys were collected online through the use of the Qualtrics Software. A total of 19 submissions were recorded online, however, only seven surveys were fully completed. The analysis of surveys has been organized according to the research participants' affiliation in their role of designing, developing or providing science education professional development. First, I will present an analysis for research participants who chose their affiliation in this process with a K-12 school district (Research participants one, two and three). I will then present an analysis for those research participants who are involved in science education professional development outside the K-12 system (Research participants four through seven). Survey data is listed in Tables 1 through 8.

Survey data of research participants within the K-12 system.

In general, research participants affiliated with a K-12 school district have diverse beliefs and views of science. Table 1 presents an overview of K-12 affiliated research participants' responses according to their philosophical position in relation to nature of science issues. In regards to the issue of the tentative nature of scientific knowledge, the responses for research participant one aligned with Kuhn's revolutionary stance while research participant two agreed with both Kuhn's revolutionary stance and Popper's evolutionary view of scientific knowledge. Research participant three chose uncertain or no comment in regards to the questions about the tentative nature of scientific knowledge. In terms of the nature of observations, research participant one was in agreement with the theory laden stance, while research participants two and three agreed with both theory laden and theory independent stances.

As far as scientific methods are concerned, participant one was in agreement with the idea of scientists using diverse methods as opposed to a universal scientific method. However, research participant one was also not opposed to the idea of teaching students a universal scientific method along with encouraging diverse methods. On the other hand, research participant two disagreed with the notion that scientists use diverse methods to obtain results or that scientific knowledge could be accidentally discovered. Research participant two agreed with the idea that scientists use the scientific method because it is a logical procedure and ensures valid, clear, logical and accurate results. Research participant three was unsure about most items regarding the scientific method but disagreed with the statement that there is no so-called scientific method and scientists use any methods to obtain results.

In regards to the idea of scientific theories and scientific laws being invented or discovered, there were also some different beliefs among K-12 affiliated research participants. Research participants one and three both agreed with the idea that scientific laws are discovered while scientific theories are invented. Alternatively, research participant two agreed that both theories and laws are discovered and disagreed with any notion of scientific laws and theories being invented. In terms of comparing scientific laws and theories, research participants one and three disagreed with the idea that some theories have more supporting evidence than some laws, while research participant two agreed with this concept. Additionally, research participants one and two both disagreed with the idea that theories are not as definite as laws while research participant three agreed with that statement. In all, research participants one, two, and three agreed that theories and laws are different types of ideas and cannot be compared.

In regards to the use of imagination by scientists, research participants one and two both agreed that scientists use their imagination in their research and as a source of innovation while research participant three was unsure about the role of imagination in scientific research. Additionally, while research participant three agreed with the idea that scientists will not use their imagination because it is not consistent with the logical principles of science, research participants one and two disagreed with this notion.

On the issue of validation of scientific knowledge, K-12 affiliated research participants also had varied beliefs. Research participants one and three strongly agreed with the notion that validation of scientific knowledge is based on the idea that there is only one truth and scientists will wait for empirical evidence before deciding to support a particular theory. On the other hand, research participant two also supports validation of scientific knowledge based on empirical evidence but through agreement with the idea that when scientists are faced with competing theories, they will accept both tentatively until sufficient empirical evidence exists to choose one. Additionally, research participants one and two also support validation of scientific knowledge in relation to the idea of paradigms as they both agreed with the statement that scientists tend to accept new theories on the basis of how far they deviate from current scientific theory. Research participant two also places greater emphasis on authority as the basis for validating scientific knowledge, while research participants one and three do not. Finally, research participant three was the only one to support the concept of parsimony in science by agreeing with the statement, scientists tend to accept the simpler theories and avoid complex theories.

Table 1
Views on Science and Education Questionnaire (VOSE) Responses for K-12 Affiliated Research participants – Part 1

Nature of Science Issue	Philosophical Position	Corresponding Survey Question #s	Research Participants Responses		
			1	2	3
Tentativeness	Revolutionary	4A	A	A	U
	Cumulative	4B	D	D	U
	Evolutionary	4C	D	SA	U

Nature of Observations	Theory laden	8A / 8B / 8E	A / D / A	D / A / SA	U / U / U
	Theory independent	8C / 8D	D / D	A / SA	A / A
Scientific methods	The universal scientific method	9A / 9B / 9F	D / D / SA	A / A / U	U / U / U
	Diverse methods	9C / 9D / 9E	A / D / A	U / D / D	U / D / U
Theories and laws	Epistemology - Discovered	5A / 5B 6A / 6B	D / D A / A	A / A A / A	D / U A / A
	Epistemology - Invented	5D / 5E / 5F 6D / 6E	SA / A / SA D / D	D / D / D D / D	A / A / SA SD / SD
	Epistemology-Discovered or invented	5C / 6C	A / D	D / D	SD / D
	Comparison - Laws being more certain	7A / 7B	D / D	D / D	A / SD
	Comparison - Different types of ideas	7C / 7D	D / SA	A / A	D / SA
Use of imagination	Yes	3A / 3B	A / A	SA / A	U / U
	No	3C / 3D / 3E	D / D / SD	D / D / D	A / D / U
Validation of scientific knowledge	Empirical evidence	1A / 1H	D / SA	A / D	SD / SA
	Paradigm	1C / 1F	D / A	D / A	D / D
	Parsimony	1D	D	D	A
	Authority	1E	D	A	SD
	Intuition	1G	D	D	SD

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

In terms of the issue of subjectivity and objectivity in science, table 2 provides K-12 affiliated research participants' responses according to survey questions addressing the objectivity or subjectivity of science. In general, research participants affiliated with professional development within the K-12 system, had a greater level of agreement with survey items associated with a subjective view. More specifically, research participants one and two agreed or strongly agreed with the notion that science is influenced by sociocultural values. Research participant three was unsure about the sociocultural influence on science. Additionally, all K-12 affiliated research participants disagreed with the statement that there is no so called scientific method and scientists use any methods to obtain results. So far, it seems that there is not a pattern for the views of the participants in the seven aspects of the nature of science measured by the questionnaire.

Table 2
Views on Science and Education Questionnaire (VOSE) Responses for K-12 Affiliated Research participants – Part 2

Nature of Science Issue	Philosophical Position	Survey Question #s	Research Participants		
			1	2	3
Subjectivity and objectivity	S - Parsimony	1D	D	D	A
	S - Authority	1E	D	A	SD
	S - Paradigm	1C / 1F / 8A / 8B	D / A / A / D	D / A / D / A	D / D / D / A
	S - Personal factors	1G / 8A 15A / 15D / 15H	D / A SA / SA / A	D / D A / SA / A	SD / D A / U / A
	S - Sociocultural influence	2A / 2B / 15B / 15C	SA / SA SA / SA	A / A A / A	U / U U / U
	S - Imagination	3A / 3B	A / A	SA / A	U / U
	S - Methodology	9D	D	D	D
	Neutral	1B	D	A	SD
	O - No influence of socioculture	2C / 2D / 15F	D / A / D	D / D / D	A / U / U
	O - Use no imagination	3C / 3E	D / SD	D / D	A / U
	O - Based on experimental facts	5B / 6B / 8D	D / A / D	A / A / SA	U / A / A
	O - No influence of personal beliefs	8C / 15E / 15I	D / D / A	A / D / D	A / U / U

	O - Methodology	8E / 9A / 9B	A / D / D	SA / A / A	A / U / U
	O - Overall	1A / 1H / 15G	D / SA / A	A / D / D	SD / SA / U

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

Finally, the survey measured individuals' attitudes towards teaching issues related to the nature of science. Table 3 presents K-12 affiliated research participants' responses to their level of agreement regarding teaching the nature of science issues. All K-12 affiliated research participants agreed or strongly agreed with the concept that students should understand the idea that scientific knowledge may change and all of them disagreed or strongly disagreed with the idea that science educators should avoid teaching students the tentativeness of scientific knowledge.

In regards to the idea that science teachers should reveal to students the theory-laden nature of observations, there was no consensus among research participants who affiliated themselves with the K-12 system. Research participant one disagreed with the idea of training students to make objective observations and agreed with statements that describe revealing the theory-laden nature of observations. Research participant two believes the opposite while research participant three was unsure about this issues. Similarly, research participants one, two and three had different opinions about teaching the universal scientific method versus encouraging diverse methods to do science. For the most part, research participant one agreed with nearly every statement, meaning they believe that students should learn the procedure of the scientific method but that teachers should also encourage other problem solving methods. On the other hand, research participant two mostly disagreed with the idea of students learning the procedure of the scientific method. Research participant three was unsure about all items regarding this issue with the exception of agreeing with the statement that there is no so-called scientific method.

All of these research participants agreed with the concept that science educators should explicitly teach the relationship between theories and laws. Finally, research participants one and two both disagreed that science educators should emphasize objectivity and agreed with teaching about the influence of personal factors and sociocultural influences in science while research participant three was unsure about these issues. All participants disagreed with the statement regarding the story of an objective scientist and a subjective scientist about science courses that are value free.

Table 3
Views on Science and Education Questionnaire (VOSE) Responses for K-12 Affiliated Research participants – Part 3

Nature of Science Issue	Survey Question #s	Research Participants		
		1	2	3
Teaching the tentativeness of scientific knowledge	12A / 12B	SA / SA	SA / SA	A / A
Avoid teaching the tentativeness of scientific knowledge	12C / 12D / 12E	SD / D / SD	D / D / SD	D / D / SD
Training students to make objective observations	11A / 11B / 11C	D / D / D	D / A/ A	U / U / U
Revealing the theory-laden nature of observations	11D / 11E	A / A	D / D	U / A
Teaching the universal scientific method	10A / 10B / 10C 10D / 10E / 10F	A / D/ A A / A/ A	D / D / A D / A / D	U / U / U U / U / U
Encouraging different methods	10G / 10H / 10I	A / A/ A	U / D / SA	U / A / U
Teaching the relationship between theories and laws	13A / 13B	SA / SA	A / A	A / U
Avoid teaching the relationship	13C / 13D	SD / SD	D / D	U / D
Teaching subjectivity Personal factors	14A / 14D	SA / SA	A / SA	U / U

Teaching subjectivity Sociocultural influences	14B / 14C	SA / SA	A / A	U / A
Emphasizing objectivity No influence of personal beliefs	14E	D	D	U
Emphasizing objectivity No influence of socioculture	14F	D	D	U
Value free in science courses	14G	D	D	D

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

Survey data results from research participants outside the K-12 system.

In this section, I will provide an analysis of the survey results for the research participants who design develop or provide science education professional development and choose their affiliation in this process with a college or university, an informal science education setting or other organization not considered a K-12 school district. Table 4 presents an overview of non K-12 affiliated research participants' responses according to their philosophical position in relation to nature of science issues. In general, research participants agreed on few items on a survey about their beliefs and views of science.

Table 4
Views on Science and Education Questionnaire (VOSE) Responses for non K-12 Affiliated Research participants – Part 1

Nature of Science Issue	Philosophical Position	Corresponding Survey Question #s	Research Participants Responses			
			4	5	6	7
Tentativeness	Revolutionary	4A	U	A	A	A
	Cumulative	4B	D	U	D	D
	Evolutionary	4C	SA	U	D	D
	Theory laden	8A / 8B / 8E	D / D / A	D / D / A	A / D / SA	A / A / A

Nature of Observation s	Theory independent	8C / 8D	D / A	A / SA	U / U	D / D
Scientific methods	The universal scientific method	9A / 9B / 9F	D / U / U	SA / SA / A	D / A / SA	SD / SD / D
	Diverse methods	9C / 9D / 9E	A / D / U	U / U / SD	D / U / A	D / D / A
Theories and laws	Epistemology - Discovered	5A / 5B 6A / 6B	D / U D / D	A / A A / A	U / A A / A	SD / SD A / A
	Epistemology - Invented	5D / 5E / 5F 6D / 6E	A / U / D A / SD	A / A / U A / A	A / A / A D / D	U / A / A SD / SD
	Epistemology-Discovered or invented	5C / 6C	D / D	A / A	A / A	A / D
	Comparison - Laws being more certain	7A / 7B	A / A	A / A	D / A	SD / SD
	Comparison - Different types of ideas	7C / 7D	D / D	U / U	A / A	SD / A
Use of imagination	Yes	3A / 3B	U / A	SA / U	SA / SA	A / A
	No	3C / 3D / 3E	D / SD / D	SD / D / SD	D / D / D	SD / D / U
Validation of scientific knowledge	Empirical evidence	1A / 1H	A / SD	SA / D	D / D	D / SD
	Paradigm	1C / 1F	SD / D	SD / SD	U / A	U / A
	Parsimony	1D	SD	SD	SA	D
	Authority	1E	SD	SD	A	D
	Intuition	1G	SD	SD	U	D

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

In relation to the issue of the tentative nature of scientific knowledge, research participant four aligned himself with Popper’s evolutionary view of scientific knowledge while research participants five, six, and seven were more aligned with Kuhn’s revolutionary views on scientific knowledge. In regards to the nature of scientific observations, all research participants agreed with the following statement “observations will be the same.

Although subjectivity cannot be completely avoided in observation, scientists use different methods to verify the results and improve objectivity." Additionally, research participants four, five and six indicated both agreement and disagreement on items that would distinguish their views on a theory laden stance versus a theory independent stance. Only research participant seven was fully in agreement with a theory laden view of science and completely disagreed with a theory independent view of science.

Concerning scientific methods, research participant five was the only participant to fully agree with the concept of a universal scientific method and disagree with the concept of scientists using diverse methods. On the other hand, research participant seven fully disagreed with the concept of a universal scientific method and partially agreed on using diverse methods. Research participants four and six were unsure about several items surrounding the belief of a universal scientific method.

In regards to the idea of scientific theories and scientific laws being invented or discovered, there were also diverse beliefs among the non K-12 research participants. Research participant four was unsure or disagreed with scientific laws and theories being discovered and simultaneously partially agreed with scientific laws and theories being invented. Research participant four also agreed with the idea that theories have less evidence to support them in comparison to laws. Research participant five agreed with nearly all questions in this part of the survey indicating scientific laws and theories may both be invented and discovered. Like research participant four, research participant five also agreed with the idea that in comparison to laws, theories have less evidence to support them. Research participant six agreed that both scientific theories and laws can be discovered but disagreed with the notion that scientific laws can be invented. Research participant six also was more likely to see scientific theories and laws as being different. Finally, research participant seven believes scientific laws are discovered and not invented while scientific theories are invented but not discovered. Research participant seven also disagrees with the notion that in comparison to laws, theories have less evidence to support them and believes that they cannot be compared.

In terms of scientists' use of imagination, research participants four, five, six, and seven agreed, or strongly agreed with the following statements: imagination is the main source of innovation and scientists use their imagination more or less in scientific research. Additionally, research participants four, five six, and seven disagreed or strongly disagreed with statements that imagination does not play a role in science.

In regards to the issue of scientific knowledge, research participants four, five, six, and seven also had varied beliefs, similar to their colleagues in the K-12 setting. Research participants four and five agree with the notion that validation of scientific knowledge is based on empirical evidence and when scientists are faced with competing theories they will accept both tentatively until sufficient empirical evidence exists to choose one. Research participant six supports validation of scientific knowledge in relation to the idea of paradigms where accepting new theories is based on how far they deviate from current scientific theory. Research participant six also believes that validation of scientific knowledge is influenced by authority through the academic status of the proposer. Finally, research participants six and seven both support the concept of parsimony in science, meaning that scientists tend to accept the simpler theories while avoiding more complex ones.

Table 5 presents non K-12 affiliated research participants' responses related to the objectivity or subjectivity of science. Overall, research participants affiliated with organizations outside the K-12 system had a greater level of agreement with survey items associated with a subjective view and a greater level of disagreement with survey items associated with an objective view. More specifically, research participants four, five, six, and seven all agreed with the notion that science is influenced by sociocultural values.

Table 5
Views on Science and Education Questionnaire (VOSE) Responses for non K-12 Affiliated Research participants – Part 2

Nature of Science Issue	Philosophical Position	Survey Question #s	Research Participants			
			4	5	6	7
Subjectivity and objectivity	S - Parsimony	1D	SD	SD	SA	D
	S - Authority	1E	SD	SD	A	D
	S - Paradigm	1C / 1F 8A / 8B	SD / D D / D	SD / SD D / D	U / A A / D	U / A A / A
	S - Personal factors	1G / 8A 15A / 15D / 15H	SD / D A / A / SA	SD / D SA / SA / A	U / A SA / SA / A	D / A SA / U / U
	S - Sociocultural influence	2A / 2B / 15B / 15C	A / D A / A	A / D A / A	A / A SA / A	SA / A A / SA
	S - Imagination	3A / 3B	U / A	SA / U	SA / SA	A / A
	S - Methodology	9D	D	U	U	D
	Neutral	1B	A	SD	D	A
	O - No influence of socioculture	2C / 2D / 15F	D / D / D	A / A / D	U / U / D	D / D / SD
	O - Use no imagination	3C / 3E	D / D	SD / SD	D / D	SD / U

	O - Based on experimental facts	5B / 6B / 8D	U / D / A	A / A / SA	A / A / U	SD / A / D
	O - No influence of personal beliefs	8C / 15E / 15I	D / D / D	A / D / D	U / D / A	D / SD / U
	O - Methodology	8E / 9A / 9B	A / D / U	D / SA / SA	SA / D / A	A / SD / SD
	O - Overall	1A / 1H / 15G	A / SD / A	SA / D / U	D / D / U	D / SD / U

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

Concerning attitudes towards teaching issues related to the nature of science, Table 6 presents non K-12 affiliated research participants' responses to their level of agreement regarding teaching the nature of science issues. All research participants associated with organizations outside the K-12 system agreed or strongly agreed with the concept that students should understand the idea that scientific knowledge may change and all of them disagreed or strongly disagreed with the idea that science educators should avoid teaching students the tentativeness of scientific knowledge.

There was also agreement by these research participants with the concept that science teachers should reveal to students the theory-laden nature of observations. Participants were unsure or disagreed with the idea of training students to make objective observations. Similar to their colleagues in the K-12 system, participants outside the K-12 system showed diverse attitudes or beliefs around teaching the universal scientific method versus encouraging diverse methods to do science. Participants five and six strongly believe in teaching the universal scientific method, participant six was also opposed to encouraging different methods. Most of these research participants, with the exceptions of research participant four, agreed with the concept that science educators should explicitly teach the relationship between theories and laws. Finally, similar to the K-12 group, all participants agreed that science educators should teach about the influence of personal factors and sociocultural influences in science and all participants disagreed about science courses that are value free.

Table 6

Views on Science and Education Questionnaire (VOSE) Responses for non K-12 Affiliated Research participants – Part 3

Nature of Science Issue	Survey Question #s	Research Participants			
		4	5	6	7
Teaching the tentativeness of scientific knowledge	12A / 12B	A / A	SA / SA	SA / SA	SA / SA
Avoid teaching the tentativeness of scientific knowledge	12C / 12D / 12E	SD / D / SD	SD / SD / SD	D / D / SD	SD / SD / SD
Training students to make objective observations	11A / 11B / 11C	D / U / D	U / U / U	D / U / D	U / D / SD
Revealing the theory-laden nature of observations	11D / 11E	A / SA	U / U	A / SA	A / A
Teaching the universal scientific method	10A / 10B / 10C 10D / 10E / 10F	A / D / D D / D / D	A / D / A A / A / A	A / A / A A / A / D	D / D / A U / A / D
Encouraging different methods	10G / 10H / 10I	SA / A / A	A / D / A	D / U / D	SA / SA / A
Teaching the relationship between theories and laws	13A / 13B	U / D	A / A	A / A	SA / SA
Avoid teaching the relationship	13C / 13D	A / D	D / SD	U / U	SD / SD
Teaching subjectivity Personal factors	14A / 14D	SD / A	A / A	SA / A	SA / U
Teaching subjectivity Sociocultural influences	14B / 14C	A / A	A / A	SA / SA	A / SA
Emphasizing objectivity	14E	D	A	D	SD

No influence of personal beliefs					
Emphasizing objectivity No influence of socioculture	14F	A	A	D	SD
Value free in science courses	14G	SD	SD	SD	SD

Note: SD = Strongly Disagree, D = Disagree, U = Uncertain or No Comment, A = Agree, SA=Strongly Agree

Interview Data and Professional Development Documents Analysis

I conducted a total of 5 interviews. The interviews were audio recorded and transcribed. I used the interview protocol found in Appendix C. After conducting interviews and completing transcripts, I collected various documents such as syllabus and agendas related to the professional development events designed by the participants. I then uploaded transcripts and documents together into the computer and used the Atlas.ti™ software to begin a reading, coding and analysis of the information. After an initial reading I identified the following themes: designing professional development and views of science and science education.

Designing professional development

Within the theme of designing professional development, I identified the following categories: goals of professional development, structure of the professional development experience, the role of standards, effective elements of professional development, and challenges of implementing professional development.

The goals of professional development are driven by a combination of factors, including the professional development designers' own education journey, the mission of the organization providing professional development and current reform efforts in science education. During interviews, research participants one, two and three shared goals similar to the response below of their professional development activities. One participant commented:

> my goals are for them to shift their instructional practices to a more student-centered approach…in alignment with the next generation science standards, uh, and the goals of three-dimensional teaching and learning. Um, so, um, for me, that's really especially focused on how do we teach teachers to engage students in the scientific and engineering practices. Um, and, um, with the added goal of facilitating the scientific discourse in their classroom as a way to engage in those practices, um, such as construction of explanations, you know, designing of investigations. All these things really require talk. (Research participant one, personal communication, September 28, 2016)

Other responses to questions about the goals of professional development included:

> The goals, I mean, really the goals stemmed out of my own hopes as a teacher that I really wanted to embrace the practices um, of the framework and of the, the NGSS. I really wanted to turn my class- classroom upside down and have me really be more of a facilitator and students really more in the driver seat, and so more student orientated uh, classroom. And so really what I was trying to always think, I guess the way that my thinking shifted, is that I was trying to think, "Now, how can I structure my classroom so that they can learn it themselves instead of me tell it to them?" (Research participant two, personal communication, September 28, 2016)

It is evident from the above responses that the designers' own experience maneuvering the instructional shifts called for by the science education reform movement has influenced their development of goals for their professional development design. As stated earlier, other factors such as the mission of the organization sponsoring the professional development experience can also influence the goals of professional development activities. One research participant, a scientist and university faculty member, commented:

> I want the teachers to be well prepared in the fundamentals of our discipline so that they can transfer this not only to their classroom but to train their colleagues so that they in turn can utilize the materials that we have developed. (Research participant eight, personal communication, July 19, 2016)

There is a clear difference between these goals, for some, the focus of professional development is about changing classroom instruction, for others it's about increasing content knowledge.

Analysis of documents related to these professional development experiences also demonstrate the contrast that exists between these goals for professional development. One document states the following goals for the workshop:

- Participants will be able plan 3D learning experiences and assessments for their students.
- Participants will be able to reflect on instructional shifts needed to implement the Next Generation Science Standards in their classroom.

While another document shows these goals:

- Educate a cadre of master oceanographic education resource teachers
- Create a national oceanographic communications network
- Disseminate and implement scientifically accurate and pedagogically sound instructional resource materials directed toward teachers

Again, a comparison of the two documents revealed the contrast between content-driven professional development and instructional technique oriented professional development.

The goals of professional development itself will in turn impact the structure of the professional development experience. In describing how they structure the professional development experience, one interviewee (a high school teacher) commented,

> my design, I suppose, for how I run PD is I model with a student, you know, a classroom with me as the teacher and my teachers as sort of my students...And then at the end, though, I will kind of say, "Okay, now we're at teacher talk, we're gonna talk and reflect on ...how that went and what were the moves that I did that made that discussion go well, or how did I structure this activity so that students

> had choices." Um, but they're willing to see what it looks like. And then, we sort of analyze it afterwards. (Research participant one, personal communication, September 28, 2016)

The rationale that research participants provided for structuring professional development experiences in this manner involves a number of reasons, first, they talk about their own experience of professional development as can be seen from this response: “the best professional development that I’ve ever gone to is where I have played the role of the student first” (Research participant two, personal communication, September 28, 2016). Second, and most importantly, they talk about the need to model the type of instruction they want professional development participants to leave with, as one interviewee said: “One, people need to live the experience. Um, they’re ... It’s so much more richer than being told about the experience, scanning the materials. But, people need to live the experience” (Research participant three, personal communication, September 28, 2016). This sentiment was also echoed by another participant:

> And I think for us, since we were taught in more of a sit and get environment, for us to change our ways and to teach in a different way than we were taught we really need to experience that and probably several times. It can’t just be one time um, for you to kind of- for teachers to kind of change their own thinking about how they want to structure their classroom with their students. (Research participant two, personal communication, September 28, 2016)

Documents and agendas from the professional development experience associated with the responses above also demonstrate that an emphasis of the workshop will be to experience the type of instruction the workshop seeks to promote, as it can be seen in the following excerpt:

> This is primarily a hands-on course. Participants will experience how teacher moves can be made to engage high school students in the NGSS scientific and engineering practices. Additional experiences will have participants engage in

> inquiry as a vehicle to develop conceptual, graphical, and symbolic understanding of phenomenon. Participants will discuss how to enhance productive student science talk, especially in explicitly comparing low- to high-evidence predictions. Whiteboards will be frequently used to demonstrate how evidence-based reasoning and data-informed decision-making can be implemented in the classroom through Board Discussions. Engineering projects will be experienced and time given to make them your own. The importance of creating models and explicitly discussing their limitations will also be a recurring theme.

Notice the word experience appears several times in the description of instructional methods for this particular workshop.

The standards reform movement is also a strong influence on science education professional development. In response to a question about the role standards play in the design of the workshop, one participant commented:

> The standards are really like guidance and especially the NGSS standards are guidance in how instruction, I don't know, should occur is- is not the right choice of words either. But this fact that it oughta be interwoven, three dimensional, is a great but awful word because no one understands it. But I- I do like that idea of the interwoven. That you can't--you don't teach things in isolation. So, yeah. I would say the standards guide, the professional development to a large extent. (Research participant three, personal communication, September 28, 2016)

Other responses to this question included:

> I think previously, standards were like a list of content...The framework suggests that science classroom should be focused on, uh, what students are doing, um, not just the content they're learning. And, and, and so the framework really calls for a, a shift in not just what we're teaching but how we're teaching it…But the NGSS is what and how. And, um, and so that has to guide PD because it's not like, you know, you're just teaching a new list of, you know, content areas. It's, it's so much beyond that. (Research participant one, personal communication, September 28, 2016)

It is also interesting to note that even outside the K-12 system, the standards do play a role in the design of professional development, although they are not the main driving force, they are a strong selling point as the comment below illustrates:

> So number one is our mission, right? We have very definitive conservation messages that we want to get out to the public, and teachers being one of those audiences. Everything that we do within education, including teacher professional development, is created, is designed through the lens of environmental literacy. So we actually have our own environmental literacy framework- ... that is, it mirrors, or it complements, or connects to Oregon Environmental Literacy Plan. So we have these conservation messages, ties back into environmental literacy, then what I do is I will take those conservation messages and I will find, within Next Generation Science Standards or Social Studies Standards, the concepts- that tie, and then that's kind of the route that I go. (Research participant five, personal communication, January 27, 2017)

Research participants also discussed the challenges of designing and implementing professional development, lessons learned from conducting professional development and the elements of effective professional development programs. One participant discussed the effectiveness of modeling sample activities from different points in the academic year,

> In this last year I was really pleased with the way that we had the professional development laid out. In the morning everyday so as we were ... We, we kind of hit different points uh, of the year. So everyday we had a theme, so like the first day was like physical and chemical changes, and so we had uh, a modelling activity, an inquiry uh, lab, and then an engineering project that all … were together on that same kind of thread. And then the next day we came back and the, the theme was atoms in the periodic table, and so again, we had like a modelling an inquiry and then that was followed by an engineering activity in the afternoon. And we did that every day. And so although that’s not going to be everyday of your classroom I felt like when participants walked away that they had a really good taste of, “Okay, I’ve done four or five now of these labs, of these engineering activities, of these modelling activities using the [inaudible 00:18:50]. I have a better idea about how to really embrace this and use it in my classroom.” ‘Cause I’ve done it as a student, and then towards the end of the week we kinda shifted it and, and had some of the participants kinda lead the discussion that followed, that the board meeting and that kind of thing where it works, students are discussing their data. By the end of the week we are trying to have the participants lead that a little bit more. (Research participant two, personal communication, September 28, 2016)

Another participant found it more useful to focus in-depth on one instructional unit as opposed to samples from different units

> I try to do one, like, full kind of really go do one unit fully in-depth so they can see what that learning progression is gonna look like in their classroom. And then for the rest of the time, I allocate the big, um, projects like engineering, like how to, you know, how to do a full engineering experience (Research participant one, personal communication, September 28, 2016)

In terms of challenges, there is an interesting contrast between professional development experiences provided by K-12 school districts and other organizations.

Views on science and science education

Within the theme of views on science and science education as part of designing professional development, there is a number of findings that are worth noting, including participants' views and beliefs about inquiry, the nature of science, and how these views relate to science education.

Participants' views about inquiry is a good starting point for this theme as there is a common thread found here. One participant commented:

> Inquiry is all about asking questions. You know, as little kids, we were born asking why and then that is killed out of us. So the whole inquiry process is trying to awaken that curiosity so that we're asking questions and then learning how to answer those questions, developing the skills to be able to answer it. (Research participant five, personal communication, January 27, 2017)

Interestingly, another participant expressed similar concerns about inquiry as children go through schooling, "I think students naturally at the younger grades are more curious. It seems like by the time they get to me in high school that that curiosity has been driven out of them" (Research participant two, personal communication, September 28, 2016). Additionally, high school science teachers framed their definition of inquiry as part of the current science standards implementation effort. For example, one interviewee said: “scientific inquiry, um, yeah. I, I basically define that as engaging in the scientific practices of the NGSS which, um, are intentionally not like sequential. (Research participant one, personal communication, September 28, 2016). Another participant also compared inquiry to the practices, stating:

> The inquiry is a practice, and so it’s a practice that every student should be participating in from kindergarten all the way to 12th grade. And then anytime we have a question about something, that we have this systematic way to test it, and then we analyze our data, and we conclude. (Research participant two, personal communication, September 28, 2016).

Furthermore, research participants, especially those in K-12 school districts, prioritize inquiry and the practices of science over other aspects of learning science. One participant commented:

> with the opportunities I present in my PD, like the things that I provide my PD are sort of through the lens of, like, I want students to be thinking as scientists and feeling like they could be scientists. So, how do I get teachers thinking and feeling like scientists themselves? So, 'cause, like, if a teacher doesn't feel like they could be a scientist, how are they gonna get their kids, students to feel like...And so, giving them talk like, like giving instructional strategies that promote autonomy. Um, because scientists are autonomous, you know. Like, they need to ask their own unique questions. They need to figure out how they're gonna collect data. If we're always telling our students how to, which questions they need to ask and how they need to do their analysis every little step of the way, they're not going to feel autonomous. So, that, that is what I focus on with teachers. Um, and then, secondly, I think it actually helped me, like, just credibility-wise. Like, I've had teachers tell me, "Well, you have to teach this because if they don't know this, they can't be successful in college, they can't successful as scientists." And I just say, you know, like, knowing every single vocabulary term is, is not necessary to be a scientist. What's actually more necessary is knowing how to do science. (Research participant one, personal communication, September 28, 2016)

Similarly, another research participant also suggested that “really it’s the skills and the practices, I think, that are more important than what we happened to be studying at the time” (Research participant two, personal communication, September 28, 2016).

Despite of the emphasis on inquiry and the practices of science, one participant alluded to the fact that the science education community continues to struggle to change classroom practice, whether it’s labeled inquiry or the practices of the Next Generation Science Standards (NGSS):

> If inquiry’s gonna drive instruction and that is so hard to do, so hard to do that so often teachers scoop in and save the day and just kind of tell them in short circuit, the inquiry. And no one wants to do that but they feel like a week’s going to be wasted if they don’t…Well if we actually want inquiry to drive instruction, then we need to work together and we need to build the scaffolds to make that inquiry. We gotta build the skills of students to have student talks so they can make sense of it and not need the teacher to come in and tell them. We need to give them the tools that when they struggle that they can save themselves. (Research participant three, personal communication, September 28, 2016)

In addition to a common understanding about the importance of inquiry or the scientific practices described by the NGSS, a common view amongst interviewees was that there is a need to more closely replicate the practice of real world science in the classroom. As one interviewee said:

> for the most part every day when students are in my, my class they’re participating in an activity, maybe they’re doing modeling, they’re doing an inquiry lab, sometimes that lab might you know, go over several different days. They’re doing an engineering project but they’re really using one of the practices to learn about science, and I felt like that was a really important thing missing from my own education because although I love science I really didn’t know how scientists do their work…So I, I’m, I’m hoping now that students are getting a better experience of really living how scientists do their work and getting a better taste for what scientists and engineers actually do, that they solve problems, that they’re curious about the natural world and ask questions, and then go, go about studying that in a systematic way. (Research participant two, personal communication, September 28, 2016)

Apart from sharing their beliefs and views about the nature of science, some research participants indicated an awareness regarding current sociopolitical views about science in this country and how these may impact science education. One participant stated,

> to me the- one of the aims of the NGSS is that you know, we have students going out into the world that respects science as a body. And you know, that, you know right now in Oregon it’s like we have this war on ... Well, and across the country we have this war on science, right? And people not wanting to listen to their doctors, and people not vaccinating their children, and, and people not really respecting you know, the body of knowledge that science has accumulated. But I think that lack of respect comes from the fact that they don’t understand how these results from the CDC are produced about... (Research participant two, personal communication, September 28, 2016)

And another commented the following,

> There's, there's a lot of news right now about how ...uh, a lot of our studies are potentially just false positives ...because of research bias. And so, like, I try to get my students thinking about how they design their ... That science is messier than sometimes we present it. And while that's okay, we need to, like, be aware of how it's messy and try to fix that. Um, but the idea that this is always gonna be some, like, linear process is, is just not true. It's not how it really plays out. Um, but we do need to work together to have, like, and work with those students so that they understand that it needs to be a rigorous process, which is validated and replicated and things like that. (Research participant one, personal communication, September 28, 2016)

Together, these results provide important insights into the design of professional development experiences for science teachers. Insights such as what is prioritized or what is absent as professional development providers reflect on their experiences creating such events. These insights will be discussed in more detail in the next section through the interpretation of the results.

Interpretation of Findings

There are several findings that emerged from this study through analysis of survey data, interviews, and documents of professional development experiences. First, survey data analysis shows there is a diverse set of beliefs professional development leaders have about the nature of science. While some survey research participants believe scientific observations are theory laden, others believe they are theory independent. Others believe in both. Study participants also have different perspectives about the scientific method. Some agree with a universal scientific method while others believe there is no one way to do science. Survey research participants also had different views about the relationship between theories and laws and their epistemology. Furthermore, while the majority of survey research participants believe in validation of scientific knowledge based on empirical evidence, survey research participants also place emphasis on other means of validating scientific knowledge. One thing nearly all survey research participants agreed about is their belief that scientists are creative and use their imagination. Participants also had some different views about the tentative nature of science, however, most agreed with a revolutionary philosophical position.

A possible explanation for these diverse beliefs about the philosophy and epistemology of science could be the participants' own distinct science education backgrounds and experience. For example, a Master of Science Education would have different requirements than a master's of education. Additionally, education programs and degrees across the nation have different requirements about including the history and philosophy of science as a requirement. Another possible explanation for the diverse beliefs about the nature of science could be the research participants' years of teaching experience since beliefs about the nature of science can change throughout a career. Since the sample for this study is small, it was not possible to determine if there is a pattern about science epistemological and philosophical beliefs between those professional development providers who are associated with a school district versus those outside the K-12 system.

It is not surprising that providers of science education professional development have diverse beliefs about the nature of science. In a study of scientists' views about the nature of science, Schwartz and Lederman (2008) found that even among scientists, beliefs about the nature of science are complex and diverse. For example, most scientists in their study agreed with the idea that scientific knowledge is subject to change and that some areas of science are more certain than others, but some scientists in their study also viewed science as progressing toward knowledge of an external reality. Schwartz and Lederman showed that scientists' views "are not necessarily consistent with any particular philosophical position, nor do any patterns emerge to suggest a predictable relationship between NOS views and science discipline" (p. 762), and scientists "do not all hold to the same view of 'the' NOS" (p. 762). Schwartz and Lederman speculated that differences in beliefs amongst scientists about the tentative nature of science could be the result of the different disciplines of science or the empirical basis of the scientists' work.

Another important finding was how the nature of science is primarily characterized by this study's research participants and in documents from professional development experiences. The nature of science was described primarily in terms of the practice of science. Earlier, I referred to the seven elements of the nature of science measured by the VOSE questionnaire. A further literature review revealed that while there are different conceptions as to what constitutes the nature of science, philosophers of science seem to agree on the following 14 characteristics:

> 1. Scientific knowledge while durable has a tentative character.
> 2. Scientific knowledge relies heavily but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
> 3. There is no one way to do science (therefore, there is no universal step-by-step scientific method).
> 4. Science is an attempt to explain natural phenomena.
> 5. Laws and theories serve different roles in science; therefore students should note that theories do not become laws even with additional evidence.
> 6. People from all cultures contribute to science.
> 7. New knowledge must be reported clearly and openly.
> 8. Scientists require accurate record keeping, peer review, and replicability.
> 9. Observations are theory-laden.
> 10. Scientists are creative.
> 11. The history of science reveals both an evolutionary and revolutionary character.
> 12. Science is part of social and cultural traditions.
> 13. Science and technology impact each other.
> 14. Scientific ideas are affected by their social and historical milieu.
> (McComas,Clough, & Almazroa, 2002, pp. 6–7)

Additionally, reviewing agendas of professional development courses, showed an emphasis on teachers participating in science activities followed by pedagogical discussion and lesson plan development. Reflecting on that list, it seems that professional development experiences that seek to give teachers an experience of science must go beyond teacher participation in science. Hodson (2002) argues,

> In order to introduce students to the cultural tools and conventions of the community of scientists, devise learning experiences that are scientifically significant as well as meaningful and interesting for students, and in order to guide, criticize and advise students, and ask and answer critical questions, teachers must have a deep understanding of both scientific knowledge and scientific methods. Moreover, they must have a thorough knowledge of the

> historical development of science, its social, economic and environmental impact, and the social, moral and ethical issues it raises for individuals and for society. This is a pretty daunting set of specifications, but one that holds out the prospect of a much more professional role for science teachers than many other models of teaching and learning, and one that points to clear targets for both pre-service and in-service teacher education. (p. 8)

This also creates a very daunting set of specifications for the professional development experience that seeks to provide teachers with a complete experience of the nature of science.

Overall, there does not appear to be a strong influence between a professional development providers' epistemological and nature of science beliefs and the events they designed. The major influence in the design of these professional development programs is the science education reform movement, the standards movement, and the mission of the science education organization providing professional development.

Limitations of Study

This research study had several limitations that include study design limitations, impact limitations and data limitations. Study design limitations refer to the available tools and procedures to measure the desired objectives. In this case, methods to reliable measure philosophical beliefs about the nature of science are still evolving. As a result, finding a relationship between epistemological and nature of science beliefs and the mediating factors affecting science education professional development was constrained by the validity and reliability of the measures used in this study.

Factors such as the research study's target population or regional focus may have an effect on the results, these limitations are often referred as impact limitations. In this case, this study focused only on educational leaders providing professional development in science education. Furthermore, this research study attempted to search for differences among science education professional development leaders within and outside the K-12 system. Finding willing research participants who provide science education professional development outside the K-12 system turned to be a difficult task. I learned that education outreach and designing professional development is only a small part of an individual's job responsibilities, making it a challenge to participate in interviews or complete a lengthy survey.

Finally, there are some data limitations. While this is linked to the small sample size, it is also important to note here that the results from this study are not generalizable and are only applicable for this small population.

Summary

In this chapter, I presented the results of this study, including an analysis of survey data, interview transcripts and documents from professional development events. I also presented my interpretation of this data and the limitations of this study. In Chapter Five, I synthesize the findings, situate them in a larger context and discuss implications for action.

CHAPTER 5: DISCUSSION / CONCLUSION

Introduction

This study set out to examine the relationship between professional development providers' science beliefs and the ways in which they implement or provide professional development for science teachers. In particular, I sought to study the epistemological beliefs and the nature of science beliefs of those involved in the planning and implementation of these professional development experiences. The central research question for this study was, "What are the epistemological and nature of science beliefs of professional developers in science education and what is the relationship between the beliefs of the professional developers and their planning and implementation of professional development experiences for science teachers?" Through the Views on Science and Education Questionnaire (VOSE), Interviews with providers of science education professional development and analysis of documents from these experiences, this study captured a small view of the major influences on the design of science teacher professional development.

Synthesis of Findings

This study has shown that the nature of science is often equated with the practice of science; the design and goals of professional development are largely guided by the current reform standards movement or the mission of the organization providing professional development; those providing science professional development have diverse beliefs about the philosophy and epistemology of science; and there does not appear to be a connection between these beliefs and the design of their professional development experiences.

Findings Situated in Larger Context

Before situating the findings of this study in the larger context, it would be beneficial to briefly revisit the context for where we are in science education. Of particular interest that is applicable here towards understanding the findings of this study, is the movement that started the instructional shift in science education. According to Bybee (2011),

> One major innovation in the 1960s reform movement was the introduction of the processes of science as a replacement for the methods of science. The processes of science shifted the emphasis from students' memorizing five steps in the scientific method to learning specific and fundamental processes such as observing, clarifying, measuring, inferring, and predicting. To complement this new emphasis, the new reformed instructional materials incorporated activities, laboratories, and investigations that gave students opportunities to learn the processes of science while developing an understanding of the conceptual structure of science disciplines. During the period 1960–1990, interest and support grew for scientific inquiry as an approach to science teaching that emphasized learning science concepts and using the skills and abilities of inquiry to learn those concepts." (p. 38)

Interview transcripts and documents of the professional development experiences analyzed as part of this study demonstrate the influence of this movement. Research participants discussed the need to provide teachers with the tools, experience, and classroom activities that support this kind of shift.

Furthermore, another influential movement in science education has been the standards movement. The first round of the standards movement in science education started in the early 1990s with publication of the National Science Education Standards (National Research Council, 1996) and Benchmarks for Science Literacy (American

Association for the Advancement of Science, 1994). We are currently experiencing the second round which started around 2013 with the Next Generation Science Standards (NGSS Lead States, 2013). A general agreement of the standards movement has been to increase student understanding of scientific concepts through more in-depth coverage of fewer curricular topics ("less is more" approach) and to expect students to be more actively involved in science through authentic inquiry experiences. Again, data from this study shows the influence of the standards movement in the design of professional development regardless of the affiliation of the individual or organization providing the professional development.

In addition to considering the science education context, it is also useful to revisit the theoretical framework for this study. Primarily, using Bandura's theory of reciprocal determinism to interpret the results. According to Bandura's theory, behavioral, personal, and environmental factors interact simultaneously to influence each other and help explain one's actions. Personal factors include cognition, attitudes and beliefs. Reviewing the interview transcripts, professional development documents and survey results, and considering the current science education context and Bandura's theoretical framework, I believe that professional development designers beliefs about the philosophy and epistemology of science have little influence on the design of science education professional development and it is the environment that plays a major role in shaping science education professional development.

The theoretical framework for this study also included Mezirow's (1996) transformative learning theory, Shulman's (1986) theory on knowledge growth in teaching and Sandoval's (2014) theory of epistemological development. Analyzing the documents from various professional development documents and interview transcripts reveals that there is little opportunity for science teachers to engage in self-reflection and introspection. This time of reflection and introspection would be necessary for the kind of professional development experience to create meaning. It seems that the main aspect of the professional development experiences examined as part of this study is to develop the practical knowledge of educators. Shulman (1986) argues that teachers' understanding of the subject matter must go beyond understanding the concepts and practices of the subject. Interestingly, even among scientists, Schwartz and Lederman (2008) found that individuals engaging "in authentic scientific inquiry may or may not develop NOS views aligned with positions for scientific literacy" (p. 764). Therefore, engaging in science inquiry and teaching science through inquiry is not enough for science teachers to develop a thorough understanding of the nature of science. Schwartz and Lederman (2008) state,

> a one-size-fits-all approach to scientific inquiry is not representative of authentic science practice and probably not appropriate for advancing consistent and desired epistemological views of science, even through explicit/reflective means. Even though the generalized NOS aspects are appropriate across disciplines, opportunities to learn how NOS can connect across disciplines may be overlooked. A variety of contexts may be required, along with explicit instruction, in order to more fully encompass the essence of authentic scientific inquiry and NOS as represented among the sciences. (p. 765)

In this study, interview transcripts and professional development documents revealed that one of the major goals of science education professional development is to provide teachers with the skills to implement inquiry learning and science as practice in their classrooms. Schwartz and Lederman (2008) and Hodson (2002) argue that this may not be enough to create a more scientifically literate society.

Implications

The findings of this study have a number of important implications for future research and future practice. As the science education community continues with the implementation of the Next Generation Science Standards (NGSS), this presents an opportunity to pursue research in the area of science education professional development design, effectiveness, and impact. However, there are a number of things that can be put into place to improve science education professional development.

Implications for Future Research

First, there is a need to continue research in the area of how one's beliefs impact one's actions. According to Southerland, Sinatra and Matthews (2001), "research in educational psychology to date has shown that knowledge and beliefs both affect learning. However, the influence of these two constructs is not always parallel" (p. 335). Southerland, Sinatra and Matthews (2001), go on to claim "we must shed light on this subject from a variety of sources—theoretical and empirical, philosophical and psychological—to advance our understanding of knowledge and beliefs and their influence on science learning" (p. 349). Through the framework of issues of power, Stroupe (2014) also argues for the need of additional research in the area of science epistemology, stating: "issues of power and epistemic agency as they relate to learning science-as-practice are undertheorized in the field of science education" (p. 489). In other words, when students engage in science as practice, similar to what teachers do during a professional development activity, they take on different roles, and these roles have power implications. The argument here is that more research is needed to examine how power structures change in the classroom, or in this case, the professional development experience when learners take on the role of creators of knowledge as opposed to passive recipients of information.

Additionally, if the debate is to be moved forward, a better understanding of what is meant by epistemological beliefs and what constitutes the philosophy and nature of science needs to be developed. Since there are multiple conceptions of the nature of science, and research participants in this study demonstrated different understandings of the nature of science, Wong and Hodson (2009) recommend: "educators, curriculum designers, and teachers should recognize, if they have not already done so, that there is no single set of NOS elements, static with time and fitting all disciplines and contexts" (p. 123). As a result, science teachers could be more critical and reflective in regards to how they represent the nature of science in their classrooms.

Another opportunity for research around the concepts of the nature of science involves examining the purpose of teaching the nature of science. According to Ostman and Wickman (2014),

> an important part of research should be to ask first why we think certain NOS content is important, in what practice and for what purposes does it sustain students. This means acknowledging that learning science epistemology is always part of some practice, which does not necessarily have only scientific epistemic purposes…NOS may be part of critically examining issues of power distribution in society or gender (cf. Brickhouse, 2011; Kilbourne, 1998, Ostman, 1996, 1998; Reis, 2007; Willinsky, 1998). It may also relate to decision making regarding socioscientific issues or carrying out an experiment to better understand some natural phenomenon. (p. 377)

Again, this calls for greater reflection on the part of professional development providers as to how they prioritize the different aspects of the nature of science and for what purpose.

Other researchers have also suggested an examination of how different experiences of inquiry may lead to different understandings of the nature of science. As a result of their study on this issue, Schwartz and Lederman (2008) propose exploring “the impact of single versus multiple inquiry experiences on epistemological views of science” (p. 765) to answer research questions like “are additional experiences and explicit instruction needed to address an inclusive view of NOS as advocated for scientific literacy?” (p. 765).

Implications for Policy and Practice

One important practical implication is that individuals in science education leadership positions participate in professional development experiences specifically focused to address views of the nature of science. Palmquist and Finley (1997) found that preservice teachers entering a nature of science course had postpositivist views of scientific theory, knowledge, and the roles of scientists and positivist views of the scientific method. Following instruction, the number of participants with mixed views about the nature of science decreased while those with postpositivist views increased. According to Palmquist and Finley, “teachers were more able to articulate their views about different aspects of the nature of science” (p. 607). I believe that prior to providing professional development that involves addressing teacher beliefs about how scientific knowledge is constructed, education leaders should be confident in articulating their own views of the nature of science. Furthermore, education leaders should be comfortable in leading discussions that involve cultural, moral, ethical, and social justice issues related to scientific knowledge. Zeidler, Walker, Ackett, and Simmons (2002) assert that

> If, indeed, our goal in science education is to develop a scientifically literate population capable of making informed decisions in a democracy (Mosher, Kenny, & Garrod, 1994; Scheffler, 1987), then including moral and ethical issues as a defining component of the nature of science is highly desirable. (p. 345)

Indeed, one research participant commented on this issue and spoke to challenges and difficulty that come with including a cultural lens

> I'm only now just starting to really wrap my head around, you know, what does this mean and how do I take a concept or concepts in science and allow learning through a cultural lens?... . It's not discussed, right? I mean, is that ever discussed? I'm not even sure what that, like ... It's one of those things that it's like, "Duh, why wouldn't we be doing this?" But we don't. And so what does it look like? I don't know. I mean, I know that in a recent workshop that I did, instead of trying to answer that question, I threw it back out to the teachers. And I said, "Okay, here is what I've done, and what are all the ways in which all I did was look at the ... I just saw this, or we just reviewed this through a dominant-culture lens. What are ways that we could move outside of that? And it's some great conversations. It's great conversations. It's starting. They're not easy conversations. It's not necessarily something I would do with every group. Because you have to really have that trust. You really have to have that trust with the people within the group. But I'm excited to think that it, you know, that it's starting. (Research participant five, personal communication, January 27, 2017)

If we are to create this environment of trust as part of the professional development experience, Darling-Hammond and McLoughlin (2011) argue that education leaders must "create and sustain settings in which teachers feel safe to admit mistakes, to try (and possibly fail), and to disclose aspects of their teaching" (p. 88). Similarly, in the science education setting, leaders should create a safe place for participants to discuss their beliefs about the nature of science to allow transitions from traditional views of the nature of science to more contemporary views.

Another application for practice involves improving the communication between professional development providers and participants regarding the nature of science. Hodson (2014) makes the argument that the science education community should distinguish between four basic learning goals: learning science, learning about science, doing science and learning to address socio-scientific issues. According to Hodson, “not all goals can be achieved by the same approach…different purposes engender different attitudes to the activity and different responses to the experience and to any data collected” (p. 2550). Therefore, those planning science education professional development can use these goals to ensure a more complete professional development experience.

Conclusion

I believe we are at a critical time to discuss our philosophical positions as they pertain to the nature of science because we have an opportunity to reflect on what it means to develop a scientifically literate society. According to Deniz (2011), “there is a disconnect between epistemological assumptions of inquiry-oriented teaching and naïve EBs [Epistemological Beliefs] in science” (p. 759). Current science education reform efforts that seek to implement inquiry teaching and constructivist approaches present a conflict with traditional, western views that scientific knowledge is objective and absolute truth is established through scientific work. This debate presents a window of opportunity to create conversation around what do we want to accomplish through teaching the nature of science. Therefore, helping science education leaders develop an awareness of the current debate around the philosophy of science and help them examine and articulate their philosophical positions about the nature of science and assess how these views integrate with their epistemological beliefs, may lead to improved efforts aimed at changing science education. More importantly, we have an opportunity to examine how social justice issues can be addressed in science education as part of our discussion. According to Harding (2004), "in a world of social inequalities and competing interests, scientific arguments always are also situated culturally and historically; they are inevitably socially engaged while also grounded in the realities of nature's order" (p. 38). I believe this should also apply to the professional development experience. Professional development providers should reflect on how the activities they choose are culturally and historically situated. It is important to note here that we, as science educators, have as our primary responsibility to engage with students in the practices of science, Harding is not advocating for eliminating the essential aspect of how science works, just that we examine historical and cultural roles that are part of those scientific practices. Harding (1986) states:

> I am not proposing that humankind would benefit from renouncing attempts to describe, explain, and understand the regularities, underlying causal tendencies, and meanings of the natural and social worlds just because the sciences we have are androcentric. I am seeking an end to androcentrism, not to systematic inquiry. But an end to androcentrism will require far-reaching transformations in the cultural meanings and practices of that inquiry. (p. 10)

Overall, my main argument is that in planning professional development, we need to move beyond just emphasizing the practice of science. Science education professional development activities could still be promoting a male dominated view of science if we are not aware of the cultural and historical placement. Hodson (2014) perfectly summarizes the point that the practice of science is not enough, stating,

> because of the idiosyncratic nature of scientific investigation, and the highly specialized but necessarily limited range of conceptual issues involved in any particular inquiry, doing science is insufficient in itself to bring about the breadth of conceptual development that a curriculum seeks. One cannot learn sufficient science by restricting activities to doing science…Nor can one learn enough about science by restricting activities to doing science. Learning about science involves more than an awareness of the nature of observation and experimentation; it includes an understanding of the ways in which scientific research is prioritized, conducted, reported and appraised; it includes some appreciation of the history, philosophy and sociology of science and scientific practice; it includes awareness of the complex interaction of science, technology, society and environment and the moral-ethical issues raised by scientific research, practice and development (p. 2551)

I strongly believe that professional development experiences should reflect this view of science education. Learning more about the history and the philosophy of science will need to take a more prominent role in the professional development of science educators, along with the cultural context where the science practice takes place.

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Appendix A

RESEARCH QUESTION MATRIX

Title of Project: An Examination of the Relationship between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs

Research Question	**Data Source 1: Questionnaire**	**Data Source 2: Interviews**
What are the epistemological and nature of science beliefs of providers of professional development for science teachers?	Views on Science and Education Questionnaire	Follow-up semi-structured interviews, interview transcripts
Research Question	**Data Source 3: Artifacts from PD programs**	**Data Source 4: Interviews**
What is the relationship between Professional Development Providers' Epistemological and Nature of Science Beliefs and their Professional Development Programs?	Documents from the professional development programs written by the providers (advertisements, online program descriptions, grant applications).	Follow-up semi-structured interviews, interview transcripts

Appendix B

VIEWS ON SCIENCE AND EDUCATION QUESTIONNAIRE

Each question of this questionnaire starts with a statement about the nature of science or science education. Most statements adopt a certain radical stance. You may strongly agree with it, strongly disagree with it, or have other thoughts about it. Each statement is followed by several responses. Please read all of the responses first, then circle your opinion on the right side (SD, D, U, A, SA) of each response according to your knowledge of scientific activities or scientists, or what ought to be taught in science courses. There is no right or wrong answer. Thank you.

SD= Strongly Disagree

D = Disagree

U = Uncertain or No Comment

A = Agree

SA = Strongly Agree

1. When two different theories arise to explain the same phenomenon (e.g., fossils of dinosaurs), will scientists accept the two theories at the same time?					
A. Yes, because scientists still cannot objectively tell which one is better; therefore, they will accept both tentatively.	SD	D	U	A	SA
B. Yes, because the two theories may provide explanations from different perspectives, there is no right or wrong.	SD	D	U	A	SA
C. No, because scientists tend to accept the theory they are more familiar with.	SD	D	U	A	SA
D. No, because scientists tend to accept the simpler theories and avoid complex theories.	SD	D	U	A	SA
E. No, the academic status of each theory proposer will influence scientists' acceptance of the theory.	SD	D	U	A	SA
F. No, scientists tend to accept new theories which deviate less from the contemporary core scientific theory.	SD	D	U	A	SA
G. No, scientists use intuition to make judgments.	SD	D	U	A	SA
H. No, because there is only one truth, scientists will not accept any theory before distinguishing which is best.	SD	D	U	A	SA

2. Scientific investigations are influenced by socio-cultural values (e.g., current trends, values).					
A. Yes, socio-cultural values influence the direction and topics of scientific investigations.	SD	D	U	A	SA
B. Yes, because scientists participating in scientific investigations are influenced by socio-cultural values.	SD	D	U	A	SA
C. No, scientists with good training will remain value-free when carrying out research.	SD	D	U	A	SA
D. No, because science requires objectivity, which is contrary to the subjective socio-cultural values.	SD	D	U	A	SA

3. When scientists are conducting scientific research, will they use their imagination?					
A. Yes, imagination is the main source of innovation.	SD	D	U	A	SA
B. Yes, scientists use their imagination more or less in scientific research.	SD	D	U	A	SA
C. No, imagination is not consistent with the logical principles of science.	SD	D	U	A	SA
D. No, imagination may become a means for a scientist to prove his point at all costs.	SD	D	U	A	SA
E. No, imagination lacks reliability.	SD	D	U	A	SA

4. Even if the scientific investigations are carried out correctly, the theory proposed can still be disproved in the future.					
A. Scientific research will face revolutionary change, and the old theory will be replaced.	SD	D	U	A	SA
B. Scientific advances cannot be made in a short time. It is through a cumulative process; therefore, the old theory is preserved.	SD	D	U	A	SA
C. With the accumulation of research data and information, the theory will evolve more accurately and completely, not being disproved.	SD	D	U	A	SA

5. Is scientific theory (e.g., natural selection, atomic theory) “discovered” or “invented” by scientists from the natural world?					
A. Discovered, because the idea was there all the time to be uncovered.	SD	D	U	A	SA
B. Discovered, because it is based on experimental **facts**.	SD	D	U	A	SA
C. Some scientists discover a theory accidentally, but other scientists may invent a theory from their known facts.	SD	D	U	A	SA
D. Invented, because a theory is an interpretation of experimental **facts**, and experimental facts are discovered by scientists.	SD	D	U	A	SA
E. Invented, because a theory is created or worked out by scientists.	SD	D	U	A	SA
F. Invented, because a theory can be disproved.	SD	D	U	A	SA

6. Is scientific law (e.g., gravitational law) “discovered” or “invented” by scientists from the natural world?					
A. Discovered, because scientific laws are out there in nature, and scientists just have to find them.	SD	D	U	A	SA
B. Discovered, because scientific laws are based on **experimental facts**.	SD	D	U	A	SA
C. Some scientists discover a law accidentally, but other scientists may invent a law from their known facts.	SD	D	U	A	SA
D. Invented, because scientists invent scientific laws to interpret discovered experimental facts.	SD	D	U	A	SA
E. Invented, since there are no absolutes in nature, therefore, the law is invented by scientists.	SD	D	U	A	SA

7. In comparison to laws, theories have less evidence to support them.					
A. Yes, theories are not as definite as laws.	SD	D	U	A	SA
B. Yes, if a theory stands up to many tests it will eventually become a law, therefore, a law has more supporting evidence.	SD	D	U	A	SA
C. Not quite, some theories have more supporting evidence than some laws.	SD	D	U	A	SA
D. No, theories and laws are different types of ideas. They cannot be compared.	SD	D	U	A	SA

8. Scientists' observations are influenced by personal beliefs (e.g., personal experiences, presumptions); therefore, they may not make the same observations for the same experiment.					
A. Observations will be different, because different beliefs lead to different expectations influencing the observation.	SD	D	U	A	SA
B. Observations will be the same, because the scientists trained in the same field hold similar ideas.	SD	D	U	A	SA
C. Observations will be the same, because through scientific training scientists can abandon personal values to conduct objective observations.	SD	D	U	A	SA
D. Observations will be the same, because observations are exactly what we see and nothing more. Facts are facts. Interpretations may be different from one person to another, but observations should be the same.	SD	D	U	A	SA
E. Observations will be the same. Although subjectivity cannot be completely avoided in observation, scientists use different methods to verify the results and improve objectivity.	SD	D	U	A	SA

9. Most scientists follow the universal scientific method, step-by-step, to do their research (i.e., state a hypothesis, design an experiment, collect data, and draw conclusions).					
A. The scientific method ensures valid, clear, logical and accurate results. Thus, most scientists follow the universal method in research.	SD	D	U	A	SA
B. Most scientists use the scientific method because it is a logical procedure.	SD	D	U	A	SA
C. The scientific method is useful in most instances, but it does not ensure results; therefore, scientists invent new methods.	SD	D	U	A	SA
D. There is no so-called the scientific method. Scientists use any methods to obtain results.	SD	D	U	A	SA
E. There is no fixed scientific method; scientific knowledge could be accidentally discovered.	SD	D	U	A	SA
F. No matter how the results are obtained, scientists use the scientific method to verify it.	SD	D	U	A	SA

10. Students in junior and senior high schools should learn the procedure of the scientific method.					
A. Yes, so the students have guidelines to work within.	SD	D	U	A	SA
B. Yes, because the students are still incapable of coming up with more appropriate methods.	SD	D	U	A	SA
C. Yes, they should learn what scientists do.	SD	D	U	A	SA
D. Yes, because the scientific method is the best method that scientists have developed so far.	SD	D	U	A	SA
E. Yes, it helps the students to learn an objective way of studying science.	SD	D	U	A	SA
F. Yes, it could help the students to understand the essence of science.	SD	D	U	A	SA
G. No, we should not only teach one scientific method. Students should be given space to think and develop their own methods.	SD	D	U	A	SA
H. No, there is no so-called the scientific method.	SD	D	U	A	SA
I. No, the teachers and the students should brainstorm different research methods together.	SD	D	U	A	SA

11. In junior and senior high school science classes, when students are observing the same event, the teacher should expect the students to come up with the same findings.					
A. Yes, the teacher should advise students to carry out objective observations to get identical findings.	SD	D	U	A	SA
B. Yes, if the students are careful enough, they should arrive at the same findings.	SD	D	U	A	SA
C. Yes, experimental facts will not differ with the person, thus no matter who makes the observation, the result will always be the same.	SD	D	U	A	SA
D. No, the observation will be affected by the students' preconceptions.	SD	D	U	A	SA
E. No, the teacher should discuss with the students how observation can be affected by preconceptions.	SD	D	U	A	SA

12. Students should understand that scientific knowledge may change.					
A. Yes, so they realize the real nature of science.	SD	D	U	A	SA
B. Yes, so they realize the reason why science advances.	SD	D	U	A	SA
C. No, it will decrease the students' interest in learning science.	SD	D	U	A	SA
D. No, it will decrease the students' acceptance of science.	SD	D	U	A	SA
E. No, the students only need to learn about the constant fundamentals of scientific knowledge.	SD	D	U	A	SA

13. The science course in high school should investigate the definitions of and the relationships between hypothesis, theory, and law.					
A. Yes, because they represent the structure of scientific knowledge.	SD	D	U	A	SA
B. Yes, because they are the fundamentals of scientific inquiry.	SD	D	U	A	SA
C. No, knowing the definition of and relationships between these terms does not help much in learning scientific knowledge.	SD	D	U	A	SA
D. No, because hypothesis, theory, and law lack definite meaning.	SD	D	U	A	SA

Please read carefully the following story about two scientists before answering the last two questions.

It is the year 2016. A and B are professors at a biotechnology center, and they are researching the selection and transfer of organic genes. If their project succeeds, humans will be free from congenital limitations. In addition to the total prevention of hereditary diseases, people will be free to choose and transfer eugenic genes. The human world will never again have congenital hereditary deficiencies. The research is already into the last step, but the general public opposes it, and even the institution itself has the intention of cutting back the budget. In fact A is already starting to question the continuation of the research. A is a devoted Christian, believing that God will open doors for everyone. Thus, even if people are born with various diseases and deficiencies, the diversity and unpredictability of humankind are what has created history. A doesn't believe that scientific development should change the core essence of a human being. Therefore, when socio-cultural values and beliefs of science are in conflict, choice should be made based on socio-cultural values because the ultimate values of science rely upon the "person" him/herself.

However, B doesn't think this way. B believes that the nature of science is absolutely objective, and that socio-cultural values are just like the public preference, always changing with the social environment, and are a very subjective representation of values. In other words, research that is rejected by today's socio-cultural values could become an aspiration of tomorrow. Therefore, it is unworthy and foolish to abandon the constant objective nature of science just for a fleeting subjective value. B and A start to fight over this matter. Finally, A chooses to withdraw from the research, but B chooses to continue developing it. Since giving up the well-developed research techniques would be very regrettable, A changes research interest to genetic selection and transfer of plants, in an attempt to choose a topic accepted by the dominant socio-cultural values. A eventually successfully transfers the anticancer genes from Taxus mairei to rye, creating anticancer rye. Looking back, A does not regret withdrawing from the project and believes that although the nature of science could be objective, the manifestation of the values should eventually return to the fundamental essence of "human beings." B, persisting in continuing the original project, has received success on animal live-forms research, continuing on to do research on humans. B does not regret the choice either and even works harder on the project because of the belief that this story does not end here. The entire nature and value of the investigation will unfold in the future. It is left for history, rather than the contemporary socio-cultural values, to judge.

14. From the perspective of science education, what can junior/senior high school students learn from these two scientists?					
A. A—scientists should have a conscience when doing research.	SD	D	U	A	SA
B. A—consider both scientific research and social values simultaneously.	SD	D	U	A	SA
C. A—scientific research cannot be totally divorced from socio-cultural values.	SD	D	U	A	SA
D. A—respect the diversity of people.	SD	D	U	A	SA
E. B—scientific research should be completely detached from personal beliefs.	SD	D	U	A	SA
F. B—scientific research should be completely detached from social subjective values.	SD	D	U	A	SA
G. Neither of them provides a good example to learn from because science courses should not involve value-choices.	SD	D	U	A	SA

15. **From the perspective of the nature of science, what aspects of A and B's thinking do you agree with?**					
A. A—scientists should have a conscience when doing research.	SD	D	U	A	SA
B. A—consider both scientific research and social values simultaneously.	SD	D	U	A	SA
C. A—scientific research cannot be completely divorced from socio-cultural values.	SD	D	U	A	SA
D. A—respect diversity in human beings.	SD	D	U	A	SA
E. B—scientific research should be completely detached from personal belief.	SD	D	U	A	SA
F. B—scientific research should be completely detached from subjective values.	SD	D	U	A	SA
G. B—persisting with the highest value of science—pursuing the truth.	SD	D	U	A	SA
H. Both, since they both have scientific spirit though they are influenced by personal values.	SD	D	U	A	SA
I. Neither, neither are objective enough since they are influenced by their personal beliefs and values.	SD	D	U	A	SA

Appendix C

PD PROVIDER INTERVIEW PROTOCOL

Institution: ____

Interviewee (Title and Name): _________________________________

____

Survey Section Used:

_____ A: Interview Background

_____ B: Current Professional Development Offerings

_____ C: Professional Development Design

_____ D: Teaching Methods in Professional Development

_____ F: Role of Teachers in Professional Development

Other Topics Discussed: ____

____

Documents Obtained: ____

____

____

Post Interview Comments or Leads: ______________________________________

____

____

Professional Development Design Interviews

Introductory Protocol

To facilitate my note-taking, I would like to audio record our conversations today. Please sign the release form. For your information, only researchers on the project will be privy to the recordings which will be eventually destroyed after they are transcribed. In addition, you must sign a form devised to meet the university's human subject requirements. Essentially, this document states that: (1) all information will be held confidential, (2) your participation is voluntary and you may stop at any time if you feel uncomfortable, and (3) I do not intend to inflict any harm. Thank you for your agreeing to participate.

I have planned this interview to last no longer than one hour. During this time, I have several questions that I would like to cover. If time begins to run short, it may be necessary to interrupt you in order to push ahead and complete this line of questioning.

Introduction

You have been selected to speak with me today because you have been identified as someone who has a great deal to share about science education professional development. Our research project as a whole focuses on learning about the relationship between one's beliefs about epistemology and the nature of science and science teacher professional development programs. This study does not aim to evaluate your techniques or experiences. Rather, I am trying to learn more about the possible relationship between science epistemic beliefs and science teacher professional development programs and their design.

A. Interviewee Background

How long have you been …
_______ in your present position?
_______ at this institution?

Interesting background information on interviewee:

What is your highest degree? ____

What is your field of study? ____

1) Briefly describe your role as it relates to providing science teacher professional development.
   a) How are you involved in professional development here?
   b) How did you get involved?

2) Would you describe a PD program (either one you took or provided) that worked well?
   a) How does it stand out in your mind?

B: Current Professional Development Offerings

3) What is one of the best PD programs at your institution?
   a) Why do you consider it a best program?

4) In your institution's view, what characterizes quality PD?

5) What are the similarities among PD offerings at your institution? How do PD offerings at your institution differ?
   a) What is the time frame?
   b) What is the frequency/duration?
   c) Are kits or specific materials used?
   d) What kind of technology is used? And how is the technology used?
   e) What teaching strategies are used?
   f) Is there a program model on which you base your PD?

C: Professional Development Design

6) When your group is discussing your institution's PD program, tell me about the challenges you discuss?

7) How do you determine science content in your institutional offerings?
   a) What science content do you think teachers need to know?
      i) How has your institution determined what science content teachers need to know?
      ii) How do you ensure that this science content is included your PD offerings?
   b) How is science content at different grade levels addressed?

8) How do you determine what PD courses are offered by your institution?
   a) How do staff qualifications, abilities, or interests affect offerings?
   b) How does demand affect offerings? What do districts ask for? What do teachers ask for?
   c) How does previous course enrolment affect offerings?
   d) What qualifications do PD providers at your institution have in order to conduct PD? How are PD providers at your institution trained?

9) What role do standards play in your offerings?
   a) When in the development process are standards incorporated into the PD content?
   b) What role do you see standards playing in the institution's future offerings?
   c) What is the impetus for incorporating standards in your PD offerings?

D: Teaching Methods / Strategies in Professional Development

10) Describe the teaching methods used in your institution's PD program. Can you give me examples?
    a) Discuss teaching methods used to reach teachers who learn in different ways?
    b) How does your PD build on teachers' prior knowledge and experiences?
    c) Can you be more specific about
        i) The teaching methods you use?
        ii) How you reach diverse learners?
        iii) How you address different genders?
        iv) How you decide which methods to use?
        v) How you teach teaching methods to teachers (e.g., modelling, telling)?

11) What teaching strategies do you encourage teachers to use in their classrooms?
    a) Why have you chosen these teaching strategies?
    b) How do you encourage teachers to use these teaching strategies in their classrooms?
    c) How does your institution's PD help teachers identify appropriate assessment for their instruction?
    d) Seek clarification—Do you model the teaching strategies? give them practice in using them? or how do you teach them about the strategies?

F: Role of Teachers in Professional Development

12) Tell me about the role of teachers in PD at your institution
    a) Do teachers give input? If so, when and how?
    b) What are your expectations of the teachers when they participate in your PD programs?
    c) And how are the expectations made explicit to the teachers?
    d) What expectations do teachers have of the PD you offer?
    e) How do you provide learning that relates directly to the demands of a teacher's school, classroom, and students?

13) There are some terms in your answers that may mean different things to different people. Could you briefly define these? (Use the key words the interviewee used. Then list below is of expected examples.)
    a) hands-on
    b) inquiry
    c) demonstrating
    d) learning styles
    e) feedback
    f) teacher-friendly
    g) best practices
    h) project-based