A Descriptive Study of Pre-Service Science Teachers' Conceptual Understanding of Scientific Inquiry using Concept Maps

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Abstract

Future science teachers serve a critical role in creating a scientifically literate citizenry. Their knowledge and understanding of the process by which science works, scientific inquiry, is fundamental to this goal of science education. This descriptive research study investigated pre-service secondary science teachers' conceptual understanding of scientific inquiry using concept maps. Thirty participants constructed concept maps describing the interrelationships among twelve scientific inquiry concepts. The concept maps were analyzed to determine how participants structured, organized, associated, and described the relationships between these concepts. The majority of participants did organize and associate a chain of inquiry concepts with one another into a scientific method series. Participants displayed an overall low number of associations between the twelve inquiry concepts. Of the concept pairs that were associated with one another, there was a lack of consistency in the linking words used to describe the relationship between them. Implications for science educators in the development and design of teaching about inquiry in pre-service teacher education programs and professional development opportunities are examined. Recommendations for further study into the conceptual understanding of beginning science teachers are also discussed.

Key Words: concept maps, scientific inquiry, pre-service teachers, teacher education

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Chapter I

Introduction

In *Project 2061: Science For All Americans* (1989), the American Association for the Advancement of Science (AAAS) states "the terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics, and technology will be at the center of that change – causing it, shaping it, responding to it. Therefore, they will be essential to the education of today's children for tomorrow's world" (cited in AAAS, 1993, p. XI). Today, over twenty years after the AAAS made this declaration, similar words have been used to characterize the importance of science in education in the United States, "science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges" (National Academy of Science [NAS], 2012, p. 1). This consistent emphasis calls for a citizenry that has a basic understanding of science.

Unfortunately, "Americans as a whole simply have not been exposed to science sufficiently or in a way that communicates, the knowledge they need to have to cope with the life they will have to lead in the twenty-first century" (Hazen & Trefil, 2009, p. xv). Further, "too few U.S. workers have strong backgrounds in these fields, and many people lack even fundamental knowledge of them. This national trend has created a widespread call for a new approach to K-12 science education in the United States" (NAS, 2012, p.

1). These assertions, along with lower rankings on international and national assessment measures, including the Trends in International Mathematics and Science Study (TIMSS), the Programme for International Student Assessment (PISA), and the National Assessment of Educational Progress (NAEP), indicate a citizenry lacking a basic understanding of science. This characterization is troubling in times when scientific discoveries and advancements are omnipresent. Many of the goals for science education and scientific literacy among Americans are not only yet to be realized, but seem all the more distant and urgent.

Background of the Study

The goals of science education in the United States, first nationally illustrated in AAAS's *Project 2061: Science For All Americans* (1989) and the *Benchmarks for Scientific Literacy* (1993), and further updated and outlined in *A Framework for K-12 Science Education* (2012), share an alternative viewpoint to this present reality and establish the goal of scientific literacy for all Americans. "The understanding of, and interest in, science and engineering that its citizens bring to bear in their personal and civic decision making is critical to good decisions about the nation's future" (NAS, 2012, p. x). These national policy documents assert the need for a citizenry that has the knowledge of scientific practices and scientific content (AAAS, 1989, 1993; NAS, 2012).

Scientific literacy has a broad scope that strives to develop an understanding of both the process and the product of science (AAAS, 1993; National Research Council [NRC], 1996, 2000; NAS, 2012). "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements – knowledge and practice – are essential" (NAS, 2012, p. 26). This notion of science as both a verb and a noun illustrate the complex challenge of achieving the goal of scientific literacy. The American Association for the Advancement of Science concluded that:

> Acquiring scientific knowledge about how the world works does not necessarily lead to an understanding of how science itself works, and neither does knowledge of the philosophy and sociology of science alone lead to a scientific understanding of the world. The challenge for educators is to weave these different aspects of science together so that they reinforce one another. (1993, p. 4)

Research supports the notion that to develop scientific literacy, individuals must have a clear understanding of scientific inquiry (Gyllenpalm, Wickman, & Holmgren, 2010; Kang, Orgill, & Crippen, 2008; Lederman, Schwartz, & Crawford, 2004; Lotter, Harwood, & Bonner, 2007). The use of scientific inquiry and a focus on the process of science in education can be traced through curricular history in the United States to the influential ideas of Spencer, Herbart, Smith and Hall, Dewey, Bruner, and Schwab, with their distinct emphasis on the call for students' active role in constructing their own understanding through an emphasis on science as a means for thinking and scientific inquiry as attitude of the mind (Barrow, 2006; DeBoer, 1991, 2004; Dewey, 1910; Pinar, Reynolds, Slattery, & Taubman, 2008).

The *National Science Education Standards* describe scientific inquiry as:

> the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry

> also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (NRC, 1996, p. 23)

The essential characteristics of scientific inquiry include: asking and identifying questions; designing and conducting investigations; using appropriate technology and tools; formulating and revising explanations and models; analyzing alternative explanations and models; communicating results; and generating new questions (NRC, 1996; 2000).

Research on the effectiveness of using inquiry in the science classroom on student learning supports the rationale for these standards and guidelines. Students who are engaged in these types of authentic, hands-on investigations of scientific phenomena have indicated positive results in helping those students learn and understand science processes and concepts (Anderson, 2002; Blanchard et al., 2010; Druva & Anderson, 1983; Shymansky, Kyle, & Alport, 1983; Songer, Lee, & McDonald, 2003; Wilson, Taylor, Kowalski, & Carlson, 2009; Yoon, Yong, & Kim, 2011).

Additionally, in a recent meta-analysis of 138 studies from 1984 to 2002 on inquiry-based science instruction, Minner, Levy, and Century (2009) found significant improvement in students' conceptual learning in science from instruction that had inquiry-based hands-on activities when compared to more traditional instruction. "This overall finding indicates that having students actively think about and participate in the investigation process increases their science conceptual learning" (Minner, Levy, & Century, 2009, p. 20).

The importance of developing scientific literacy through inquiry was evidenced in an excerpt from a recent speech by President Obama:

> Everyone in this room understands how important science and math can be. And it goes beyond the facts in a biology textbook or the questions on an algebra quiz. It's about the ability to understand our world: to harness and train that human capacity to solve problems and think critically, a set of skills that informs the decisions we make throughout our lives. (2009a, November, 23)

If we are to afford students with the opportunity to develop these types of critical thinking and problem-solving skills, key elements of scientific literacy, the use of inquiry-based instruction by skillful teachers can serve as a means to realize this goal.

The *National Science Education Standards* outline that "all students should develop: abilities necessary to do scientific inquiry, and understandings about scientific inquiry" (NRC, 1996, p. 173). They further describe the fundamental abilities and concepts that underlie each of these standards. Similarly, the Minnesota Department of Education provides academic standards for high school students and requires that students will understand that "scientific inquiry uses multiple interrelated processes to investigate and explain the natural world" (2009, p. 28). These academic standards clearly emphasize the need for students to be able to use the inquiry process and conduct scientific investigations in a similar manner that scientists would use to investigate questions about the natural world. In order to do so, students must have teachers with the knowledge and skills to be able to create these types of learning experiences.

The *National Science Education Standards* also provides teaching standards that describe the use of scientific inquiry in the classroom to help achieve the goals for science education. Standard A states "teachers of science plan an inquiry-based science program for their students" (NRC, 1996, p. 30). Standard B states "teachers of science guide and facilitate learning. In doing this, teachers … encourage and model the skills of scientific inquiry, as well as the curiosity, openness, to new ideas and data, and skepticism that characterize science" (NRC, 1996, p. 32). Standard E states "teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning" (NRC, 1996, p. 45).

Similarly, the Minnesota Department of Education has teaching standards that provide guidelines for future and current science teachers requiring that "a teacher of science must demonstrate science perspectives, including … understanding and conducting science inquiry" (2009). These teaching standards clearly define the need for teachers of science to have a solid understanding of the process of scientific inquiry and be able to use this process with their students in conducting scientific investigations to study the natural world.

Teachers are fundamental to developing a scientifically literate citizenry. Research has reinforced the notion that a solid knowledge base is essential for effective science teaching (Ireland, Watters, Brownlee, & Lumpton, 2011; Lederman, Schwartz, & Crawford, 2004; Lotter, Harwood & Bonner, 2007; Marshall, Horton, Igo, & Switzer, 2009; Roehrig & Luft, 2004; Gyllenpalm et al., 2010). Teachers generate meaning of scientific concepts from what they have been taught and have experienced. Teachers construct their own conceptions of the topics they teach, from which they generate representations to make these conceptions comprehensible to students (Abd-El-Khalick & Lederman, 2000; Eick & Reed, 2002; Shulman, 1987; Windschitl, 2004). Teachers' knowledge and opinions of the content can affect both what they will teach and how they will teach it, having a significant impact upon their students' attitudes and understandings (Shulman, 1987). Grossman (1995) stated "teachers are likely to emphasize those areas in which they are more knowledgeable and to avoid or de-emphasize the areas in which they have relatively less content knowledge" (cited in Cutter-Mackenzie & Smith, 2003, p. 499). Teachers with little knowledge of scientific inquiry may be more likely to omit this fundamental aspect of the nature of science, leaving their students with minimal understanding of or inaccurate information about the nature of scientific inquiry.

Statement of the Problem

The *National Science Education Standards* were developed in "an effort to move away from the accumulation of science facts and identify the major principles that underlie scientific thought: to focus curriculum on the big ideas of science" (Amaral & Garrison, 2007, p. 156), with the ultimate goal of fostering scientific literacy (NRC, 1996, 2000). However, how these science standards are implemented and utilized in science classrooms depends upon teachers' past experiences with and interpretations of the topics within these standards. Given this variability, students might develop a range of different understandings regarding the nature of science and scientific inquiry. Amaral and Garrison (2007) further explain that "teachers must learn to adapt instruction to reflect the curriculum designed to get students to understand the concepts in the standards," (p. 157) which often is dependent upon the past experiences of each teacher and their understandings of the content and methods used in teaching about science (Eick & Reed, 2002; Windschitl, 2004).

Barrow (2006) points out that there is a major gap between what is being recommended by science educators (as in *A Framework for K-12 Science Education* and the *National Science Education Standards*), and what is actually happening in the K-12 classroom regarding the use of inquiry. In a study of science education in classrooms across the United States, inquiry as content for observed classes ranked from 15% of the time in grades K-5 to merely 2% of the time in grades 9-12 classrooms (Weiss, Pasley, Smith, Banilower, & Heck, 2003). Given this finding, the process of inquiry seems to be almost non-existent and underutilized in high school science classrooms. With the current emphasis on the practices of science and use of scientific inquiry (NAS, 2012; NRC, 1996; 2000), there appears to be a major disconnect between these recommendations and what is actually occurring in science classrooms.

Amaral and Garrison (2007) assert that a "critical part of a science lesson occurs when teachers provide the opportunity for students to connect the learning from the lesson to the overarching science concepts" (p. 167). Teachers who use inquiry based instruction need the requisite understandings and skills to develop a classroom that allows students to independently investigate scientific questions and conduct scientific inquiries. In order to make this characterization a reality in classrooms, science teachers need a strong foundational understanding of scientific inquiry.

Teachers' knowledge and understanding of a topic can have a significant impact on planning and instructional practices in the science classroom (Amaral & Garrison, 2009; Crawford, 2007; Shulman, 1987; Simmons et al., 1999). Several studies have described the influence of teachers' knowledge and understanding of the nature of science and scientific inquiry have upon instruction (Gyllenpalm et al., 2010; Ireland et al., 2011; Lederman, Schwartz, & Crawford, 2004; Lotter et al., 2007; Marshall et al., 2009; Roehrig & Luft, 2004).

Research has shown that teachers' knowledge and understanding of inquiry serve as foundations of effective science teaching (Davis et al., 2006; Ireland et al., 2011). This knowledge is based upon teachers' abilities to use the language of inquiry to express to their students how these essential characteristics and concepts are related. Gyllenpalm et al. state:

> A prerequisite for teachers and students to gain access to words and concepts to talk about scientific inquiry, and thereby participate in it and develop an understanding of the characteristics of scientific inquiry, is that their teachers introduce and use a relevant language that makes this possible. (2010, p. 1156)

The ways in which these words and concepts are related form a teachers' conceptual understanding of scientific inquiry. Research indicates that these conceptions strongly influence teachers' practices in the classroom (Crawford, 2007; Porlan & Martin del Pozo, 2004; Shulman, 1987). Artiles, Mostert and Tankersley (1994) reported that the presence or absence of specific concepts on pre-service teachers' concept maps may be closely related to future teacher behaviors in the classroom setting. If pre-service secondary science teachers lack a solid understanding of scientific inquiry, it may prove difficult for them to effectively guide their students toward developing their own solid understanding of scientific inquiry, likely resulting in a continuation of low levels of scientific literacy currently evident in the United States.

Numerous research studies have been conducted assessing science teachers' knowledge and understanding of inquiry using a variety of research methods, including: survey instruments (Fazio et al., 2010; Marshall et al., 2009; Porlan & Martin del Pozo, 2004), interviews (Crawford, 1999, 2000; Gyllenpalm et al., 2010; Sadler, 2006; Windschitl, 2004), classroom observations (Crawford, 1999, 2000; Lotter et al., 2007; Yoon et al., 2011), card sorting activities (Harwood et al., 2006), reflective journals (Aulls & Ibrahim, 2012; Davis et al., 2006; Sadler, 2006; Windschitl, 2004) and lesson plan development and analysis (Breslyn & McGinnis, 2012; Crawford, 1999, 2007; Duncan et al., 2010). All of these methods are important techniques that have been used to better understand science teachers' knowledge, skills, beliefs, and attitudes about inquiry.

Purpose of the Study

The purpose of this descriptive study is to investigate pre-service secondary science teachers' conceptual understanding of the essential characteristics of scientific inquiry. In order to use a research methodology that more effectively evaluates conceptual understanding and organization, pre-service teachers' understanding of scientific inquiry will be evaluated through their creation of concept maps. Concept maps have been shown to be a valid and reliable research method that can be used to effectively assess conceptual understanding (Gerchak, Besterfield-Sacre, Shuman, & Wolfe, 2003; Nesbit & Adesope, 2006; Novak & Gowin, 1984; Novak, 2005; Rice, Ryan, & Samson, 1998; Ruiz-Primo & Shavelson, 1996; Rye & Rubba, 2002; Zimmaro & Zappe, 1999). Concept maps serve as an additional method that can contribute to the research literature regarding pre-service science teachers' conceptual understanding of inquiry.

Research Questions

1) How do future secondary science teachers organize concepts related to scientific inquiry?
2) What understandings do future secondary science teachers have regarding essential characteristics of scientific inquiry?
3) How do future secondary science teachers describe the relationships between and among these essential characteristics of scientific inquiry?

Significance of the Study

The results from this descriptive study will provide insight on pre-service science teachers' understandings of specific aspects of the inquiry process that they are required to teach their students. The information gathered from this research study will help science educators in the development and design of teaching about inquiry in pre-service teacher education programs and professional development opportunities.

Definition of Terms

Inquiry –

multi-faceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)

Concept Map - "a schematic device for representing a set of concept meanings embedded in a framework of propositions" (Novak & Gowin, 1984, p. 15).

Proposition - consists of two concepts and a labeled arrowed line that denotes the "proposed" relationship between the two concepts (Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996).

Originating Concept - the primary concept that is connected to a linked concept by an arrowed line (Zak & Munson, 2008).

Linked Concept - refers to the secondary concept that is connected to the originating concept (Zak & Munson, 2008).

Linking Words - the descriptive word(s) on an arrowed line that expresses the proposed relationship between the originating concept and the linked concept (Zak & Munson, 2008).

Generalized Proposition - a proposition resulting from the analysis and coding of several propositions having similar meaning (Zak & Munson, 2008).

Theoretical Framework

The foundation for this research study draws from the *theory of meaningful learning*, which places an emphasis on the role that prior knowledge has on new learning (Ausubel, Novak, & Hanesian, 1968). For meaningful learning to occur, concepts and ideas must be presented using language and examples that are understandable to the learner and build upon prior existing knowledge. Concept maps aim to access learners' existing knowledge structures and provide an external representation of their understanding of scientific inquiry.

Assumptions

The following assumptions underlie the study:

1. Participants put forth their best effort in the construction of their concept maps.
2. The concept maps created represent participants' current knowledge and understanding of scientific inquiry.
3. Participants in the study are a typical representation of pre-service secondary science teachers from teacher preparation programs in Minnesota.
4. Differences in the timing of data collection from different institutions did not influence concept map construction.

Limitations

The following limitations underlie the study:

1. Participant numbers are limited to a purposive sample and may not be typical of the population.

2. Participants' accurate representations of inquiry on their concept maps may be limited due to their collection taking place over several months of an academic semester.

3. Instrumentation is limited to the collection of concept maps.

Summary

This dissertation includes five chapters.

Chapter One provides an introduction to the study, background of the study, statement of the problem, purpose of the study and the research questions. Also included in Chapter One are the significance of the study, definition of terms, assumptions of the study, and limitations of the study.

Chapter Two provides a review of the literature and contains the following sections: introduction; definition; history of inquiry in American education; goals of science education and scientific literacy; research on the influence of inquiry on student learning; inquiry in the science classroom; science teacher standards, teachers' understanding of inquiry; teachers' current practices of inquiry; barriers to inquiry teaching; teacher beliefs, conceptions and knowledge of inquiry; inquiry in teacher preparation; conceptual understanding of inquiry; concept maps; structuring concept maps; and scoring concept maps.

Chapter Three describes the research design for the study and contains sections on research methodology, research design, participants and procedures. Also included in Chapter Three is a description of the methods for data analysis.

Chapter Four reports the results of the study.

Chapter Five closes with conclusions, discussion, and implications for future research based upon the results of the study.

Chapter II

Literature Review

Introduction

In a recent address to the National Academy of Sciences, President Obama remarked that “science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been” (2009b). Our world is profoundly influenced and shaped by scientific discoveries. With the rapid development and proliferation of technology and communication, scientific discoveries and the technological applications of those discoveries are accelerating at exponential rates. In order to make informed and critical decisions about scientific issues relating to our prosperity, our security, our health, our environment, and our culture, citizens will need to have an understanding of basic scientific concepts, the nature of science and scientific inquiry.

Throughout American educational history, there have been repeated calls for students and the general population to develop greater understandings of science (DeBoer, 1991). A recent report from the United States Commission on National Security for the 21st Century (2001) echoed these calls stating that “second only to a weapon of mass destruction detonating in an American city, we can think of nothing more dangerous than a failure to manage properly science, technology and education for the common good” (p. 4).

In *Rising Above the Gathering Storm, Revisited* (2010), a report from the National Academy of Sciences, National Academy of Engineering and Institute of Medicine, the importance of citizens developing an understanding of science, technology, engineering and mathematics (STEM) is further supported and advocated. The National Academies of Science report:

> The *Gathering Storm* committee concluded that a primary driver of the future economy and concomitant creation of jobs in the 21^{st} century will be innovation, largely derived from advances in science and engineering. While only 4 percent of the nation's work force is composed of scientists and engineers, this group disproportionately creates jobs for the other 96 percent. (2010, p. 4)

To address this concern, the committee offers four overarching recommendations, one of which focuses on recruiting and supporting 100,000 new mathematics and science teachers over the next decade, along with strengthening the skills of 250,000 current mathematics and science teachers through professional development and curricular support (NAS, 2010). The committee unanimously determined this recommendation as its highest priority.

Similarly, Change the Equation, a non-profit, nonpartisan initiative led by over 100 CEOs from corporations and businesses, has also called attention to the need to improve STEM education in the United States. Change the Equation states:

> It is no secret that U.S. students have been falling behind their international peers in science, technology, engineering and mathematics. Business leaders worry that this growing gap poses a serious threat to America's competitiveness, prosperity

> and health as a democracy. Without firm grounding in STEM, our students will have little chance to contribute to the kinds of innovation that have fueled U.S. economic growth for decades. (2010)

By developing an understanding of the nature of science and scientific inquiry, citizens will be able to utilize this understanding to search for answers to questions of importance and relevance related to the ever more complex issues that govern the future, and uncover a deeper understanding and appreciation of our world.

Definition of Inquiry

Investigation of these complex issues and the natural world can take on a variety of forms and processes, but share several common essential characteristics. The *National Science Education Standards* define scientific inquiry as:

> the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 23)

The essential features of scientific inquiry include: asking and identifying questions, designing and conducting investigations, using appropriate technology and tools, formulating and revising explanations and models, analyzing alternative explanations and models, communicating results, and generating new questions (NRC, 1996; 2000). These essential features can be used to introduce students to many of the important aspects of the nature of science while helping them develop a clearer and deeper knowledge of science content, concepts and processes. Scientific inquiry engages students in many of the same activities and thinking processes as the scientists who are seeking to expand our understanding of the natural world. Through formulation of scientific questions, establishing criteria for evidence, to proposing, evaluating, and communicating explanations, students learn both the process by which we generate new scientific understandings along with the scientific concepts and content typical of school science programs (NRC, 2000). An emphasis on inquiry asks that students think about "what we know, why we know, and how we have come to know" (NRC, 2000, p. 5).

History of Inquiry in American Education

The notion of using scientific inquiry in American education is not a new idea. Rather, the emergence of scientific inquiry in education shadows the prominence of scientific discoveries and their influence on society stemming back to the Renaissance, and the application of those ideas throughout the industrial revolution of the eighteenth and nineteenth centuries. The processes of science and scientific inquiry offered an alternative to classical, perennialist approaches to learning and education.

Herbert Spencer was an early proponent of this alternative approach to learning and advocated its use as a means to help cultivate the mind. Spencer asserted that:

> The constant habit of drawing conclusions from data, and then of verifying those conclusions by observation and experiment, can alone give the power of judgment correctly. And that it necessitates this habit is one of the immense advantages of science. (1864, p. 88)

Further, in reference to education, he called for school children to take an active role in their learning through these scientific processes. "Children should be led to make their own investigations, and to draw their own inferences. They should be *told* as little as possible, and induced to *discover* as much as possible" (Spencer, 1864, p. 124). Similarly, the ideas of Johann Friedrich Herbart, popularized by DeGarmo (1895) in the United States, proposed that "the best way for students to develop an understanding of new concepts was by having them discover the relationships between phenomena on their own and by having teachers relate new concepts to the experiences of the learner" (DeBoer, 2004, p. 23). Both Spencer and Herbart's suggested focus on the student as the center of the learning process served as a sharp contrast to the classical approaches to education of this time period (Pinar, Reynolds, Slattery, & Taubman, 2008).

In 1893, the study of science and the use of scientific inquiry were legitimized in the curriculum by the recommendations of the National Education Association's *Committee of Ten*, led by Charles Eliot, the president of Harvard University and strong advocate for the role of science in education. The *Committee of Ten*, supported by the subcommittees of each of the different content areas of science, advocated for the study of science and the use of the laboratory to help students develop a deeper understanding of the process of science and cultivate their inductive thinking skills as a means to develop the mind (DeBoer, 1991).

Unfortunately, in the early twentieth century, these recommendations for the use of the laboratory to help students investigate their own questions and make their own discoveries were sparsely implemented in the United States. This is characterized by a

New York State report "While the laboratory method is almost universally approved by the science teachers, the text-book method prevails in the schools, to such an extent that laboratory work is incidental, inefficient, and in many cases excluded altogether" (University of the State of New York, 1900, p. 706). In an effort to address the lack of use and the challenges faced by science teachers in using scientific inquiry in the laboratory, Smith and Hall (1902) offered recommendations and examples on using three different methods to help students understand the nature of science and scientific inquiry for learning new science concepts in chemistry and physics. First, *true discovery* allowed students to investigate their own questions, methods and conclusions. Second, *verification* had students confirm existing scientific principles and conclusions through predetermined questions and methods. Third, the *inquiry* approach struck a balance between the two by keeping a student "just enough in the dark as to the probable outcome of his experiment, just enough in the attitude of discovery, to leave him unprejudiced in his observations" (Smith & Hall, 1902, p. 278). Often, in using the *inquiry* approach, teachers would raise the questions, provide the materials and then serve as a guide helping students formulate their own methods to develop conclusions and to discover scientific concepts and explanations (Smith & Hall, 1902). These different approaches to teaching science, spreading inquiry along a continuum, parallel later manifestations proposed by Schwab (1960), Herron (1971) and Llewellyn (2005).

One prominent and highly influential voice that contributed to the further recommendation of using inquiry in education was John Dewey. In *How We Think* (1910), Dewey advocated using children's innate curiosity to actively involve them in the learning process. He outlined five steps of the "scientific method" to help provide students and teachers with guidance in learning how to logically approach and solve problems in their lives as a result of their experiences in the world. Dewey states:

> the disciplined, or logically trained, mind – the aim of the educative process – is the mind able to judge how far each of the steps needs to be carried in any particular situation …. The trained mind is one that best grasps the degree of observation, forming of ideas, reasoning, and experimental testing required in any special case, and that profits the most, in future thinking, by mistakes made in the past. (1910a, p. 78)

Dewey was a harsh critic of how science was typically being taught during the early part of the twentieth century as:

> … science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed. (1910b, p. 121)

Students were to create their own understanding of the natural world and learn scientific concepts through direct experiences. "Only by taking a hand in the making of knowledge, by transferring guess and opinion into belief authorized by inquiry, does one ever get a knowledge of the method of knowing" (Dewey, 1910b, p. 124). Most science educators of the first half of twentieth century were in agreement and recommended that science education focus on this notion of providing students direct experience with the natural world and the laboratory rather than through the recitation or memorization of words written in a textbook or spoken by a teacher (DeBoer, 1991). However, "… poorly prepared teachers who did not understand the natural world would be forced to rely on the old techniques of rote memorization and recitation" (DeBoer, 1991, p. 48). This lack of preparation and the misinterpretation of Dewey's "scientific method" led to its decontextualized use and formulaic application in science classrooms, which has endured and remains as an entrenched feature of science education today (Finley & Pocovi, 2000; Tang, Coffey, Elby, & Levin, 2009).

On October 4, 1957, *Sputnik I* was launched by the Soviet Union and directly called into question the quality of science education and science teaching in the United States. In response to this significant historical event, Congress passed the *National Defense Education Act* in 1958 calling for more educational opportunities to be made available that would fund curriculum improvements in science, mathematics and foreign languages (DeBoer, 1991; Marshall, Sears, Allen, Roberts, & Schubert, 2007). The Woods Hole Conference, led by Jerome Bruner, along with mainly scientific and military elites, helped to shape how science would be taught in the future. This event was hallmark in calling for a shift from the current practice of science education focused merely on teaching science content to renew again the emphasis on students thinking like scientists by having them observe, classify, infer, and control or manipulate variables (Barrow, 2006; Pinar et al., 2008). Bruner emphasized a focus on the "act of discovery" in learning science and how discovery teaches students "to acquire information in a way that makes that information more readily viable in problem solving" (Bruner, 1961, p. 26). Further, "discovery … is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights" (Bruner, 1961, p. 22). Having students engage in the process of science and understand what scientists do and how they work again became priority as an issue of national security. *Sputnik* ultimately led to the creation and implementation of a series of major educational programs funded by the National Science Foundation in the areas of physics (PSSC), chemistry (CHEM Study), biology (BSCS), earth science (ESCP), and elementary science (ESS and SCIS) during the 1960's to have students learn science through scientific inquiry (DeBoer, 1991).

During the post-*Sputnik* era, another prominent and influential figure added to the historical conversation about inquiry's role in science education. Joseph Schwab charged that scientific content and scientific processes were intimately connected and inseparable. Scientific content needed to be taught in the context of and in relationship to the scientific methods that generated that knowledge (DeBoer, 2004). Through the process of inquiry, Schwab (1966) believed that "students would view science as a series of conceptual structures that should be continually revised when new information of evidence is discovered" (cited in Barrow, 2006, p. 266). This focus on both the process and product of science served to help students better understand the nature of science through inquiry, and ultimately develop a citizenry that was knowledgeable and supportive of the scientific enterprise. "Through the activities of invention, analysis, and critical evaluation, these classrooms and laboratories afford, he can participate in, and be conditioned to, the vicissitudes of inquiry" (Schwab, 1960, p. 192).

Similar to Smith and Hall (1902) in the early twentieth century, Schwab characterized inquiry by varying levels. Herron (1971) expanded upon this notion of levels of inquiry and described each level in terms of what information teachers provide to students regarding the question, procedure and the answer. These levels move from more structure provided by the teacher to less structure. In *confirmation/verification* inquiry, students are given the question, procedure and the answer. In *structured* inquiry, students are provided with the question and the procedure, but left to find out the answer on their own. In *guided* inquiry, students are provided with a question or challenge and asked to develop their own procedure to arrive at their own answers and conclusions. *Open* inquiry invites students to ask their own questions, design their own procedures, and come to their own conclusions about these questions (Herron, 1971).

Building upon these ideas, Welch, Klopper, Aikenhead and Robinson (1981) further outlined the role of inquiry in science education by identifying contextual factors, practices in the classroom, and desired student outcomes related to inquiry. They reported a general discrepancy between the importance of inquiry in science teaching and its use in actual practice in science classrooms. They recommended a model (Student Profile of Inquiry Competencies) to guide the use of inquiry throughout a student's educational experience. "The goals component contains a longitudinally arranged inventory of those inquiry-related competencies which the individual is expected to develop throughout his or her years in school" (Welch et al., 1981, p. 45). These recommendations served as a precursor to the development of more formalized, national efforts to define student understandings of inquiry in science education.

This continued focus and emphasis on the use of inquiry in science education was further supported in the development of two documents created by the American Association for the Advancement of Science (AAAS), solidifying inquiry's place as an important component in the contemporary science curriculum. *Science for All Americans* (1989) and *Benchmarks for Scientific Literacy* (1993) called for students to engage in scientific inquiry to develop a better understanding of the nature of science. Researchers have supported this recommendation that an understanding of scientific inquiry and the nature of science is regarded as fundamental to developing scientific literacy (Abd-El-Khalick & Lederman, 2000; Gyllenpalm, Wickman, & Holmgren, 2010; Lederman, Schwartz, & Crawford, 2004).

Goals of Science Education & Scientific Literacy

As established frameworks for scientific literacy, *Science for All Americans* (1989) and *Benchmarks for Scientific Literacy* (1993) led to the development of the *National Science Education Standards* (NRC, 1996) and *Inquiry and the National Science Educational Standards* (NRC, 2000), which serve as seminal guiding documents that: (a) define inquiry for students and teachers; (b) how inquiry is to be implemented throughout the science curriculum; and (c) how it can be used to support the goals of scientific literacy.

Inquiry in the classroom is described as "a set of interrelated processes by which … students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a right understanding of concepts, principles, models, and theories" (NRC, 1996, p. 214). The *Standards* describe the specific abilities and knowledge that students need in order to develop an understanding of inquiry as the vehicle by which new scientific knowledge is produced. In this way, the *Standards* seek "to build student understanding of how we know what we know and what evidence supports what we know" (NRC, 1996, p. 13). Thus, it is recommended that:

> …designers of curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students will then learn science in a way that reflects how science actually works. (NRC, 1996, p. 214)

Students engaged in scientific inquiry throughout their K-12 educational experience will develop an understanding of the nature of science and scientific inquiry that is characteristic of scientific literacy.

The *National Science Education Standards* define scientific literacy as "...the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996, p. 22). Further, scientific literacy can be characterized as the intercept between the nature of science, scientific inquiry, and science subject matter and the understanding of how these domains are utilized by the individual and society (Lederman, Schwartz, & Crawford, 2004).

And thus, the goals for science education in the *National Standards Education Standards* aim to prepare students who would be able to:

- experience the richness and excitement of knowing about and understanding the natural world;

• use appropriate scientific processes and principles in making personal decisions;

• engage intelligently in public discourse and debate about matters of scientific and technological concern; and

• increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers. (NRC, 1996, p. 13)

Inquiry serves as *the* means to accomplish these goals and help students develop the scientific understanding and the habits of mind to search for answers and investigate the questions, problems, challenges, and uncertainties of our world.

In order to achieve the goals of science education and develop a scientifically literate citizenry that will be able to address current and future challenges, the goals and guidelines that outline the knowledge and related skills regarding scientific inquiry in the *National Science Education Standards* (NRC, 1996) are fundamental and serve as a starting point by which to proceed. The *Standards* specifically state that "all students should develop: abilities necessary to do scientific inquiry, and understandings about scientific inquiry" (NRC, 1996, p. 173). They further describe the fundamental abilities and concepts that underlie each of these standards:

a) identify questions and concepts that guide scientific investigations,

b) design and conduct scientific investigations,

c) use technology and mathematics to improve investigations and communications,

d) formulate and revise scientific explanations and models using logic and evidence,

e) recognize and analyze alternative explanations and models,

f) communicate and defend scientific argument, and

g) understandings about scientific inquiry. (NRC, 1996, p. 173)

Similarly, the Minnesota Department of Education provides academic standards for high school students and requires that students will understand that “scientific inquiry uses multiple interrelated processes to investigate and explain the natural world” (2009). This academic standard includes the following benchmarks where students will be able to:

1) Formulate a testable hypothesis, design and conduct an experiment to test the hypothesis, analyze the data, consider alternative explanations and draw conclusions supported by evidence from the investigation.

2) Evaluate the explanations proposed by others by examining and comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the scientifically acceptable evidence, and suggesting alternative scientific explanations.

3) Identify the critical assumptions and logic used in a line of reasoning to judge the validity of a claim.

4) Use primary sources or scientific writings to identify and explain how different types of questions and their associated methodologies are used by scientists for

investigations in different disciplines. (Minnesota Department of Education, 2009)

In 2012, the National Academies of Science generated a Framework for K-12 Science Education as the start to developing a new set of national science standards. This framework "highlights the power of integrating understanding the ideas of science with engagement in the practices of science and is designed to build students' proficiency and appreciation for science over multiple years of school" (NAS, 2012, p. x). This national policy document places an emphasis on eight practices of science characteristic of scientific inquiry:

1) Asking questions (for science) and defining problems (for engineering)

2) Developing and using models

3) Planning and carrying out investigations

4) Analyzing and interpreting data

5) Using mathematics and computational thinking

6) Constructing explanations (for science) and designing solutions (for engineering)

7) Engaging in argument from evidence

8) Obtaining, evaluating, and communicating information. (NAS, 2012, p. 42)

The framework asserts that "students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves" (NAS, 2012, p. 30).

These academic standards and recommendations clearly emphasize the need for students to be able to use the inquiry process and conduct scientific investigations in a similar manner that scientists would use to investigate questions about the natural world.

Research on the Influence of Inquiry on Student Learning

Research on the effectiveness of using inquiry in the science classroom on student learning supports the rationale for these standards and guidelines. Students that are engaged in these types of authentic, hands-on investigations of scientific phenomena have been shown to have positive results on helping students learn and understand science processes and concepts (Anderson, 2002; Blanchard et al., 2010; Druva & Anderson, 1983; Shymansky, Kyle, & Alport, 1983; Songer, Lee, & McDonald, 2003; Yoon, Yong, & Kim, 2011).

Similarly, Wilson, Taylor, Kowalski, and Carlson (2009) examined the effectiveness of inquiry-based instruction using randomized controls and found that students in the inquiry-based group reached significantly higher levels of achievement for three learning outcomes (scientific knowledge, scientific reasoning through application of models, and construction and critique of scientific explanations) than students experiencing more traditional instruction. This difference was consistent for each of these measured learning outcomes and across time frames (immediately following the instruction and four weeks later; Wilson et al., 2009, p. 276).

The results of this study are further supported by a meta-analysis of 138 research studies from 1984 to 2002 focused on the effects of inquiry-based science instruction on student learning. Generally, Minner et al. (2009) found significant improvement in student conceptual learning in science from instruction that had inquiry-based hands-on activities when compared to more traditional instruction. Specifically, among six studies (Chang & Barufaldi, 1997, 1999; Chang & Mao, 1998; Lumpe & Staver, 1995; Marinopoulos & Stavridou, 2002; and Smith, Maclin, Grosslight, & Davis, 1997) they highlight statistically significant increases in student conceptual understanding of science when using inquiry instruction compared to more traditional instruction. Minner et al. state:

> There is a clear and consistent trend indicating that instruction within the investigation cycle (i.e., generating questions, designing experiments, collecting data, drawing conclusion, and communicating findings), which has some emphasis on student active thinking or responsibility for learning, has been associated with improved student content learning, especially learning scientific concepts. This overall finding indicates that having students actively think about and participate in the investigation process increases their science conceptual learning. Additionally, hands-on experiences with scientific or natural phenomena also were found to be associated with increased conceptual learning. (2009, p. 20)

This research synthesis provides convincing evidence and support for the effectiveness of inquiry in science teaching. Historically, this notion of personally engaging students in direct, hands-on experiences and investigations characteristic of inquiry to learn about the nature of science has long been advocated for, and this body of research offers evidential credence to those long-standing recommendations.

Inquiry in the Science Classroom

Even while there is strong evidence on the positive effects of inquiry teaching on student learning, and with guiding documents characterizing and recommending the use of inquiry in science classrooms, inquiry in practice can have myriad meanings and its use influenced by multiple factors. Inquiry "means so many different things to different people, …[it] is difficult for many people to visualize in actual practice and …is so difficult for many teachers to put into successful practice" (Anderson, 2002, p. 3). Because scientific inquiry can take on a variety of forms and processes, this has led to repeated confusion and misinterpretation about inquiry in science teaching (Costenson & Lawson, 1986; Crawford, 2000; DeBoer, 2004; NAS, 2012).

In an effort to clarify and to better illustrate inquiry teaching in science classrooms, *Inquiry and the Science Education Standards* (NRC, 2000) describes suggestions of how each of the essential features of inquiry (p. 25) can be implemented in the classroom in several ways, depending upon the level of ownership and structure provided by teachers in contrast to the amount of responsibility given to the students. In order to develop a broader understanding of inquiry and each of these essential characteristics, it is encouraged that students, and teachers, at all grade levels have opportunities to engage in these various types of inquiry, along a continuum from more structured, to guided, to more open inquiry, similar to those previously described by Smith and Hall (1902), Schwab (1960) and Herron (1971). "The form that inquiry takes depends largely on the educational goals for students, and because these goals are diverse, highly structured and more open-ended inquiries both have their place in science classrooms" (NRC, 2000, p. 10). For teachers to effectively incorporate and use these different types of inquiry in the classroom, they will need to understand and utilize a variety of skills to be able to support their students' learning.

Effective inquiry teachers are flexible and skilled at dealing with the unexpected questions, situations and discoveries that can occur. They challenge students to conduct and/or develop investigations that are within their capabilities and are able to engage students because of their solid understanding of their content area (Costenson & Lawson, 1986, NRC, 2000; Songer, Lee, & McDonald, 2003). Effective inquiry teachers are able to shift the responsibility for learning to their students and engage them in observing, questioning, predicting and hypothesizing. This is often accomplished through small groups of students involved in a variety of more or less self-guided activities, with the teacher circulating between groups to act as a facilitator or guide (Aulls & Ibrahim, 2012; NRC, 2000; Rankin, 2011; Songer, Lee, & McDonald, 2003) and the "teacher's work in an inquiry-based classroom requires taking on a myriad of roles - roles that demand a high level of expertise" (Crawford, 2000, p. 932). Specifically, this role as a *facilitator* was particularly shown to be a dominant feature of effective inquiry instruction and coincided with the changing roles in the classroom that required students to take more responsibility for their learning (Aulls & Ibrahim, 2012). In this capacity, effective inquiry teachers engage their students in reflective activities and discussions that enable them to construct their understandings of science concepts and the process of scientific inquiry based upon their classroom experiences (Eick & Reed, 2002; NRC, 2000; Schwartz, Lederman, & Crawford, 2004). Inquiry teachers utilize real-world phenomena in the classroom, the outdoors or the laboratory and are able to guide their students in their abilities to weave these experiences and information into an understanding of science concepts (Amaral & Garrison, 2007; Rankin, 2011).

To further illustrate these practices, Crawford (2000) conducted a case study investigating the actions of a teacher and students in an inquiry-based high school biology classroom. Based upon multiple sources of data, Crawford identified and described six key characteristics common to this example inquiry classroom: (a) situating instruction in authentic problems; (b) grappling with data; (c) collaboration of students and teacher; (d) connection with society; (e) teacher modeling behaviors of a scientist; and (f) development of student ownership (2000). Additionally, these characteristics necessitated the use of different roles that were unique to this inquiry classroom for both teacher and students in contrast to more traditional classrooms. In addition to more traditional roles, the teacher took on the roles of motivator, facilitator, innovator, experimenter and researcher; while students also became collaborators, leaders, apprentices, teachers and planners. As a result, inquiry-based instruction demands a significant shift in terms of a teacher's and students' actions and what they are actually doing in the science classroom (Crawford, 2000).

Using inquiry effectively necessitates a balance and flexibility between the varying the roles that students and teachers can serve in a science classroom. While there is no prescriptive determination for this balance between teacher direction and student responsibility, several important considerations can influence the success of using inquiry. Teachers must have clearly defined goals for student learning and how to structure meaningful learning experiences in a manageable about of time. Teachers must also have a clear understanding of their students' abilities to utilize scientific process skills that are characteristic of inquiry (Rankin, 2011). Additionally, teachers must consider the scientific theories, experimental tools, resources and traditions of their content area that will allow their students to engage in these various forms of inquiry (Breslyn & McGinnis, 2012; Songer, Lee, & McDonald, 2003). In order to create these types of learning experiences, students must have teachers with the knowledge and pedagogical skills to be able to teach using inquiry.

Science Teacher Standards

The *National Science Education Standards* provide three teaching standards that describe the use of scientific inquiry in the classroom to help achieve the stated goals of science education. Standard A states "teachers of science plan an inquiry-based science program for their students" (NRC, 1996, p. 30). Standard B states "teachers of science guide and facilitate learning. In doing this, teachers … encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science" (NRC, 1996, p. 32). Standard E states "teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning" (NRC, 1996, p. 45). These teacher standards illustrate a science classroom based upon the characteristics of inquiry teaching.

Similarly, the Minnesota Department of Education has teaching standards that provide guidelines for future and current science teachers requiring that:

> a teacher of science must demonstrate science perspectives, including: 1) understanding and conducting science inquiry as evidenced by the ability to: (a) ask appropriate theoretical or empirical questions about a given system or event that build on current scientific knowledge and can be answered scientifically; (b) design and conduct, using appropriate methods, technology, and mathematical tools, a scientific investigation to answer a given question; (c) develop, using appropriate sources of information, qualitative and quantitative solutions to problems; (d) communicate clearly and concisely, using words, diagrams, tables, graphs, and mathematical relationships, the methods and procedures, results and conclusions for a given empirical question or problem; (e) justify a scientific explanation of a given system or event, compared to alternative explanations, based on the available empirical evidence, current scientific understanding, and logical arguments; and (f) criticize, using knowledge of common errors of evidence and logic, a given science-related claim or argument. (2009)

These teaching standards clearly reinforce the need for teachers of science to have solid understanding of the process of scientific inquiry and be able to use this process with their students in conducting scientific investigations to study the natural world.

While both the student standards and teaching standards place an emphasis on the use of inquiry in science classrooms, history has shown that inquiry teaching is more rare than common (DeBoer, 2004). Depending upon how teachers view and use the standards associated with scientific inquiry, students might develop a range of different understandings regarding the role and importance of inquiry in science. Amaral and Garrison (2007) explain that "teachers must learn to adapt instruction to reflect the curriculum designed to get students to understand the concepts in the standards," (p. 157) which often is dependent upon the past experiences of each teacher and their understanding of the methods used in teaching science.

Teachers' Understanding of Inquiry

While standards and policy documents serve as foundational resources for establishing the goals for science education, ultimately educational reform efforts hinge upon the interactions that occur between the teacher and the students in the classroom (Elmore, 2004; Fullan, 2005). The American Association for the Advancement of Science states:

> Although creative ideas for reforming education come from many resources, only teachers can provide the insights that emerge from intensive, direct experience in the classroom itself. They bring to the task of reform knowledge of students, craft, and school structure that others cannot. (1989, p. 212)

Teachers possess valuable perspective and specialized knowledge acquired through pre-service education, years of teaching experience in the classroom and professional development opportunities, and serve as core agents in science education reform efforts (Luft & Lee, 2008). Teachers use their procedural knowledge to make instructional decisions in their classrooms based upon the complex interaction of several factors that include their own content and pedagogical knowledge, motivation, beliefs, capabilities and teaching context (Fazio, Melville & Bartley, 2010; Roehrig & Luft, 2004; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Given the vital role that teachers serve, it is important to investigate teachers' current practices, beliefs toward, and knowledge of inquiry to better understand how inquiry is being utilized in K-12 science classrooms.

Teachers' Current Practices of Inquiry

Following the launch of Sputnik, and after the implementation of the major science curricular reform efforts of the 1960's and 1970's that focused on inquiry, a study by Hurd, Bybee, Kahle, and Yager (1980) reported that the textbook continued to serve as the primary source by which teachers used to make decisions about how to teach science in their classrooms. The researchers also found that teachers rarely used laboratory activities in their instruction and that the common sequence of instruction was to "assign, recite, test and discuss the test," all based upon information from the textbook (Hurd et al., 1980). While these findings are from a generation ago, current science teachers learned much of their science content from the teachers from this era and experienced learning science in this manner. While many factors influence classroom instruction, teachers tend to teach as they have been taught (Costenson & Lawson, 1986; Harwood, Hansen & Lotter, 2006; Shumba & Glass, 1994).

More recently, Weiss, Pasley, Smith, Banilower, and Heck (2003) found similar results in their national study of science education in classrooms. They reported that "the percentage of lessons with a focus on science inquiry (typically in combination with another topic) varies from 2 percent of lessons in grades 9–12 to 15 percent of lessons in elementary schools" (p. 22). In an international study of science teachers, Marshall, Horton, Igo, and Switzer (2009) indicated similar trends. They found that as the grade level increased from elementary to middle to high school, both the typical percentages of time and the ideal percentages of time science teachers allocated to inquiry decreased dramatically in their classrooms (Marshall et al., 2009). The results from this study suggest that elementary teachers utilize and value inquiry teaching more than middle school and high school science teachers. Additionally, "teachers at all grade levels in the present study consistently report an ideal percentage of instructional time that should be devoted to inquiry about one standard deviation above their current percentage of time devoted to inquiry" (Marshall et al., 2009, p. 590). While inquiry may be valued by these science teachers, in practice, inquiry is still significantly underutilized. For many teachers, "inquiry is a luxury, rather than a necessity; many teachers who use it periodically consider it to be in addition to the regular teaching of science, and oftentimes it is used as a reward for students after covering the required material" (Johnson, 2006, p. 133). With this major disconnect from what is being recommended and the reported lack of inquiry teaching occurring in science classrooms, it is important to consider potential reasons and factors that influence this occurrence.

Barriers to Inquiry Teaching

Teaching science through inquiry can be challenging for even the most experienced teacher (Crawford, 1999). Many teachers have difficulty creating classroom environments that are inquiry-based and face numerous challenges that influence the use of inquiry. Costenson and Lawson (1986) provided an initial list of some challenges and reasons commonly expressed by biology teachers for not using inquiry in their classrooms:

1. Time and Energy - Too much time must be devoted to developing good inquiry materials. Too much energy must be expended to maintain level of enthusiasm through five classes each day.

2. Too Slow - We have district curricula and must cover all the material. The class will not cover all they will need to know.

3. Reading Too Difficult - The students cannot read the inquiry book.

4. Risk Is Too High - The administration will not understand what is going on and think I am doing a poor job. I am not sure how each unit will turn out.

5. Tracking - There are no formal thinkers left in regular biology.

6. Student Immaturity - Students are too immature. Students waste too much time and, therefore, will not learn enough.

7. Teaching Habits - I've been teaching this way for 15 years, and I cannot change now.

8. Sequential Material - Inquiry textbooks lock you into the order of the book. I cannot skip labs because there is too much new material in each.

9. Discomfort - I feel uncomfortable not being in control of what is going on in my classroom. Students feel too much discomfort.

10. Too Expensive - My lab is not equipped for inquiry. My district will not buy materials needed to maintain an inquiry approach. (p. 151)

Table 1 shows additional research studies conducted more recently stating reasons and barriers teachers experience when considering the use of inquiry in their science classrooms.

Table 1

Research Studies Reporting Barriers to Teaching Inquiry

Barrier	Research Studies
Lack of time	*Johnson, 2006; Roehrig & Kruse, 2005*
Classroom management issues	*Johnson, 2006*
Lack of understanding on using prepared materials	*Anderson, 2002; McDonald & Songer, 2008*
Complexity of inquiry instruction	*Marshall et al., 2009*
Lack of curricular resources	*Marshall et al., 2009; Songer, Lee & McDonald, 2003*
Traditional teacher-centered beliefs about science	*Roehrig & Kruse, 2005*
School organization	*Roehrig & Kruse, 2005*
Beliefs about traditional teacher roles	*McDonald & Songer, 2008*
Lack of understanding of the nature of science	*Fazio, Melville & Bartley, 2010; Wallace & Kang, 2004*
Lack of knowledge and experience with inquiry	*Duncan, Pilitsis & Piegaro, 2010; Fazio, Melville & Bartley, 2010; Marshall et al., 2009; Roehrig & Kruse, 2005*

In order for teachers to develop inquiry-based classrooms, numerous studies have emphasized the importance of sufficient knowledge of and prior experience with scientific inquiry as a precursor to using it in their classrooms (Crawford & Cullin 2004;

Davis 2006; Justi & van Driel 2005; Schwarz & Gwekwerere 2007). Duncan et al. point out that:

> Developing appropriate instruction is a formidable challenge as teachers themselves have rarely had any experiences with scientific inquiry as learners and therefore lack models of what inquiry-based classrooms look like or how to design such learning environments. (2010, p. 82)

Wright and Wright (2000) argued that, "One cannot teach, model, or support what one does not know, feel, or accept" (as cited in Johnson, 2006, p. 133), which characterizes many of the internal barriers that teachers experience listed and described above.

These challenges are even more pronounced amongst pre-service and beginning science teachers, as much of their energy tends to be focused on learning content, lesson planning, classroom management and the presentation of content (Roehrig & Luft, 2004), resulting in science instruction that is more teacher-directed (Simmons et al., 1999). Many of these teachers are focused on learning how to survive as beginning teachers instead of using inquiry in their teaching.

Teacher Beliefs, Conceptions and Knowledge of Inquiry

Teacher beliefs are another factor that can influence the use of inquiry in the science classroom. Teacher belief structures play a significant role in teacher decisions in the classroom, particularly when making decisions about curriculum and instructional tasks (Nespor, 1987; Pajares, 1992; Richardson, 1996). Several research studies (Cochran-Smith & Lytle, 1999; Mellado, 1998; Pajares, 1992) indicate that "teachers' beliefs color and influence their teaching practices, how they believe content should be taught, and how they think students learn" (as cited in Harwood et al., 2006, p. 69). Several other studies show similar indications about how teachers' beliefs have a direct impact on teacher decisions about whether to use inquiry in their science classrooms (Crawford, 2007; Keys & Bryan, 2001; Roehrig & Kruse, 2004; Roehrig & Luft, 2004). Teachers' beliefs about student abilities, science content, student learning, teaching, and their role in instruction have developed through teachers' experiences in science classrooms over time. Harwood et al. report:

> Further, these beliefs have been steadily forming since their beginning school years through a process of apprenticeship by observation that makes it difficult for prospective teachers to consider alternative approaches to teaching and learning that are different from how they were taught. (2006, p. 70)

These beliefs are often resistant to change because of their close relationship and development with practical experiences in the classroom, and how they influence science teachers' practices in the classroom (Lotter et al., 2007). Teacher beliefs have also been shown to serve as barriers to implementing the recommendations regarding the use of inquiry teaching as described in national policy documents (Eick & Reed, 2002; Wallace & Kang, 2004). While teacher beliefs can provide greater insight into the practices exhibited by science teachers, it is important to also consider how teachers conceptualize and understand scientific inquiry.

Similar to teachers' beliefs, teachers' knowledge and understanding of a topic can have a significant impact on planning and instructional practices in the science classroom (Amaral & Garrison, 2009; Crawford, 2007; Shulman, 1987; Simmons et al., 1999).

Several studies have described the influence of teachers' knowledge and understanding of the nature of science and scientific inquiry have upon instruction (Gyllenpalm et al., 2010; Ireland et al., 2011; Lederman, Schwartz, & Crawford, 2004; Lotter et al., 2007; Marshall et al., 2009; Roehrig & Luft, 2004). "To *teach* science, one must have knowledge of the concepts and effective approaches to teaching science. As such, to teach NOS [nature of science] and inquiry, the teacher needs knowledge of NOS and inquiry, and pedagogical knowledge for each" (Lederman, Schwartz, & Crawford, 2004, p. 637). This notion is further nuanced in that teachers must also have a clear understanding of the functional language of inquiry (Gyllenpalm et al., 2010) and have a solid understanding of how concepts associated with inquiry are interrelated (Costenson & Lawson, 1986; Lotter et al., 2007; Marshall et al., 2009). "Knowledge that is fragmented or compartmentalized does not help the teacher in crafting instruction that best represents science as inquiry" (Roehrig & Luft, 2004, p. 4). For teachers to effectively instruct their students about scientific inquiry, they need to be knowledgeable about scientific inquiry themselves.

The interplay of teachers' knowledge and beliefs can have a significant impact upon their students' understanding about the nature of science and scientific inquiry. Teachers develop their own conceptual understanding of the topics they teach, from which they generate representations to make these ideas comprehensible to students (Abd-El-Khalick & Lederman, 2000; Roehrig & Luft, 2004; Shulman, 1987). Similarly, teachers' knowledge of the content area they are teaching affects both what they teach and how they will teach that content. Grossman (1995) stated "teachers are likely to emphasize those areas in which they are more knowledgeable and to avoid or de-emphasize the areas in which they have relatively less content knowledge," (cited in Cutter-Mackenzie & Smith, 2003, p. 499). Teachers with little knowledge of scientific inquiry would be more likely to omit this fundamental aspect of the nature of science from their instruction, leaving their students with minimal understanding of or inaccurate information about the process by which science operates to generate new knowledge.

Inquiry in Teacher Preparation

As one important component in developing and influencing teacher knowledge and beliefs, teacher education programs serve a critical function and must provide pre-service teachers with a broad background in both science content and pedagogy. In preparing teachers to instruct students about the nature of science, scientific inquiry and scientific content, university teacher preparation programs in the United States vary greatly in their levels of preparation. Unfortunately, many programs fail to provide pre-service and beginning teachers with adequate experiences and models of inquiry in the classroom (Barrow, 2006; Davis et al., 2006; Windschitl, 2004). As mentioned above, a lack of experience with scientific inquiry was cited as a major reason that teachers do not use inquiry in their curriculum (Costenson & Lawson, 1986; Duncan et al., 2010; Fazio et al., 2010; Marshall et al., 2009; Roehrig & Kruse, 2005). Pre-service teachers often receive much of their scientific knowledge and understanding through undergraduate coursework that often has little emphasis on the nature of science or scientific inquiry (Barrow, 2006; Davis et al., 2006). Teachers with minimal experience with and partial conceptions of scientific inquiry significantly limited the amount of class time they devoted to using scientific inquiry when compared with those who had more experience (Lotter et al., 2007). It is little surprise that many beginning science teachers feel unprepared to teach using scientific inquiry based on current trends in teacher preparation programs.

As colleges and universities prepare pre-service teachers to begin a career in teaching, they attempt to provide future teachers with accurate information and the skills to be successful. To do so, researchers recommend that pre-service teacher education programs provide future teachers with first hand experiences doing inquiry (Davis et al., 2006; Gyllenpalm et al., 2010), opportunities to critique, adapt, and design inquiry-based materials (Duncan et al., 2010) and conceptualize their understanding of scientific inquiry (Windschitl, 2004). Upon entering the profession, these new teachers will have considerable influence upon their students' learning and will need to be able to provide them with accurate information about the nature of science and scientific inquiry as recommended by national and state science standards. It is critical to the goals of science education that these future teachers are knowledgeable about, experienced with and have a solid understanding of the nature of science and scientific inquiry.

Conceptual Understanding of Inquiry

As science teachers contemplate the recommendations on inquiry espoused in the standards documents, search for curricular resources, make considerations regarding their students, classroom supplies, school culture, and reflect upon their own beliefs, past experiences, and knowledge, a complex picture of inquiry teaching emerges into varying forms of classroom practice. While considering the interaction of the multitude of these expressed factors that influence inquiry teaching in science classrooms, several areas warrant further investigation and research.

It is clear that teachers' knowledge and understanding of inquiry serve as foundations of effective science teaching (Davis et al., 2006; Ireland et al., 2011). This knowledge is predicated on teachers' abilities to utilize the language of inquiry to express to their students how its essential characteristics and concepts are related. Gyllenpalm et al. assert:

> A prerequisite for teachers and students to gain access to words and concepts to talk about scientific inquiry, and thereby participate in it and develop an understanding of the characteristics of scientific inquiry, is that their teachers introduce and use a relevant language that makes this possible. (2010, p. 1156)

How these words and concepts are related form a teachers' conceptual understanding of scientific inquiry. Several researchers indicate that these conceptions strongly influence teachers' practices in the classroom (Crawford, 2007; Porlan & Martin del Pozo, 2004; Shulman, 1987). Several studies call for further research into teachers' conceptual understanding of scientific inquiry (Crawford, 2007; Davis et al., 2006; Gyllenpalm et al., 2010; Ireland et al., 2011; Lotter et al., 2007).

As noted in Chapter One, numerous research studies have been conducted assessing science teachers' knowledge and understanding of inquiry using a variety of quantitative and qualitative research methods, including: survey instruments (Fazio et al., 2010; Marshall et al., 2009; Porlan & Martin del Pozo, 2004), interviews (Crawford, 1999, 2000; Gyllenpalm et al., 2010; Sadler, 2006; Windschitl, 2004), classroom observations (Crawford, 1999, 2000; Lotter et al., 2007; Yoon et al., 2011), card sorting activities (Harwood et al., 2006), reflective journals (Aulls & Ibrahim, 2012; Davis et al., 2006; Sadler, 2006; Windschitl, 2004) and lesson plan development and analysis (Breslyn & McGinnis, 2012; Crawford, 1999, 2007; Duncan et al., 2010). Much of this prior research on teachers' understanding of scientific inquiry has been limited to these research methodologies. All of these methods are important techniques that have been used to assess knowledge, understanding, skills, beliefs, and attitudes. However, an additional method can offer insight to the research literature regarding pre-service science teachers' conceptual understanding of inquiry.

Concept Maps

Concept mapping is based upon David Ausubel's theory in cognitive psychology that learning occurs when new concepts are assimilated into the learners' existing conceptual frameworks (Ausubel, Novak, & Hanesian, 1968). In 1972, Joseph Novak was researching children's knowledge of science concepts and found difficulty with identifying specific changes in their understanding through analysis of interview transcripts. In seeking to use a more effective way to represent children's conceptual understanding of science concepts, Novak began to have participants map out their understanding and describe the relationships between concepts (Novak & Canas, 2006).

Concept maps can provide a visual representation of how important concepts in a subject area are mentally organized and structured (Gerchak, Besterfield-Sacre, Shuman, & Wolfe, 2003; Novak & Gowin, 1984; Rice, Ryan & Samson, 1998; Ruiz-Primo & Shavelson, 1996; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Rye & Rubba, 2002;

Wallace & Mintzes, 1990). Concept maps allow teachers to not only understand what their students know, but how they organize their knowledge (Rice et al., 1998; Ruiz-Primo & Shavelson, 1996; Rye & Rubba, 2002; Wallace & Mintzes, 1990). Similarly, researchers can use concept maps to assess participants' understanding and learn how they organize their knowledge of a specified topic. Concept maps can be used to measure not only simple facts, but how those facts and different concepts relate to one another. Concept maps urge participants to think on a deeper cognitive level than a "fill-in-the-blank" test might require (Jacobs-Lawson & Hershey, 2002; Ruiz-Primo & Shavelson, 1996). It has been shown that "concept maps can potentially reveal if the student has a comprehensive, well-structured and correct understanding of the field of study" (Gerchak et al., 2003, p. 24).

Concept maps have been shown to be a useful and valid research tool (Nesbit & Adesope, 2006; Novak, 2005; Wallace & Mintzes, 1990; Williams, 1998; Zimmaro & Zappe, 1999). They have shown strong content validity and concurrent validity when compared to other measures of knowledge such as standardized tests, multiple-choice tests, and essays (Rice et al., 1998; Ruiz-Primo & Shavelson, 1996, Zimmaro & Zappe, 1999). Concept maps have also exhibited strong construct validity in their ability to perform in accordance with theoretically derived expectations (Kearney & Kaplan, 1997; Ruiz-Primo & Shavelson, 1996).

A review of literature reveals that a significant number of recent research studies have examined the use of concept maps in the assessment of knowledge in different content areas: medical education (West, Park, Pomeroy, & Sandoval, 2002), teacher education (McLay & Brown, 2003; Nickles, 2003), psychology (Jacobs-Lawson & Hershey, 2002), science education (Rice et al., 1998; Robinson, 1999; Slotte, & Lonka, 1999), mathematics (Bolte, 1999; Williams, 1998), ecology (Zak & Munson, 2008), and biology (Kinchin, 2000; Martin, Mintzes, & Clavijo, 2000; Mintzes, Wandersee, & Novak, 2001; Thompson & Mintzes, 2002). As concept maps were initially developed and used as a research tool, the research literature has shown them to be effective in representing participants' understanding in a variety of areas and topics.

The fundamental unit of a concept map is a *proposition*, which consists of two nodes and a labeled line that denotes the "proposed" relationship between two concepts (Ruiz-Primo & Shavelson, 1996; Ruiz-Primo et al., 2001). Each proposition consists of two concepts connected with a linking word(s) on a labeled line identifying the relationship between the two concepts (see Figure 1). The resulting proposition often reads like simplified sentence, for example, "trees have leaves" (Novak & Gowin, 1984). An individual's concept map - a network of interrelated propositions - can be characterized and analyzed to assess the map structure, content accuracy, and depth of conceptual knowledge held within a subject area (Johnson, O'Connor, Pirnay-Dummer, Ifenthaler, Spector, & Seel, 2006; Ruiz-Primo & Shavelson, 1996; Ruiz-Primo et al., 2001; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005; Zak & Munson, 2008).

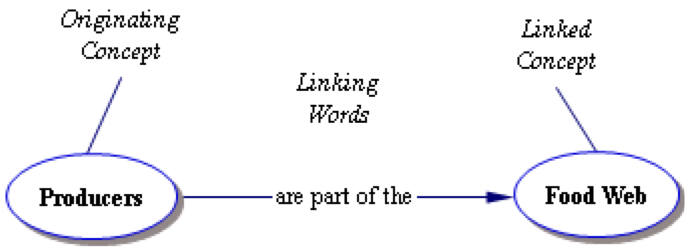

Figure 1. Example of a proposition from a concept map on ecosystems.

Structuring Concept Maps

There are myriad ways of structuring concept maps. Concept maps can range from highly structured versions to maps with relatively little structure at all. Individuals may be asked to create a concept map from scratch or fill in provided blanks on the concept map. They may be asked to organize a list of concepts provided for them or develop a list of concepts on their own. A comprehensive summary that describes various methods of structuring concept maps and rationale for use can be found in several sources (Novak & Gowin, 1984, pp. 97-107; Ruiz-Primo & Shavelson, 1996, p. 586; Ruiz-Primo et al., 2001, p. 267).

Highly structured concept maps, such as fill-in-the-node and fill-in-the-lines, have been limited measures of participant knowledge due to their use of expert-developed concepts that impose too much structure upon participant responses (Kaplan & Kearney, 1997; Ruiz-Primo et al., 2001). Schau and Mattern (1997) assert that developing a concept map from scratch where no concepts are provided is too difficult to offer an accurate representation of a participant's knowledge (p. 174). In addition, research has shown that using concept maps with different designs that measure the same content area may produce different results from participants (Ruiz-Primo et al.,1997; Ruiz-Primo et al., 2001). Considering these limitations, the method used to design a concept map needs to incorporate enough structure to be able to assess a common area of knowledge without providing too much structure that restricts the participants' ability to accurately describe the relationships between concepts in a given content area.

Scoring Concept Maps

"Although concept maps are a viable method for capturing such desired integrated knowledge, to date the difficulty of scoring these qualitative instruments has greatly limited their use as an assessment tool" (Gerchak et al., 2003, p. 20). As with any instrument that is used in the evaluation or assessment of a specified content area, a certain level of subjectivity is inherent. In developing a scoring system to evaluate concept maps, Novak and Gowin (1984) outline the need to analyze and quantify four components of a concept map that include: (a) the accuracy of provided propositions, (b) hierarchical structure of the map from general to more specific, (c) valid cross-links between separate areas on the concept map; and (d) examples that pertain to provided concepts. Similar components are outlined and described by Ruiz-Primo and Shavelson (1996, p. 582). As one method of scoring concept maps, this type of analysis provides researchers with a quantitative method for assessing conceptual understanding among individuals.

However, Ruiz-Primo et al. (1997) assert that "… there is no need to impose a hierarchical structure on concept maps if the structure of the content domain to be mapped is not hierarchical" (p. 7). Concept maps constructed with a non-hierarchical structure may be scored lower using this previously described scoring system, resulting in inaccurate evaluations of individuals' representations of a specified topic.

Ruiz-Primo and Shavelson (1996) outline several alternative options that could be used to score concept maps. Each proposition can be scored individually by analyzing: (a) the relationship between two concepts; (b) the accuracy of the description linking the two concepts; and (c) the direction of the relationship. The researchers also propose the idea of creating a criterion map that can be used to make comparisons with constructed concept maps. These guidelines are supported by and outlined in further detail in several research studies (Ruiz-Primo et al., 1997; Ruiz-Primo et al., 2001; Rye & Rubba, 2002). In addition to these evaluation methods, a scoring rubric can be used to assess each provided proposition for depth and accuracy (Ruiz-Primo et al., 1997; Gerchak et al., 2003).

These scoring methods address the quantitative aspects of concept maps, but concept maps can also provide information that is qualitative in nature as well. Each concept map is comprised of numerous propositions that describe a "proposed" relationship between two concepts. The relationships between two concepts within a subject area, described by the linking words that connect the concepts, can be categorized and analyzed collectively for similarities within a given population. This form of qualitative analysis can be useful in providing another perspective that shows patterns of understanding by a given population for a specified content area (Buitink, 2009; Ritchhart, Turner, & Hadar, 2009; Wheeldon & Faubert, 2009; Zak & Munson, 2008).

Chapter III

Method Overview

In considering which methodology to utilize in a research study, it is critical that the research question(s) fit the design selected for the study (Blaikie, 2010) and that the knowledge claims sought, the strategies for inquiry, and the methodology employed are aligned (Creswell, 2003). Concept maps have been used widely in research to analyze peoples' conceptual understanding by graphically depicting how they structure and organize their knowledge in a specified domain.

Statement of the Problem

While academic and teaching standards for scientific inquiry exist, how these standards are implemented and addressed in the classroom by teachers is dependent upon their past experiences with, understandings of, beliefs about and interpretations of scientific inquiry. One significant indicator of instructional practices in the classroom is a teacher's knowledge and understanding of a topic (Amaral & Garrison, 2009; Crawford, 2007; Porlan & Martin del Pozo, 2004; Shulman, 1987; Simmons et al., 1999). This knowledge and understanding are predicated on the language and concepts of scientific inquiry (Gyllenpalm et al., 2010), and form a teachers' conceptual understanding of scientific inquiry. Several studies call for further research into teachers' conceptual understanding of scientific inquiry (Crawford, 2007; Davis et al., 2006; Gyllenpalm et al., 2010; Ireland et al., 2011; Lotter et al., 2007). The purpose of this descriptive study was to investigate pre-service secondary science teachers' conceptual understanding of the essential characteristics of scientific inquiry.

Research Questions

1. How do future secondary science teachers organize concepts related to scientific inquiry?
2. What understandings do future secondary science teachers have regarding essential characteristics of scientific inquiry?
3. How do future secondary science teachers describe the relationships between and among these essential characteristics of scientific inquiry?

Research Methodology

In order to develop a clearer picture of pre-service science teachers' conceptual understanding of scientific inquiry and address each of these research questions, participants in this descriptive study created concept maps of the essential characteristics of scientific inquiry. Concept maps have been shown to effectively assess conceptual understanding in a variety of fields (Gerchak, Besterfield-Sacre, Shuman, & Wolfe, 2003; Greene, Lubin, Slater, & Walden, 2012; Nesbit & Adesope, 2006; Novak & Gowin, 1984; Rice, Ryan, & Samson, 1998; Rye & Rubba, 2002; Zak & Munson, 2008; Zimmaro & Zappe, 1999).

Concept maps are composed of multiple *propositions*, consisting of two concepts and a labeled arrowed line that denotes the "proposed" relationship between the two concepts (Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996; Ruiz-Primo, Schultz, Li, & Shavelson, 2001). Concept maps can be analyzed from both qualitative and quantitative perspectives to determine the depth and structure of knowledge for a given topic area. "Concept mapping provides a visual image of the 'big picture,' as well as the concept relationships in small instructional segments" (Novak & Gowin, 1984, p. 83).

Qualitatively, concept maps and their propositions can be analyzed for how they are organized and structured, looking for clusters of repeated concepts across the sample. Individual propositions describing the relationship between two concepts can also be analyzed and coded for similarities in meaning and usage across the sample. Quantitatively, individual concepts and their propositions can be analyzed for their frequency of use, how often they are linked to other concepts, and how often they are omitted from concept maps amongst the sample. Concepts can also be analyzed for how often they are associated with other concepts from the list. These forms of qualitative and quantitative analysis can offer a more detailed sense of how pre-service secondary science teachers organize and describe their thinking about scientific inquiry.

Research Design

In order to investigate these research questions, a list of essential concepts characteristic of scientific inquiry were developed. In generating a list of concepts to assess a given topic area or domain, a set of ten to fifteen concepts was recommended for participants to be able demonstrate concept association and differentiation (Novak & Gowin, 1984). Several sources (AAAS, 1989, 1993; NAS, 2012; NRC, 1996; 2000; National Science Teachers' Association, 2004) were selected based upon the thorough and collaborative process in which they were developed as policy documents, and used to represent a consensus perspective on characteristics of inquiry in K-12 education.

Sections of these documents focusing specifically on scientific inquiry were analyzed for major concepts and essential features of scientific inquiry to generate a list of prominent concepts mentioned. In order to narrow this list of concepts to recommended numbers, concepts were ranked by how often they were expressed amongst these sources and those expressed most frequently were utilized in this study.

Participants

The Minnesota Association of Colleges of Teacher Education (MACTE) is a consortium of all thirty-one teacher preparation institutions in the state of Minnesota. In 2010-2011, 178 undergraduate and graduate students received their initial licensure in teaching secondary science (chemistry – 30 students, earth/space science – 11 students, life science – 68 students, physics – 9 students, and middle school (grades 5-8) general science – 61 students; Measures of Teacher Quality in Minnesota, 2012). From this population, a purposive sample of thirty pre-service secondary science teachers from teacher preparation programs at four universities in Minnesota were used in this descriptive study (Blaikie, 2010). From these institutions, class section(s) of pre-service secondary science teachers, enrolled as full-time students seeking secondary science teaching licensure in chemistry, earth/space science, life science, physics and middle school (grades 5-8) general science were invited to participate in this study. Participants were in the final year prior to completing their student teaching practicum. This descriptive study focused on the conceptual understanding of scientific inquiry from this purposive sample of pre-service secondary science teachers enrolled in typical teacher preparation programs in Minnesota.

Procedures

In a classroom setting at each institution, participants were introduced to concept maps by being provided with several types of information (see Appendix A). This process included showing an example of a concept map, explaining procedures on how to create concept maps, examining an example of a well-constructed concept map using linking words, and explaining the instructions and materials for creating their own concept map on the essential features of scientific inquiry (Ruiz-Primo & Shavelson, 1996; Stoddart, Abrams, Gasper & Canaday, 2000). Canas and Novak (2006) emphasized the importance of using a focus question to help guide participants in the construction of their concept maps. Participants were presented with a situation in which they were asked to imagine that they would be teaching their future students about scientific inquiry. They were asked to consider the focus question "How does scientific inquiry work?" Participants were provided with the list of inquiry concepts and asked to think about how they might organize these concepts and how they are related to one another to address this focus question.

Each participant received an 11x17 blank piece of paper and was asked to write these inquiry concepts separately onto provided mini Post-It ™ notes and post them individually on the left hand side. Starting with what participants thought to be the most general concept, they organized these Post-It ™ notes to create a concept map that included all of the provided inquiry concepts. If participants were unsure of a concept's meaning or how it might fit into their map, they were instructed to leave it out of their constructed concept maps. Once arranged, participants described the relationships and interrelationships between and among concepts by connecting them with arrowed lines and descriptive linking words (Novak & Gowin, 1984: Ruiz-Primo & Shavelson, 1996). Participants had unlimited time to construct their concept maps, although most completed them within 40 minutes (Hay, Kinchin & Lygo-Baker, 2008; Ruiz-Primo & Shavelson, 1996; Stoddart, Abrams, Gasper & Canaday, 2000; Zak & Munson, 2008). Once completed, concept maps were transcribed from these paper versions and recreated electronically using Inspiration ® software. Each map was rechecked for position of concepts, arrowed lines and linking words against the original to ensure accuracy.

Data Analysis

The concept maps developed by the pre-service secondary science teachers provided a visual representation of how they organized, associated and described the relationships between essential concepts of scientific inquiry. The data compiled from the concept maps were analyzed for three major types of information to provide feedback about this purposive sample of pre-service teachers' shared understanding of these essential concepts.

First, one form of qualitative analysis used a holistic, visual approach (Greene, Lubin, Slater, & Walden, 2012; Kinchin, 2000; 2001; McClure, Sonak, & Suen, 1999; Williams, 1998; Zak & Munson, 2008) where all concept maps were compared with one another, looking for patterns in structure, content, and organization. The overall structure of each concept map was visually analyzed for common trends among concepts that showed collective patterns or repeated clusters of concepts that appeared to be consistent across participant concept maps.

Secondly, each concept map was broken down into its individual propositions, a general process used to quantitatively analyze and evaluate concept maps (Derbentseva & Safayeni, 2004; Gershak, Besterfield-Sacre, Shuman, & Wolfe, 2003; Ruiz-Primo & Shavelson, 1996; Yin, Vanides, Ruiz-Primo, Ayala & Shavelson, 2005). Each proposition consisted of three distinct parts: the *originating concept*, the *linking word(s)*, and the *linked concept* (see Figure 1). The *originating concept* referred to the primary concept that is connected to a linked concept by an arrowed line. *Linking words* were the descriptive word(s) on an arrowed line that expresses the proposed relationship between the originating concept and the linked concept. The *linked concept* referred to the secondary concept that is connected to the originating concept (Zak & Munson, 2008). For example, the *originating concept* "investigations" might be connected to the *linked concept* "tools" by the *linking words* "use," forming the proposition, "Investigations use tools."

Each proposition was analyzed to determine all of the associations that were made between concepts. Every originating concept, each linking word, and every linked concept from all concept maps were recorded and compiled into a database. These propositions were categorized and sorted by both originating concept and linked concept. This process generated an inventory of all the concepts that were associated and connected with each originating concept and linked concept. These two inventories were combined to determine the frequencies of links made to and from each concept, the average number of links connected to a concept, and the percentage of participants making associations between any two concepts. The frequency of concepts that were not linked at all in the mapping process was also noted.

Third, the linking words in the propositions that described a “proposed” relationship between two concepts from all participants’ concept maps were qualitatively analyzed. These described relationships were analyzed collectively and coded for patterns of use. This form of qualitative analysis has been useful in providing perspective to show patterns of understanding by a given population for a specified content area (Buitink, 2009; Ritchhart, Turner, & Hadar, 2009; Wheeldon & Faubert, 2009; Zak & Munson, 2008). Individual propositions were coded into groups where the linking word(s) appeared to identify similar meaning in the relationship among the originating and linked concept to create *generalized propositions*. The frequencies of generalized propositions were calculated to identify how many of the participants’ described the relationship between two concepts in the same way. These frequencies of generalized propositions were also compared with the percentage of participants making associations between concept pairs to determine if they were describing the relationship between two concepts similarly.

Summary

“Concept maps are thus powerful tools for observing the nuances of meaning a student holds for the concepts embedded in his or her map. When concept maps are conscientiously constructed, they are remarkably revealing of students’ cognitive organization” (Novak & Gowin, 1984, p. 35). By using concept maps, along with this mix of qualitative and quantitative analysis, this research study provided a descriptive picture of how this sample of pre-service secondary science teachers organize, associate, and describe the relationships between essential concepts of scientific inquiry.

Chapter IV

Results

The purpose of this descriptive study was to use concept maps to explore and describe pre-service secondary science teachers' conceptual understanding of the essential characteristics of scientific inquiry to address the following research questions.

Research Questions

1. How do future secondary science teachers organize concepts related to scientific inquiry?
2. What understandings do future secondary science teachers have regarding essential characteristics of scientific inquiry?
3. How do future secondary science teachers describe the relationships between and among these essential characteristics of scientific inquiry?

This chapter presents information gathered from the research process including: descriptive data, list of inquiry concepts, overall concept map structure, organization and content, associations among inquiry concepts and generalized propositions made about inquiry concepts, concluding with a summary of results.

Descriptive Data

A total of thirty participants (n=30) completed concept maps for this research study. Participants were enrolled at teacher education programs from two small, private liberal arts colleges (thirteen students) and two medium-sized, public universities (seventeen students). Eighteen students were female and twelve were male. Twenty three of the participants were concurrently enrolled in a science methods course. Participants reported seeking licensure in the following areas, with eleven reporting they were pursuing licensure in multiple content areas: chemistry – 7, earth/space science – 6, life science – 18, physics – 1, and middle school (grades 5-8) general science – 10.

List of Inquiry Concepts

In determining a list of concepts for a given topic area, a set of ten to fifteen concepts are recommended for participants to be able demonstrate differentiation and association among those concepts (Novak & Gowin, 1984). A list of essential concepts characteristic of scientific inquiry was developed through the analysis of several national science education policy documents and resources (AAAS, 1989, 1993; NAS, 2012; NRC, 1996; 2000; National Science Teachers' Association, 2004). Sections of these documents focusing specifically on scientific inquiry were analyzed to generate a list of major concepts and essential features characteristic of scientific inquiry (see Table 2). Concepts with similar meanings were identified in this process. These concepts were combined and listed as one concept. For example, "instruments" and "tools" have similar meanings and were listed as "tools." In order to narrow the list of concepts developed through this process to recommended numbers, concepts that were described in 50% of these documents were used. The following twelve concepts related to scientific inquiry met those criteria: *explanations*, *evidence*, *questions*, *investigations*, *data*, *tools*, *logic*, *communication*, *results*, *observations*, *predictions* and *bias* (see Table 2).

Table 2

List of Major Concepts Characteristic of Scientific Inquiry

	Source							
Concept	NAS, 2012	NSTA, 2004	NAP, 2000	NSES, 1996	AAAS, 1993	AAAS, 1989	Total	%
Explanations	x	x	x	x	x	x	6	100
Evidence	x	x	x	x	x	x	6	100
Questions	x	x	x	x	x		5	83
Investigations	x	x	x	x	x		5	83
Data	x	x	x		x	x	5	83
Tools		x	x	x	x	x	5	83
Logic		x	x	x	x	x	5	83
Communication	x	x	x	x			4	67
Results		x	x	x	x		4	67
Observations			x		x	x	3	50
Predictions			x		x	x	3	50
Bias			x		x	x	3	50
Models	x			x			2	33
Mathematics	x			x			2	33
Hypothesis					x	x	2	33
Technology				x			1	17
Scientific Argument				x			1	17
Sources of Information			x				1	17
Measurements						x	1	17
Peer Review						x	1	17
Variables					x		1	17
Theories					x		1	17
Conclusions		x					1	17

Note. An ‘x’ indicates this term or a term with a similar meaning was a major concept in found the listed document.

Presentation of Results

A collective analysis of the 30 pre-service secondary science teachers’ concept maps provided the following results, which are grouped by concept map structure, organization, associations made among inquiry concepts and generalized propositions used to describe the relationships between concept pairs.

Concept map structure.

In looking for common patterns in overall structure, a holistic, visual analysis of the concept maps (Greene, Lubin, Slater & Walden, 2012; Kinchin et al., 2000; Williams, 1998; Zak & Munson, 2008) showed that 80% of participants positioned *questions* and/or *observations* as the primary node at the top of their concept maps with arrowed lines and linking word descriptions extending downward from them (see Figure 2 and Figure 3 for examples).

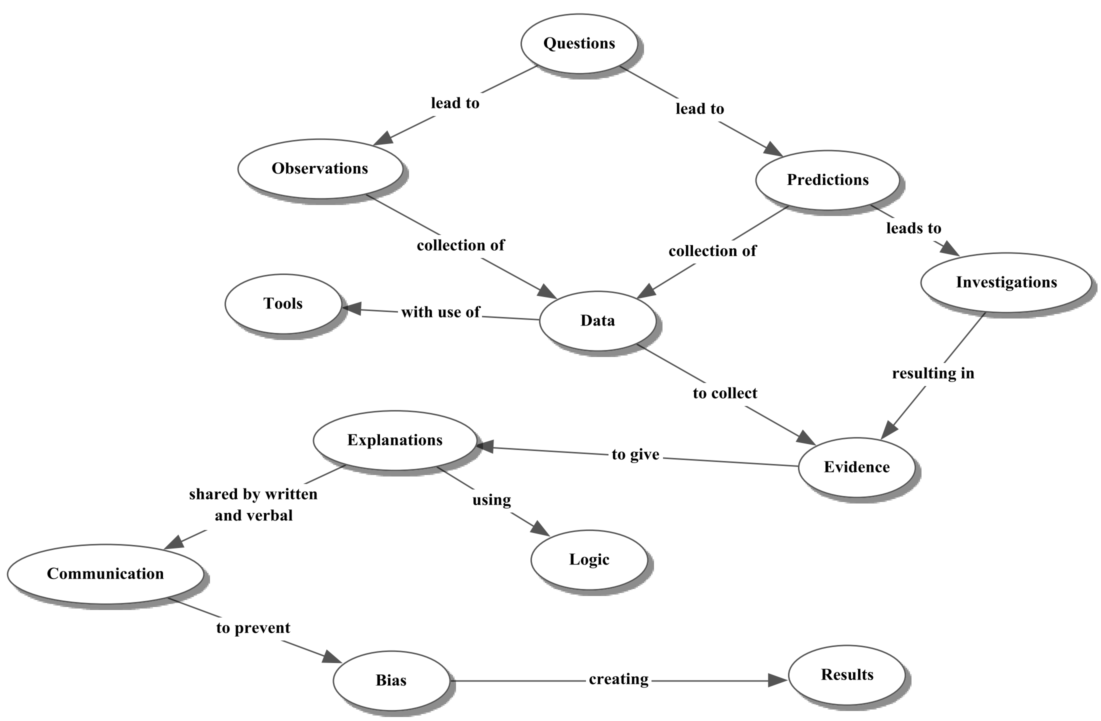

Figure 2. Participant concept map #6 using *questions* as the primary node at the top of the concept map.

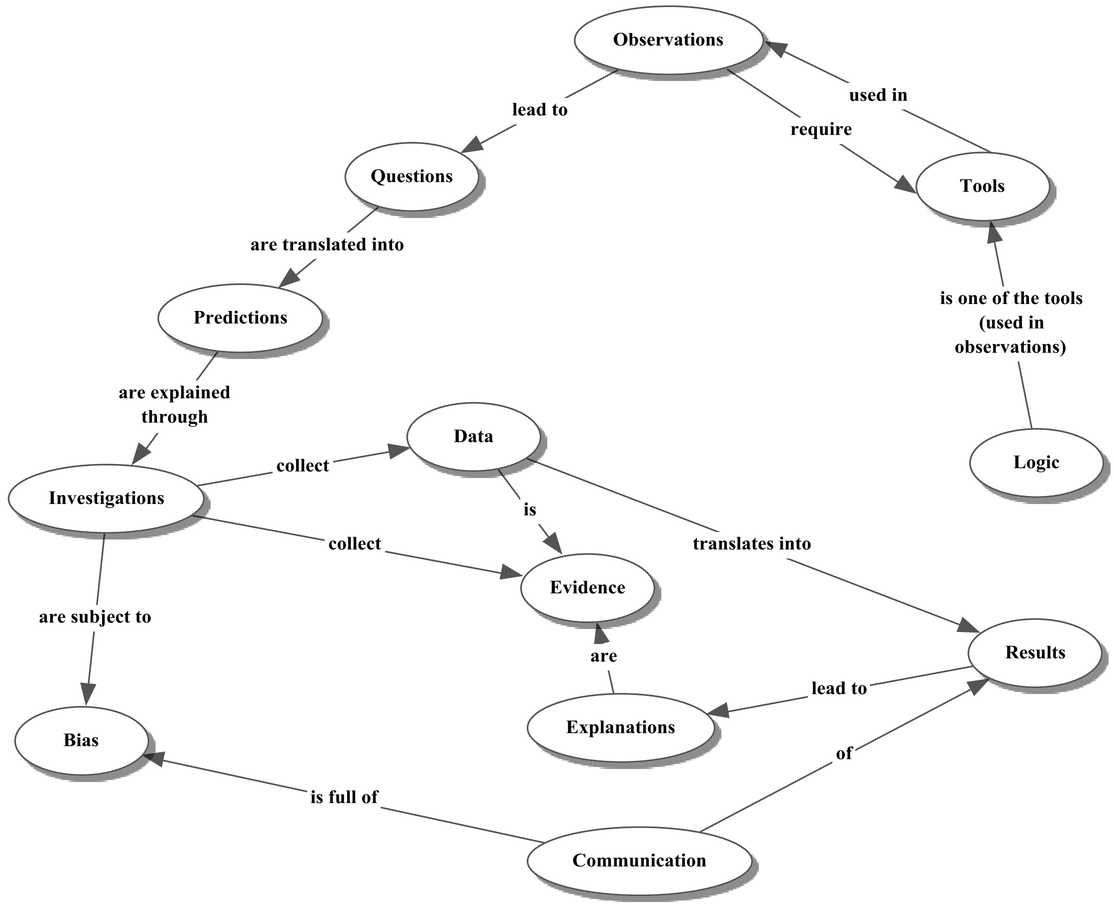

Figure 3. Participant concept map #14 using *observations* as the primary node at the top of the concept map.

These concepts were often used at the start of a chain of concepts, typically with one or two other concepts connected with them. These two concepts were also connected to one another on 57% of participant concept maps.

The visual analysis of concept maps revealed that 57% of participant concept maps demonstrated a chained (see Figure 4) or a cyclical (see Figure 5) pattern, as opposed to a more hierarchical structure (Hay, Kinchin & Lygo-Baker, 2008; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996). This pattern of organization had concepts linked in a series with the same sequence of concepts, typically with one arrowed line connecting concepts. While visually the concept maps may appear to show differences in organization, further analysis revealed that a group of concepts were connected with one another and appeared regularly on 87% of participant concept maps (see Figure 6). This group of concepts appeared in varying arrangements on concept maps and included the following eight concepts: *explanations, evidence, questions, investigations, data, results, observations* and *predictions*. Further analysis showed that this group of concepts was predominately arranged in a series connected in the following order: *observations – questions – predictions – investigations – data – evidence – results – explanations*. This *scientific method series* was found on 50% of the concept maps. Some of concept maps

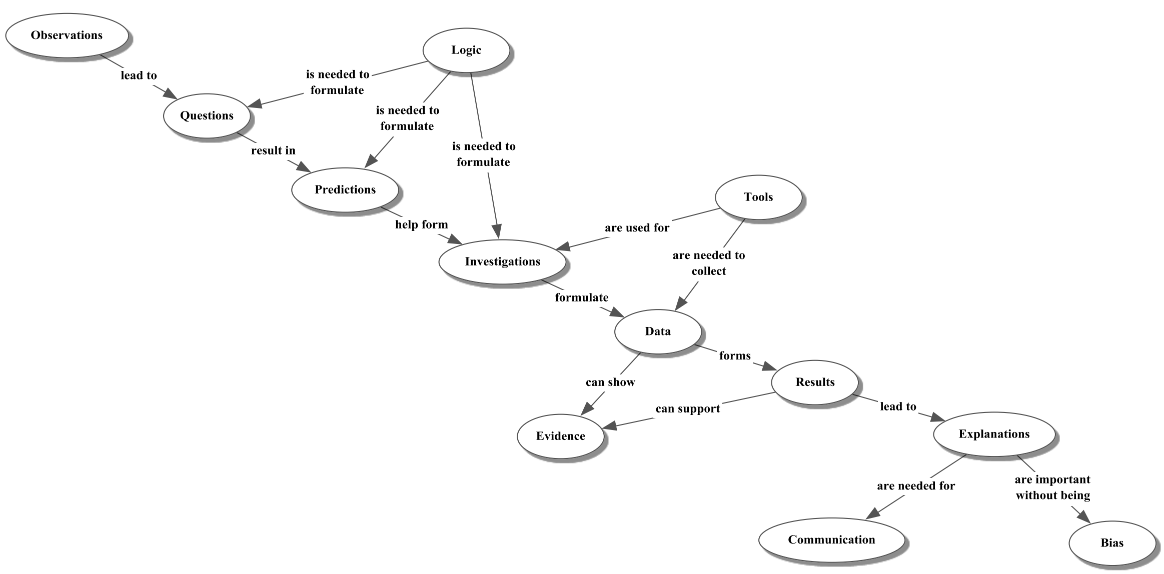

Figure 4. Participant concept map #16 organizing inquiry concepts in a chained pattern.

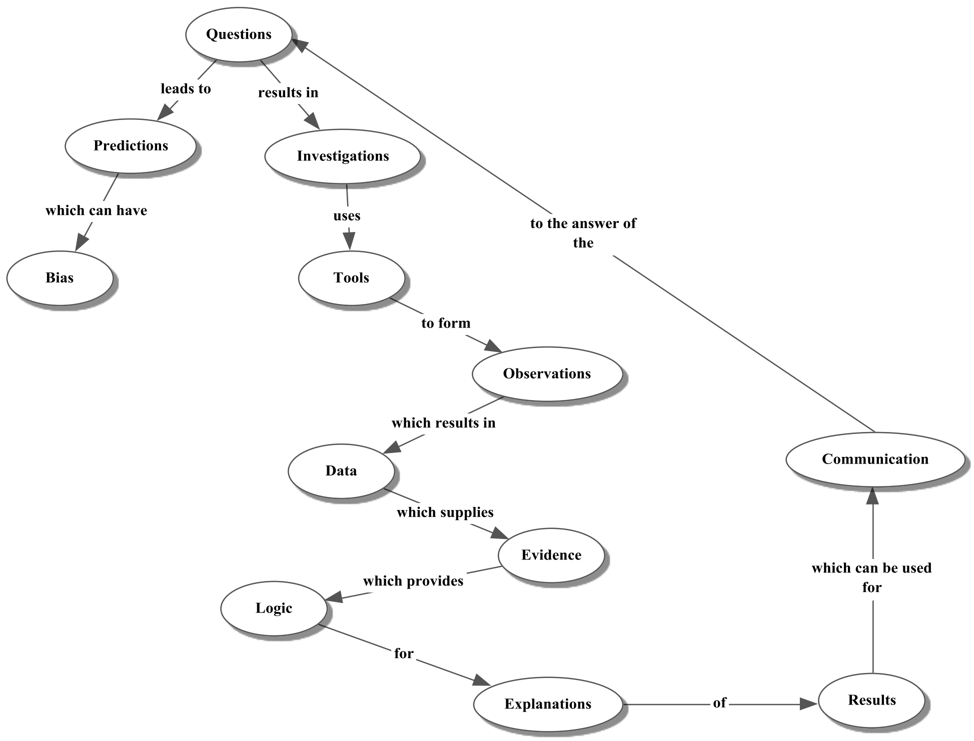

Figure 5. Participant concept map #11 organizing inquiry concepts in a cyclical pattern.

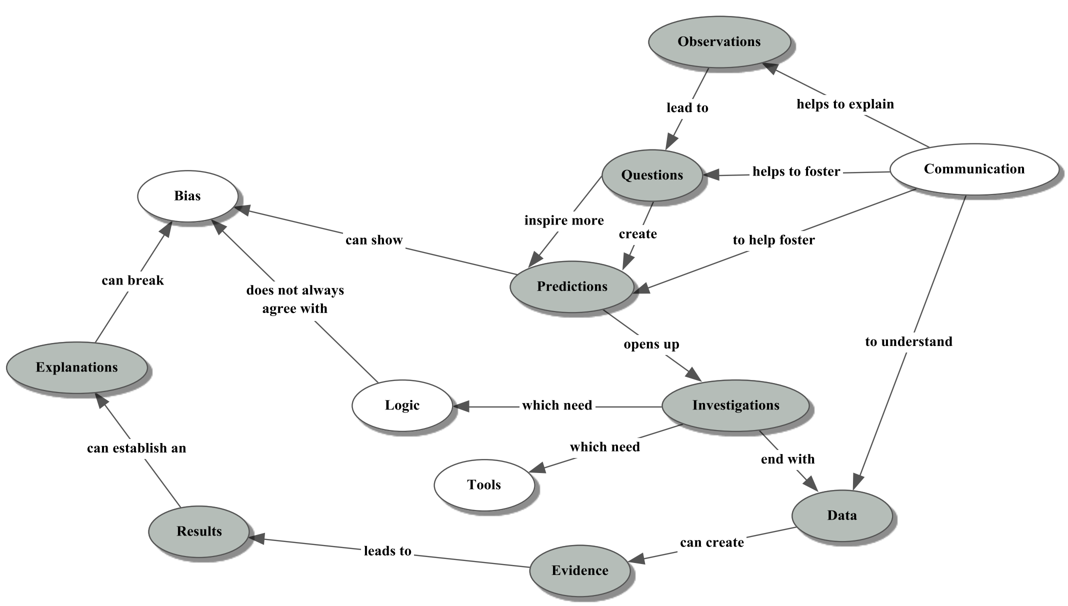

Figure 6. Participant concept map #5 demonstrating scientific method series of concepts.

with this scientific method series also included the concept *tools* and linked it with the concepts *investigations* and/or *data* (as seen in Figure 4).

Concept map organization.

All twelve inquiry concepts were analyzed for organization to determine how many connections each participant made that were originating from and/or going to each concept. For example, in Figure 7 the concept *observations* serves as an originating concept five times, having five arrowed lines with descriptive linking words extending to five other concepts. *Observations* also has three arrowed lines going to it from three other concepts, for a total number of eight connections. In contrast, the concept *bias* has zero arrowed lines with descriptive linking words extending from it, and only one arrowed line going to it from one other concept, for a total of one connection.

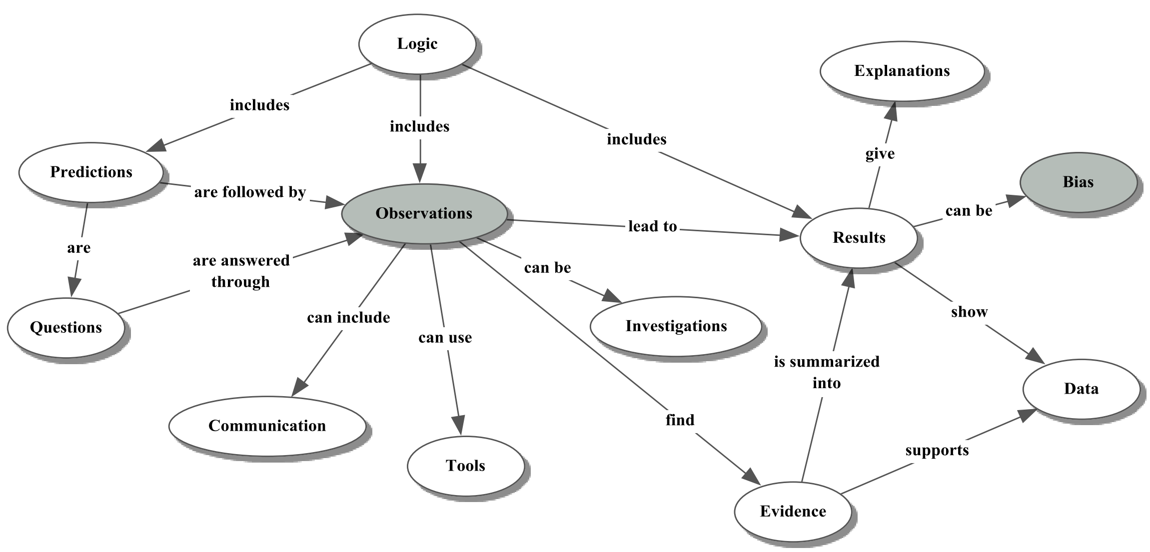

Figure 7. Participant concept map #22 demonstrating variance in use of two inquiry concepts.

Each concept map was analyzed to determine how many connections each participant made originating from and going to each inquiry concept. The number of participants making connections originating from each inquiry concept is shown in Table 3. Most participants used each inquiry concept as an originating concept to connect it to only one or two other concepts. Seventeen participants (57%) used *observations* as an originating concept to make connections to two or more other concepts. Conversely, twenty one participants (70%) and thirteen participants (43%) did not use the concepts *bias* and *communication* as originating concepts, respectively.

Table 3

Number of Participants making Originating Connections from each Inquiry Concept

	No. of originating connections				
Inquiry concept	Zero connections	One connection	Two connections	Three connections	Four or more connections
Explanations	5	16	6	2	1
Evidence	5	17	5	3	0
Questions	1	17	9	1	2
Investigations	1	11	9	7	2
Data	1	15	10	3	1
Tools	10	12	6	1	1
Communication	13	10	4	1	2
Results	3	12	7	7	1
Logic	7	15	4	3	1
Observations	2	10	11	3	4
Predictions	0	18	7	3	2
Bias	21	7	1	1	0

Note. Indicates the frequency each inquiry concept was used by participants as an originating concept (n=30).

The number of participants making connections going to each inquiry concept was also determined (see Table 4). Most participants used each inquiry concept as a linked concept by having only one other concept going to them. Eighteen participants (60%) used *data* as a linked concept where two or more other concepts were connected to it. Conversely, nine participants (30%) did not use *observations* as a linked concept.

Table 4

Number of Participants making Connections going to each Inquiry Concept

	No. of connections				
Inquiry concept	Zero connections	One connection	Two connections	Three connections	Four or more connections
Explanations	0	20	6	3	1
Evidence	3	18	5	2	2
Questions	3	16	10	1	0
Investigations	1	19	7	2	1
Data	0	12	12	4	2
Tools	4	21	5	0	0
Communication	3	20	5	2	0
Results	1	17	8	2	2
Logic	7	14	7	1	1
Observations	9	11	7	2	1
Predictions	0	18	8	3	1
Bias	0	17	7	3	3

Note. Indicates the frequency each inquiry concept was used by participants as a linked concept (n=30).

Each inquiry concept was also analyzed to determine the total number of connections originating from and/or going to each concept. Some inquiry concepts were found to have more connections originating from and going to them than other concepts.

The frequencies of the total number of connections made with each inquiry concept are shown in Table 5. The concepts *investigations* and *observations* had the most connections originating from them. The concepts *communication* and *bias* had the least number of connections originating from them. The concepts *data, predictions,* and *bias* had the most connections going to them. The concepts *tools* and *observations* had the least number of connections going to them. The concepts *investigations* and *data* had the highest average number of connections per concept map and *tools* and *bias* had the lowest average number of connections per concept map. No concepts were left off of the maps, indicating that participants were familiar with all of the listed concepts and attempted to use them in the construction of their concept maps. One participant added the concept *hypothesis* and used this concept on the concept map in addition to the provided list.

Associations among inquiry concepts.

While analyzing their overall structure and organization, along with the frequency of usage for each individual concept, the concept maps also provided information about how participants made connections and associated concepts with one another. Collectively, every originating concept connected to a linked concept revealed that certain pairs of concepts were associated more frequently than others. The frequency of associations between concept pairs was determined from both directions, noting connections from originating concept to linked concept, and connections from linked concept to originating concept. These numbers of associations were combined and listed

Table 5

Number of Connections made per Inquiry Concept

Inquiry concept	No. originating from concept	No. connected to concept	Total no. of connections	Avg. no. of connections per concept map
Investigations	63	42	105	3.50
Data	49	56	105	3.50
Predictions	50	50	100	3.33
Results	51	47	98	3.27
Observations	62	33	95	3.17
Explanations	38	46	84	2.80
Questions	46	37	83	2.77
Evidence	36	41	77	2.57
Logic	36	35	71	2.37
Communication	29	36	65	2.17
Tools	32	30	62	2.07
Bias	12	50	62	2.07

Note. Shows total number of connections made by participants from all concept maps (n=30).

as percentages for all of the associations that were made between concept pairs on participant concept maps, which are shown in Table 6. For example, four participants made a connection from *investigations* to *predictions*, while fourteen participants connected *predictions* to *investigations*, resulting in these two concepts being associated with one another on a total of 18 concept maps (60%). Several concepts were only infrequently connected with one another on all of the concept maps (as indicated by the lowest percentages in Table 6). For example, associations between the concept pairs *evidence-tools*, *questions-tools*, *results-tools,* and *bias-tools* were only connected once on all of the maps. *Communication-tools* was the only concept pair that was not connected on any of the participant concept maps. Overall, the majority of possible concept pairs

Table 6

Associations made between Inquiry Concept Pairs

Percentage of participants

Explanations	X											
Evidence	33	X										
Questions	17	10	X									
Investigations	13	23	33	X								
Data	20	**50**	17	43	X							
Tools	7	3	3	**70**	**53**	X						
Communication	40	20	23	13	13	0	X					
Results	**57**	**57**	10	13	**60**	3	33	X				
Logic	23	7	23	33	13	13	13	27	X			
Observations	23	20	**57**	27	**50**	37	17	20	20	X		
Predictions	17	20	**67**	**60**	13	13	13	20	47	37	X	
Bias	30	13	13	20	17	3	30	27	17	10	27	X
	Explanations	*Evidence*	*Questions*	*Investigations*	*Data*	*Tools*	*Communication*	*Results*	*Logic*	*Observations*	*Predictions*	*Bias*

Note. Participants associating concept pairs 50% or more of the time are indicated in bold (n=30).

revealed low percentages (10%-40%) of associations on concept maps, indicating no clear pattern of connections made by participants between these concepts. In contrast, the concept pairs of *investigations-tools* and *questions-predictions* showed the highest percentage of associations on concept maps, 70% and 67% respectively. Concept pairs that were associated with one another by at least 50% of the participants are indicated in bold.

Further, these most frequently associated concept pairs (those indicated in bold on Table 6) are also displayed in Table 7. Here, the number of concept maps with associations between associated concept pairs is also provided, with the originating concept listed first in the concept pair to indicate the direction of the relationship.

Generalized propositions describing inquiry concept pairs.

In addition to participants associating inquiry concepts with one another, each associated concept pair provided descriptive linking words revealing how participants described the relationship between those two concepts. The descriptive linking words contained in the concept pairs that were associated with one another most frequently (see Table 7) were analyzed for similarity in meaning. Individual propositions were coded into groups where the linking word(s) appeared to share similar meaning in the described relationship among the concept pair to create generalized propositions. For example, several participants listed the following propositions:

> "investigations involve tools"
> "investigations use tools"
> "investigations make use of tools"
> "tools are used for investigations"
> "tools used in investigations"

The linking words "involve," "use," "make use of," "are used for" and "used in" were synthesized to create generalized linking words resulting in the generalized proposition "investigations use tools." This process was used to develop the percentage of generalized propositions made on participants' concept maps shown in Table 8. The generalized propositions of "investigations use tools" and "questions lead to predictions" were found on 70% and 53% of all participant concept maps, respectively. While the

Table 7

Most Frequently Associated Inquiry Concept Pairs

Inquiry concept pair	No. of associations	Inquiry concept pair	No. of associations	Total no. of concept maps with associations	% of concept maps
Investigations-Tools	18	*Tools-Investigations*	3	21	70
Questions-Predictions	18	*Predictions-Questions*	2	20	67
Investigations-Predictions	4	*Predictions-Investigations*	14	18	60
Data-Results	15	*Results-Data*	3	18	60
Explanations-Results	3	*Results-Explanations*	14	17	57
Evidence-Results	7	*Results-Evidence*	10	17	57
Questions-Observations	3	*Observations-Questions*	14	17	57
Data-Tools	4	*Tools-Data*	12	16	53
Evidence-Data	4	*Data-Evidence*	11	15	50
Data-Observations	3	*Observations-Data*	12	15	50

Note. Shows associated concept pairs found on 50% or more of concept maps (also indicated in bold on Table 6).

Table 8

Percentage of Generalized Propositions made by Participants

Originating concept	Linking words	Linked concept	%
Investigations	use	Tools	70
Questions	lead to	Predictions	53
Data	generates	Results	47
Predictions	lead to	Investigations	43
Results	lead to	Explanations	43
Observations	lead to	Questions	43
Tools	collect	Data	40
Observations	result in	Data	30
Results	provide	Evidence	20
Data	can show	Evidence	20

Note. Shows percentage of generalized propositions made by participants on all concept maps (n=30).

concept maps showed that many concepts were associated with one another (as seen in Table 6), there was a lack of consistency in the linking words used to describe the relationship between them (as indicated in lower percentages in Table 8). The percentages of participants making associations between concept pairs (see Table 6) were compared with percentages of generalized propositions (see Table 8). This comparison determined if participants that chose to associate two concepts with another were describing the relationship between these two concepts in similar manner (see Table 9). For example, twenty one participants associated the concept *investigations* and *tools* with one another. In analyzing the linking words to describe the proposed relationship

Table 9

Percentage of Generalized Propositions generated from Associated Concept Pairs

Originating concept	Generalized linking words	Linked concept	No. of concept maps making generalized proposition	No. of concepts making concept pairing	%
Investigations	use	Tools	21	21	100
Questions	lead to	Predictions	16	20	80
Data	generates	Results	14	18	78
Results	lead to	Explanations	13	17	76
Observations	lead to	Questions	13	17	76
Tools	collect	Data	12	16	75
Predictions	lead to	Investigations	13	18	72
Observations	result in	Data	9	15	60
Data	can show	Evidence	6	15	40
Results	provide	Evidence	6	17	35

Note. Shows generalized propositions found on 50% or more of concept maps where concept pairs were associated.

between these two concepts, all twenty one of those participants (100%) described the relationship in the same way, "investigations use tools." Whereas, seventeen participants connected the concept *results* with the concept *evidence*, but only six of them (35%) described the relationship using similar linking words, demonstrating a lack of consistency in the linking words used to describe the relationship between them (also indicated by lower percentages found in Table 8).

Summary

The major findings from this research study showed that some consistent results were present on participants' concept maps. Participants displayed an overall low number of associations between the twelve inquiry concepts. The majority of participants did organize and associate a chain of inquiry concepts with one another into a scientific method series. Chapter five discusses the findings from this chapter in light of their relationship to pre-service science teachers' understandings of specific aspects of the inquiry process. Implications for science educators in the development and design of teaching about inquiry in pre-service teacher education programs and professional development opportunities are examined. Recommendations for further study into the conceptual understanding of beginning science teachers are also discussed.

Chapter V

Discussion and Conclusion

The purpose of this descriptive study was to further understand future secondary science teachers' conceptual understanding of scientific inquiry. The use of concept mapping provided perspectives on how this sample of pre-service teachers organized, associated and described the relationships among and between concepts characteristic of scientific inquiry. One might expect that participants would show variance among their concept maps and that no two concept maps would be exactly the same. However, the results of this descriptive study provide some informative observations, point toward implications and invite further questions and investigations.

Summary of Findings

Structure and organization.

The results from the analysis of the overall structure among concept maps showed that 80% of participants began organizing their concept maps with the inquiry concepts *questions* or *observations*. This finding is supportive of recent policy documents that describe the nature of science and scientific inquiry as a process of investigation that begins with observations and questions (Achieve, Inc., 2013; NAS, 2012). As future teachers aim to organize their thinking about how to teach their students about scientific inquiry, the importance of making observations and generating questions to guide student inquiries serves as a solid beginning point.

The group of concepts: *observations – questions – predictions – investigations – data – evidence – results – explanations,* and more specifically the scientific method series found repeatedly on concept maps, demonstrated how many of the participants viewed the way that scientific inquiry works. This pattern of representation is more characteristic of the traditional view of a single "scientific method" (Finley & Picovi, 1991; Tang, Coffey, Elby & Levin, 2009; Windschitl, 2004) instead of the historic notions of developing an understanding of scientific habits of mind (Dewey, 1910a) and more recent calls focusing on the practices of science (Achieve, Inc., 2013; NAS, 2012). The "practices are used iteratively and in combination; they should not be seen as a linear sequence of steps to be taken in the order presented" (NAS, 2012, p. 49). From a constructivist perspective, pre-service teachers with a more thorough understanding of scientific inquiry would presumably be able to show more cross-links and inter-connections among these concepts on their concept maps, instead of the pattern of chained concepts found in the organization analysis, as seen in Figures 4, 5 and 6 (Ausubel et al., 1978; Hay, Kinchin & Lygo-Baker, 2008; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996; Stoddart, Abrams, Gasper & Canaday, 2000).

Concept map content.

In looking at how the participants used each inquiry concept, a similar pattern followed. This chained pattern is further evidenced in the low frequencies of connected concepts represented on Tables 3, 4, and 5, where most of concepts used by participants where only connected to one other concept. These lower frequencies demonstrate a single described connection or relationship between inquiry concepts, representative of this more traditional view of a single "scientific method."

While most of the concepts demonstrated a limited number of connections, the concepts *investigations, data*, *predictions, results* and *observations* (highest averages from Table 5) did show that at least 30% of participants made two or more connections to and/or from these concepts to other concepts. This may indicate that some of the participants were more apt to make connections for inquiry concepts that they had a better understanding of, and the role that those concepts play in the scientific inquiry process (Ausubel et al., 1978; Hay, Kinchin & Lygo-Baker, 2008; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996; Stoddart, Abrams, Gasper & Canaday, 2000).

Conversely, the concepts *bias* and *communication* showed the lowest average use by participants on their concept maps (see Table 5). Table 3 displays that 70% and 43% of participants respectively, did not use these concepts as originating concepts on their concept maps. This may indicate a lack of understanding of how to associate these concepts with other inquiry concepts provided (Hay, Kinchin & Lygo-Baker, 2008). Overall, a substantial number of participants did not use these concepts in meaningful ways on their concept maps. These results relate to similar findings on the limited emphasis teachers placed upon the role that evaluating explanations and communicating those explanations serve in scientific inquiry (Asay & Orgill, 2010; Kang, Orgill & Crippen, 2008).

It is important for future science teachers to understand the integral role that communication and the influence that bias can play in scientific inquiry. "A major practice of science is … the communication of ideas and the results of inquiry" (NAS, 2012, p. 51). Additionally, experimenter bias can influence many aspects of the scientific inquiry process, especially investigations, results and explanations (AAAS, 1993; NRC, 2000). Based upon participants' concept map structure and organization, it appears that they had difficulty integrating these important inquiry concepts with elements of the more traditional "scientific method."

Associations among inquiry concepts.

The concept pairs *investigations-tools* and *questions-predictions* were produced most frequently on participant concept maps. When participants thought of *investigations*, 70% of them chose to associate the concept *tools* with this concept. Similarly, when participants thought of *questions*, 67% of them chose to associate this concept with *predictions*. This consistency amongst participants may indicate that they are more likely to attribute meaning to these concept pairs (Hay, Kinchin & Lygo-Baker, 2008). The next most prominent concept pairs associated by participants on their concept maps are *predictions-investigations* (60%) and *data-results* (60%). These four concept pairs also appear consistent with the findings of the scientific method series and match common descriptions of the "scientific method" found in schools that focus on questions, predictions, investigations, data, and results (DeBoer, 1991; Windschitl, 2004).

The results from participant concept maps showed that concept pairs *results-evidence* (57%) and *results-explanations* (57%) were frequently associated with one another. This may indicate that a majority of participants in this study created meaningful relationships between these inquiry concepts. This is encouraging as current recommendations call for teachers to help students "develop explanations of what they observe when conducting their own investigations and to evaluate their own and others' explanations for consistency with the evidence" (NAS, 2012, p. 69).

Similarly, the participant concept maps showed that concept pairs *observations-data* (50%), *data-tools* (53%) and *data-evidence* (50%) were frequently associated with one another. These associations are also reassuring as they may point toward pre-service teachers' understanding of the role that data plays in scientific inquiry. Current recommendations call for teachers to engage students in gathering, analyzing, and interpreting data (Achieve, Inc., 2013; NAS, 2012). These findings are consistent with a common theme found in research that indicated teachers' prominent emphasis on the use of the inquiry practices of "evidence" and the "analysis of data" when compared to other inquiry practices in their inquiry lesson plans (Asay & Orgill, 2010; Kang, Orgill & Crippen, 2008).

While any concept could potentially be associated with any other concept, an inconsistent pattern among possible concept pairs (see Table 6) from this group of pre-service teachers may indicate a lack of understanding on how to make significant associations between these concepts (Hay, Kinchin & Lygo-Baker, 2008; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996). As indicated in results described above, the majority of concepts only had only one or two connections made to other concepts. Many of these inquiry concepts have multiple important relationships with one another and were infrequently made by participants on their concept maps. For example, *observations* can serve as informative *evidence* or significant *results* (Achieve, Inc., 2013; NAS, 2012), but only 20% of participants associated those concepts with one another (see Table 6). Similarly, *communication* of *evidence* and *results* are fundamental to scientific inquiry (Achieve, Inc., 2013; NAS, 2012), but only 20% and 33% of participants respectively, associated those concepts with one another (see Table 6). This consistent lack of associations between these and other inquiry concepts invites further investigation into participants' understandings of these inter-relationships.

Generalized propositions and meaning.

While associations between concept pairs may indicate participants' organizational thinking (Ausubel et al., 1978; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996), the linking words can provide insight into how participants describe those relationships and reveal what they understand about these concepts. In analyzing the linking words to form generalized propositions, only "investigations use tools" (70%) and "questions lead to predictions" (53%) showed a consistent descriptive relationship on the majority of participant concept maps (see Table 8). These generalized propositions seem to indicate that when many of these participants thought of the inquiry concepts of *investigations* and *tools,* or when they thought of the inquiry concepts *questions* and *predictions*, they described how they relate to one another in a similar manner. These findings are encouraging as they are consistent with current recommendations on carrying out systematic investigations using appropriate tools and generating scientifically oriented questions and predictions (Achieve, Inc., 2013; NAS, 2012).

However, of all the possible concept connections, this overall lack of consistent use in how participants describe the relationships between concepts is an important finding. This may indicate that participants have different understandings about the relationships between commonly associated inquiry concepts. These findings may also indicate that participants might associate two concepts with one another, but they might not have a clear understanding of the relationship that exists between them. For example, 17 participants associated the concepts *results* and *evidence* with one another. Only six of those 17 described a relationship between these two concepts in a similar manner (see Table 9). Additionally, fifteen participants associated the concepts *data* and *evidence* with one another. However, only six of those 15 described a relationship between these concepts similarly. This supports the need for further investigation on participants' understanding of the role that data and results play in formulating evidence through scientific investigations.

Further, in analyzing the descriptive linking words, another interesting finding points toward how some participants can show a more nuanced understanding of the relationship between two concepts. The concept pair *data-results* was associated on 18 (60%) participant concept maps. From these, the generalized proposition of "data generates results" was shown on 14 of the 18 concept maps. Of those 14 concept maps, five concept maps shared descriptive linking words that would create the generalized proposition "data is analyzed to provide results." This inclusion of and focus on the role that analysis plays in the relationship between generating data and determining results invites further investigation as to how beginning teachers conceptualize the relationship between these inquiry concepts.

Implications

Three major implications emerge from the information gathered in this research study.

From scientific method to scientific practices.

Finley & Pocovi (1991) state that “in many instances in science education, scientific inquiry is equated or nearly equated with the traditional notion of the scientific method” (p. 47) and that “the traditional idea of the scientific method is just too deeply entrenched in our culture to be replaced quickly or easily” (p.48). The findings from this study reinforce this notion and support similar findings on pre-service science teachers’ understandings of scientific inquiry (Crawford, 2007; Duncan et al., 2010; Gyllenpalm et al., 2010; Windschitl, 2004).

Unfortunately, research has shown that using the “scientific method” in this linear manner can serve as a barrier to students’ abilities to conduct scientific inquiries and develop an accurate understanding the nature of science (Schwartz, Lederman & Crawford, 2004; Tang, Coffey, Elby & Levin, 2010). Research has also indicated that teachers viewing inquiry as the “scientific method” can serve as a barrier for them in engaging their students in scientific inquiry (Crawford, 2000; Windschitl, 2004). It appears that this group of pre-service secondary science teachers still looks at the nature of scientific inquiry as a series of linear steps to follow, as in the “scientific method,” rather than as a complex, integrative process. These results aren’t surprising as “most science teachers have never directly experienced authentic scientific inquiry during their education in the sciences or within teacher education programs” (Abd-El-Khalick et al., 2004, p. 404). This oversimplification of scientific inquiry distorts one initial purpose and current value of science's role in the curriculum as a means to help engage students in and develop their inductive reasoning (DeBoer, 1991, 2004; Dewey, 1910a; NAS, 2012; NRC, 1996; Spencer, 1864).

Further, Windschitl found that:

> most students supported the notion that the scientific method is not a linear process by which researchers unproblematically move from observations to questions to hypotheses, and so on; however, most students were unable to articulate a coherent model of inquiry. (2004, p. 486)

The results from this research study support other research recommendations about science teachers' understandings of scientific inquiry that call for further investigation of how science teachers' knowledge and beliefs influence their understanding and use of scientific inquiry with their students (Crawford, 1999, 2007; Duncan et al., 2010; Keys & Bryan, 2000) and how those ideas progress and change over time (Kang, Orgill & Crippen, 2008).

A Framework for K-12 Science Education (NAS, 2012) and the Next Generation Science Standards (Achieve Inc., 2013) acknowledge this challenge and offer constructive perspective. "A focus on practices (in the plural) avoids the mistaken impression that there is one distinctive approach common to all science – a single 'scientific method'" (NAS, 2012, p. 44). The use of inquiry in the science classroom to accomplish this goal has largely been unsuccessful due to a lack of clarity on its meaning and usage in practice (Anderson, 2002; Costenson & Lawson, 1986; Crawford, 2000;

DeBoer, 2004). Thus, "attempts to develop the idea that science should be taught through a process of inquiry have been hampered by the lack of a commonly accepted definition of its constituent elements. Such ambiguity results in widely divergent pedagogic objectives" (NAS, 2012, p. 44). This shift in guiding policy documents to focus more on the practices of science, and reframe the characteristics of inquiry, can help both teachers and students think differently about the nature of science and how it works in the world and in their classrooms.

More experiences doing authentic inquiry.

In order for beginning teachers to move past "the scientific method" and accommodate their ideas and beliefs about scientific inquiry and how it works, these research findings suggest they will need more experience engaging in their own authentic inquiries. Beginning teachers ascribing to the notion of a linear "scientific method" need opportunities to engage in authentic investigations and utilize the practices of science (Achieve, Inc., 2013; NAS, 2012). "Pre-service teachers need such experiences to develop their understandings of authentic scientific investigations" (Windschitl, 2004, p. 485). This will allow beginning teachers to experience firsthand the role and interplay that each of the inquiry concepts from this study have in the inquiry process.

The finding that many of the pre-service teachers in this study had difficulty incorporating the concepts *communication*, *bias* and *logic* into their concept maps speaks to the need for them to engage in and experience these elements of the inquiry process and reflect upon how they relate to other aspects of this process. "For science teachers to embrace their role as teachers of science communication and of practices of acquiring, evaluating, and integrating information from multiple sources and multiple forms of presentation, their preparation as teachers will need to be strong in these areas" (NAS, 2012, p. 259). Further, it is through engagement in and reflection on these types of authentic inquiry investigations that teachers are more likely to engage their students in these same types of investigations (Crawford, 1999; Windschitl, 2004).

There have been repeated calls for pre-service teachers to be able to engage in more of these types of experiences (and not necessarily more coursework) in both science and educational coursework (Brown & Melear, 2006; Costenson & Lawson, 1986; Crawford, 1999; Davis et al., 2010; Ost & Baird, 1989; Windschitl, 2004). "Rarely are college-level science courses designed to offer would-be science teachers, even those who major in science, the opportunity to develop these understandings. Courses with this goal are needed" (NAS, 2012, p. 256). The findings from this study lend additional support to those claims.

Couple inquiry experiences with applications to teaching.

While being engaged in authentic inquiry experiences can be beneficial to the development of beginning teachers' conceptual understanding of scientific inquiry, this approach needs to be supported by reflection on those experiences and incorporate a pedagogical perspective. In order for beginning science teachers to help engage their own students in the practices of science, as recommended in the Next Generation Science Standards (Achieve Inc., 2013), their authentic inquiry experiences need to be coupled with opportunities to consider how they might develop the skill of utilizing this knowledge in the classroom. Several considerations can provide support towards accomplishing this goal.

Beginning science teachers need to see examples of inquiry models and materials (Kang, Orgill & Crippen, 2010). Further, Duncan et al. state:

> Implementing inquiry instruction is a formidable challenge for teachers as they often lack models for using and adapting inquiry-based instructional materials. Teacher education programs can provide scaffolded contexts for developing teachers' ability to critique, adapt, and design inquiry-based materials. (2010, abstract)

Given authentic experiences engaging in the practices of scientific inquiry, beginning teachers can reflect upon how these available models and materials relate to those experiences and how they can be implemented in their own instructional practice. From this, beginning science teachers can develop the skill of analyzing lesson plans and resources to structure them so they focus on the integrative nature of scientific inquiry (Kang, Orgill & Crippen, 2008, Yoon et al., 2010). "Our research findings … indicate that an explicit and reflective approach to learning and doing inquiry-based science within C&I courses can successfully augment teachers' perceptions of inquiry-based science" (Fazio et al. 2010, p. 677).

For example, given that many of the beginning teachers from this study had difficulty incorporating and utilizing the inquiry concepts of *communication, bias* and *logic* into their concept maps, science educators and pre-service teacher preparation programs could provide models and materials on how to utilize these inquiry concepts in science instruction. Asay and Orgill recommend that:

> As science teacher educators understand which of the essential features of inquiry are currently being used in classrooms and how those features are being used, they can design experiences to help teachers enhance their abilities to implement the features that are not as prevalent or to modify their implementation of other features. (2010, p. 60)

Coupling experience with applications to teaching can help expand beginning science teachers understanding of how to utilize this information in the classroom.

Once in the classroom, beginning science teachers need to witness students engaged in this type of authentic inquiry during their practicum placements and to observe exemplary science teachers teaching these investigations (Crawford, 2007; Fazio et al., 2010; Sadler, 2006). "School practicum experiences contextualize the inquiry experience for the preservice teachers" (Fazio et al. 2010, p. 676). These classroom experiences can help shape both their own perspectives on the practices of scientific inquiry and how to engage their students in those practices as well. Beginning science teachers also need support and guidance through induction programs (Lee & Luft, 2004) during their first years of teaching. Roehrig and Luft suggest:

> To assist beginning teachers in implementing 'science as inquiry', induction programs are needed that attend to these constraints. Without this support, science teachers will enact instruction that best serves them and often not the student. The

> importance of induction programs for beginning science teachers cannot be overemphasized. (2004, p. 21)

As science educators consider how best to prepare and provide professional development for secondary science teachers to achieve current policy recommendations, these forms of support need to be incorporated into both pre-service teacher preparation programs and in-service professional development opportunities.

Recommendations for Further Research

As a result of this study, further research on the conceptual understanding of science teachers using concept maps is warranted. The following recommendations emerged from this study:

1) While this descriptive research study involved 30 participants, including more pre-service secondary science teachers to compare results would be informative. Additional research should be conducted to explore how teachers at all levels of science teaching conceptualize their understanding of inquiry. These results could provide a broad perspective on how inquiry is conceptualized by science teachers teaching students at different age levels. Within secondary science education, further study on how different content area teachers conceptualize inquiry should be investigated, as preliminary findings suggest there may be significant differences (Breslyn & McGinnis, 2012).

2) As described in the implications of the research, studying how science teachers' conceptions of inquiry change over time (Kang, Orgill & Crippen, 2008) through teaching experiences and professional development opportunities is encouraged. This information would be important in providing the science education community with

insight into the types of experiences that have the most influence on teachers' conceptual understandings of inquiry and how those understandings translate into observed practice in the classroom.

Conclusion

This descriptive study used concept mapping to illustrate pre-service secondary science teachers' conceptual understanding of scientific inquiry. The results and analysis of these concept maps indicate important similarities and differences in how this group of pre-service teachers applied their knowledge and understanding of scientific inquiry. A series of concepts related to the traditional linear notion of the "scientific method" appeared on the majority of these beginning teachers' concept maps, indicating they may have a limited understanding of the integrative nature of scientific inquiry. Analysis of concept map components revealed that some important inquiry concepts such as *communication* and *bias* were used infrequently and may not be fully understood in relation to other inquiry concepts. Overall, a general lack of associations and generalized propositions among concept pairs was found on these pre-service teachers' concept maps, perhaps indicating either a lack of understanding or misconceptions about these concepts and their inter-relationships.

By understanding the relationships between essential features of inquiry, educators will be more effective in engaging and guiding their students in the practices of scientific inquiry and helping them to develop their own understandings of these concepts. Future science teachers are critical to the goal of cultivating a scientifically literate citizenry. The use of concept mapping in this research study has provided important perspective into how some future pre-service secondary science teachers organize, associate, and describe the relationships among twelve inquiry concepts.

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Appendix A – Protocol Materials

Conditions of Testing:
The primary investigator will provide each of the participants with information about concept maps, how to create concept maps, examples of concept maps, and the instructions and materials for creating their concept map of scientific inquiry.

Primary Investigator Script:

Greetings. My name is (*researcher's name*) and I'm conducting a research study about scientific inquiry using concept maps. This research study will take about 40-50 minutes to complete.

Your participation today is completely voluntary and at any time you are free to not answer any question or withdraw from the research study.

Do you have any questions before we get started? (*pause*)

How many of you are familiar with concept maps?

How many of you have made concept maps before?

Concept maps can provide a visual representation of how important concepts in a subject area are mentally organized and structured.

Let's look at Example 1 of a concept map showing key features of concept maps. The words in boxes represent major concepts, and the linking words on the lines describe the relationship between those concepts. These concepts (boxed words) and linking words (arrowed lines with words) form a short "sentence" called a "proposition" which describes the proposed relationship between two concepts. The arrowed line tells us how the sentence should be read. For example …The concept "proposition" is connected to the concept "units of meaning" by the linking word "are," forming the short sentence "Propositions are units of meaning." Similarly, the concept "Organized knowledge" is related to "effective teaching" in that it is "necessary for" it to occur, forming the relationship "Organized knowledge is necessary for effective teaching."

Now, if we wanted to create a concept map on a topic familiar to most people, let's use "Plants" as an example shown in Example 2. The following list of concept words might come to mind: plants, petals, color, green, food, flowers, roots, stems, leaves, seeds. In constructing a concept map, we might start by listing these concepts off to the left side of a sheet of paper (see Step 1). From this list, we might think about the provided focus question: "What is a plant?" and start by grouping related concepts into categories and subcategories from general to more specific, (for example "roots" and "stems" are more general than "petals" and "seeds").

Next, we might arrange these concepts in such a way that represents our understanding of the relationships that exist between these concepts (see Step 2). We might think that plants can be arranged into three subcategories: "roots," "leaves" and "stems." As we think of "stems" we might associate "flowers" "petals" and "seeds" as being somehow related. We could then use lines with arrows to connect our concepts and describe the relationships between them using linking words. For example, the relationship between “flowers” and “seeds” might be described with the linking words “produce” forming the statement “Flowers produce seeds.”

There many different ways of organizing these concepts. There is no one “right” method of organizing and relating these concepts to one another.

Does anyone have any questions? (*pause*)

Let’s look at another example of a concept map, Example 3. This is an example of a well-constructed concept map on the topic of “measurement” with a focus question of “How do we make measurements?” The concept map has many cross links that connect concepts with other concepts. This concept map also uses detailed linking words to describe the relationships between these concepts.

(Provide each participant with the research instrument, a pencil, and an 11x 17 sheet of paper with Post It ™ Notes that contain 15 inquiry concepts. Read the instructions on the instrument aloud):

Next, as a part of this research study, you will be asked to create a concept map for the following situation.

Making Your Concept Map:

Imagine that you are going to be teaching your future students about **scientific inquiry**. Provided is a list of 12 common concepts related to scientific inquiry. Think about **how you might organize these concepts** and **how these concepts are related to one another**. Consider how you might use these concepts to address the focus question of “How does scientific inquiry work?”

a) **Starting with your most general concept**, create a concept map that tries to include **all** 12 of the listed concepts related to scientific inquiry. If you are **unsure of a concept’s meaning**, **leave it off** to the left side of your sheet of paper.
b) **Describe** the relationships between these concepts by connecting them **with arrowed lines and linking words**. **Be detailed** with your linking words.

There many different ways of organizing these concepts. There is no one “right” method of organizing and relating these concepts to one another.

Also, as you complete your concept map, please answer the three demographic questions on your sheet.

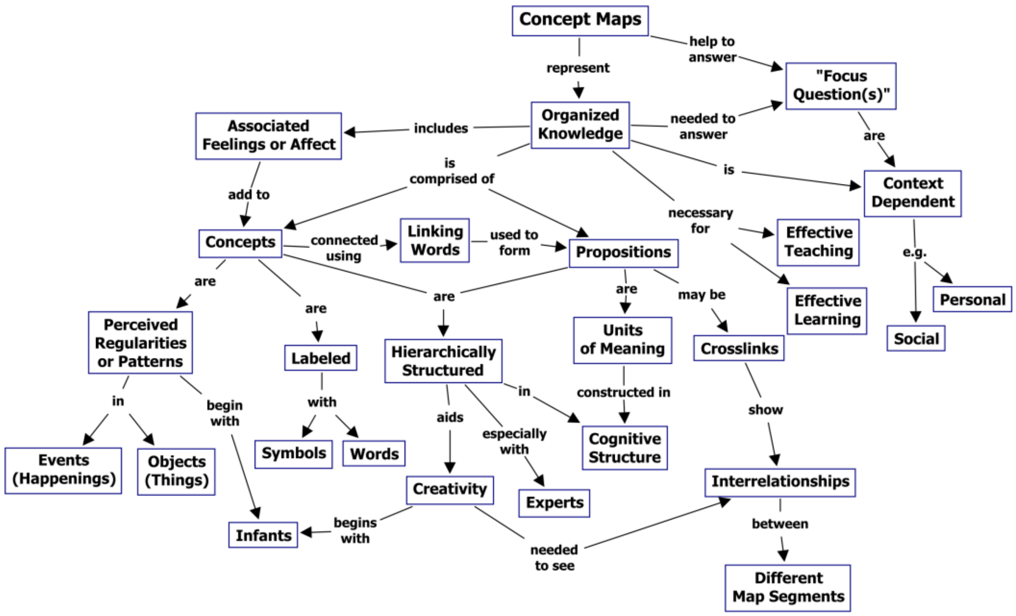
Do you have any questions?

(Allow each participant to complete this task.)

(The faculty member will collect each participant’s completed concept map.)

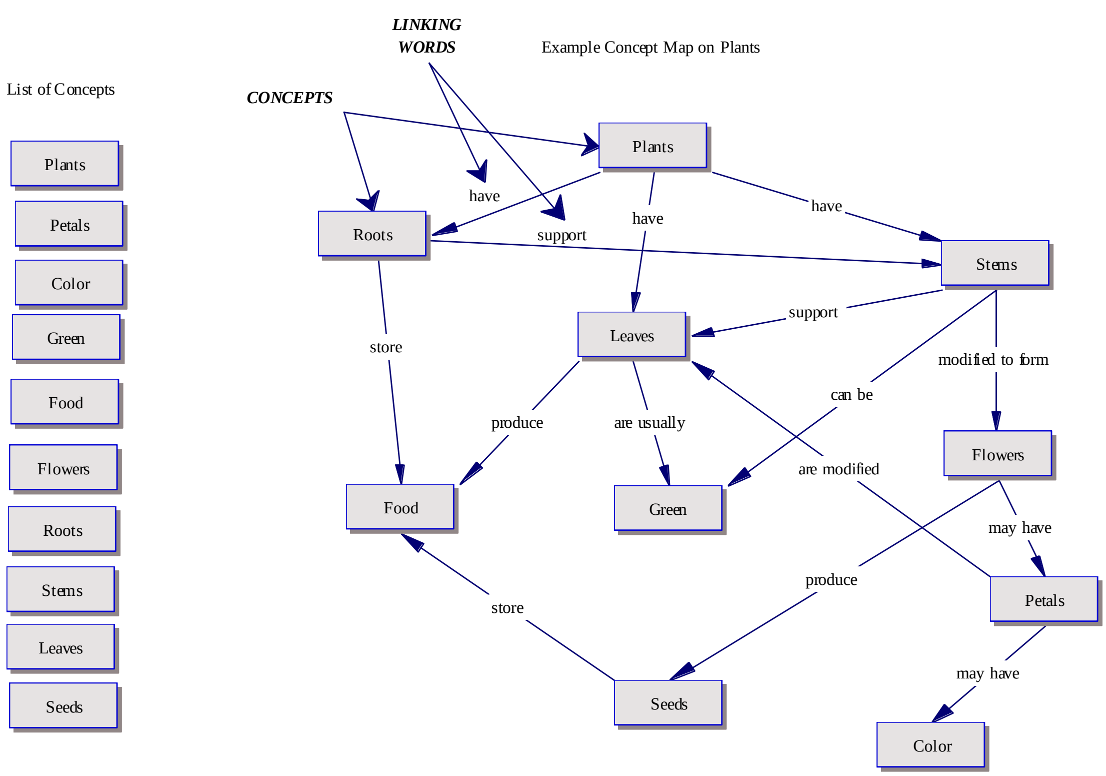
Thank you for your participation in this research study. Your time and efforts are greatly appreciated.

Example 1: Concept map showing key features of concept maps

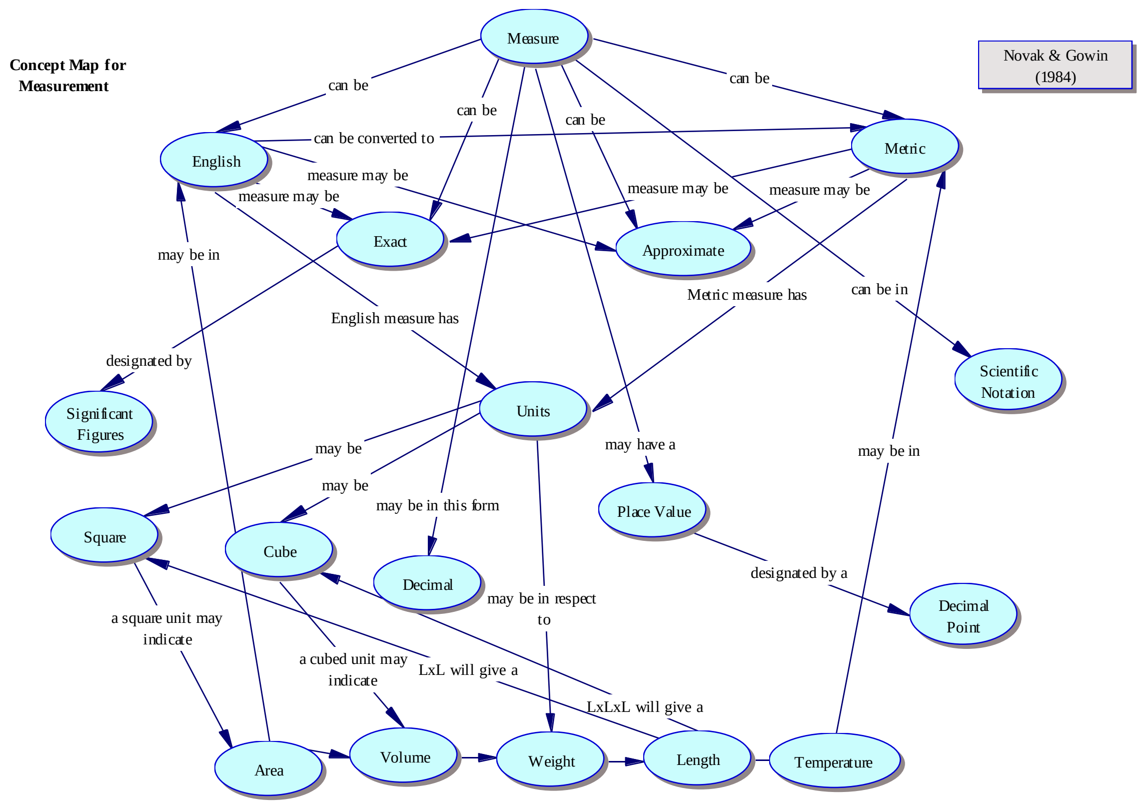


Example 2: Focus Question: What is a plant?

STEP 1: **STEP 2:**



Example 3: Focus Question "How do we make measurements?"



<u>Making Your Concept Map</u>

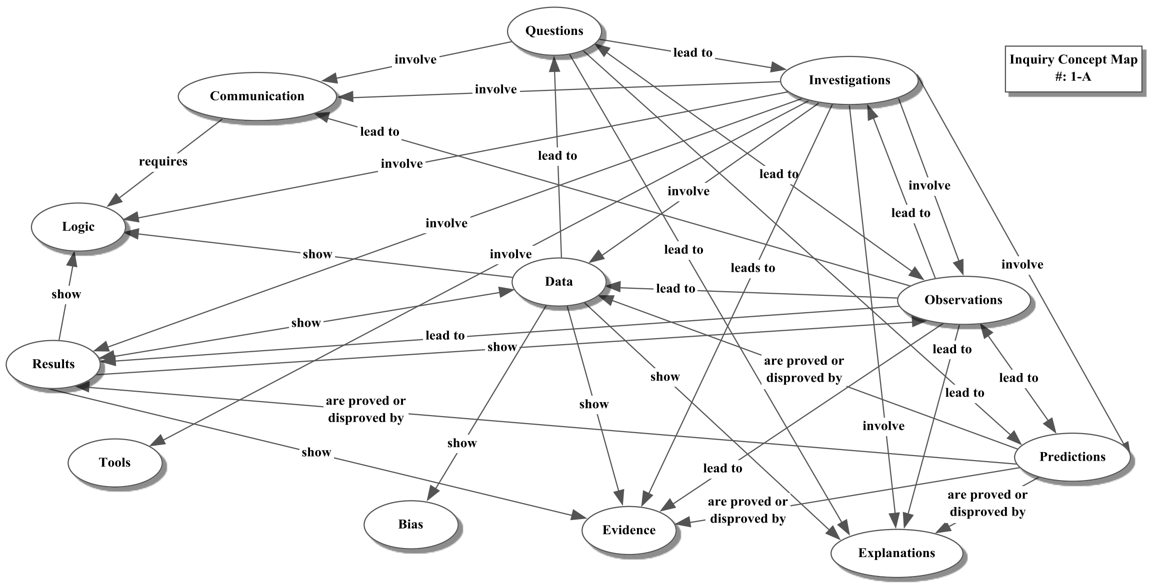
Imagine that you are going to be teaching your future students about **scientific inquiry**. Provided is a list of 12 common concepts related to scientific inquiry. Think about **how you might organize these concepts** and **how these concepts are related to one another**. Consider how you might use these concepts to address the focus question of "How does scientific inquiry work?"

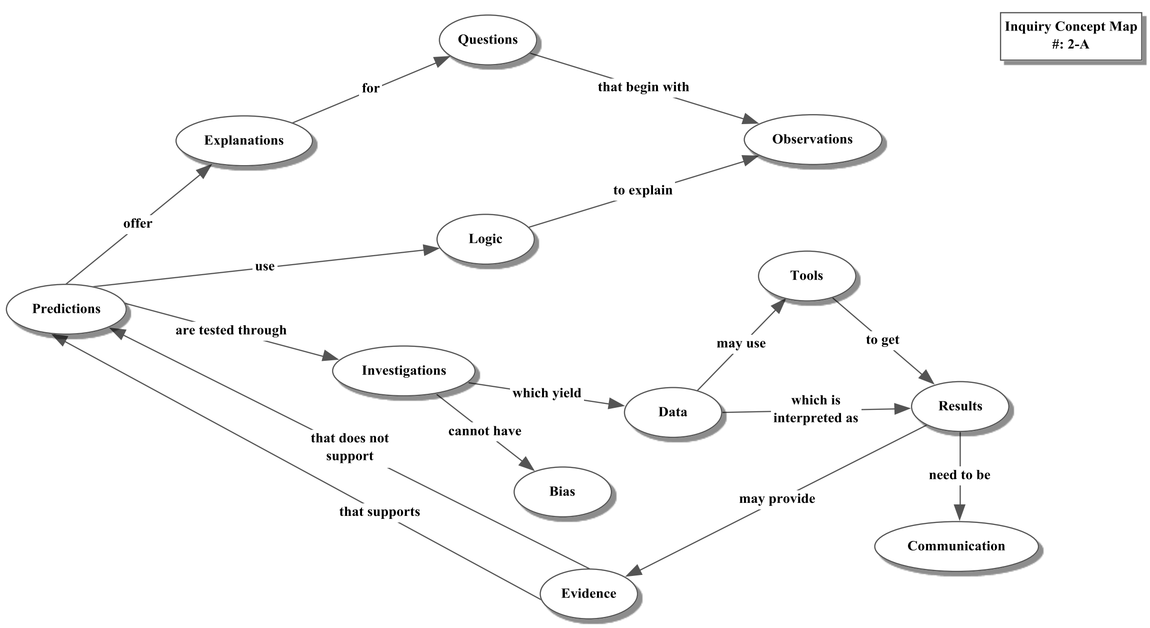
a) **Starting with your most general concept**, create a concept map that tries to include **all** 12 of the listed concepts related to scientific inquiry. If you are **unsure of a concept's meaning**, **leave it off** to the left side of your sheet of paper.
b) **Describe** the relationships between these concepts by connecting them **with arrowed lines and linking words**. **Be detailed** with your linking words.

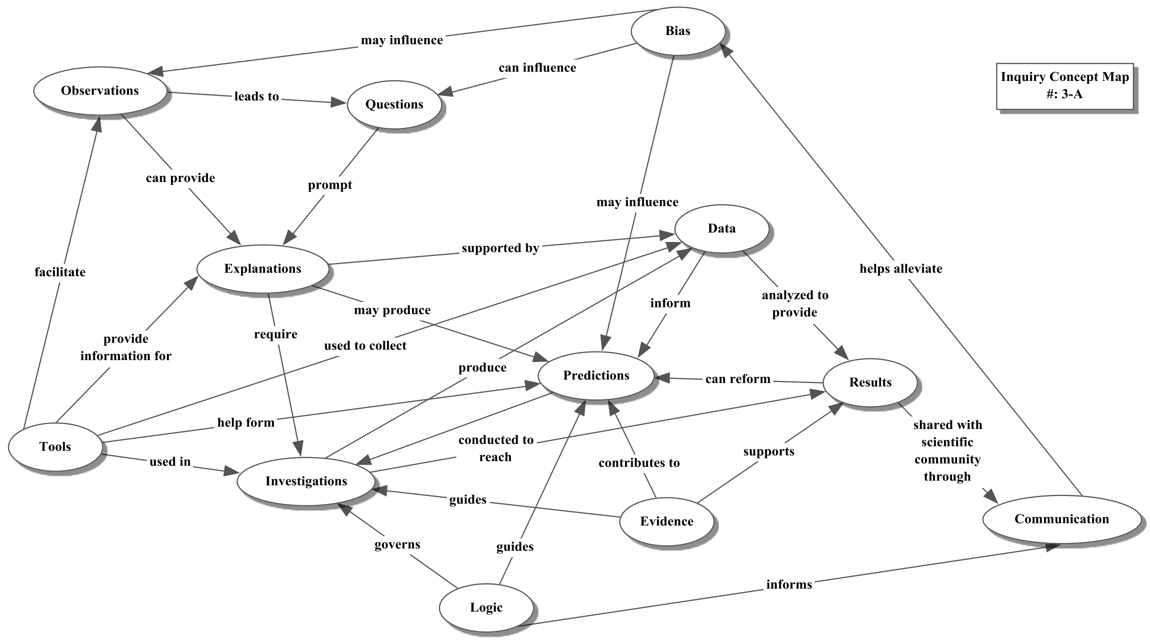
There many different ways of organizing these concepts. There is no one "right" method of organizing and relating these concepts to one another.

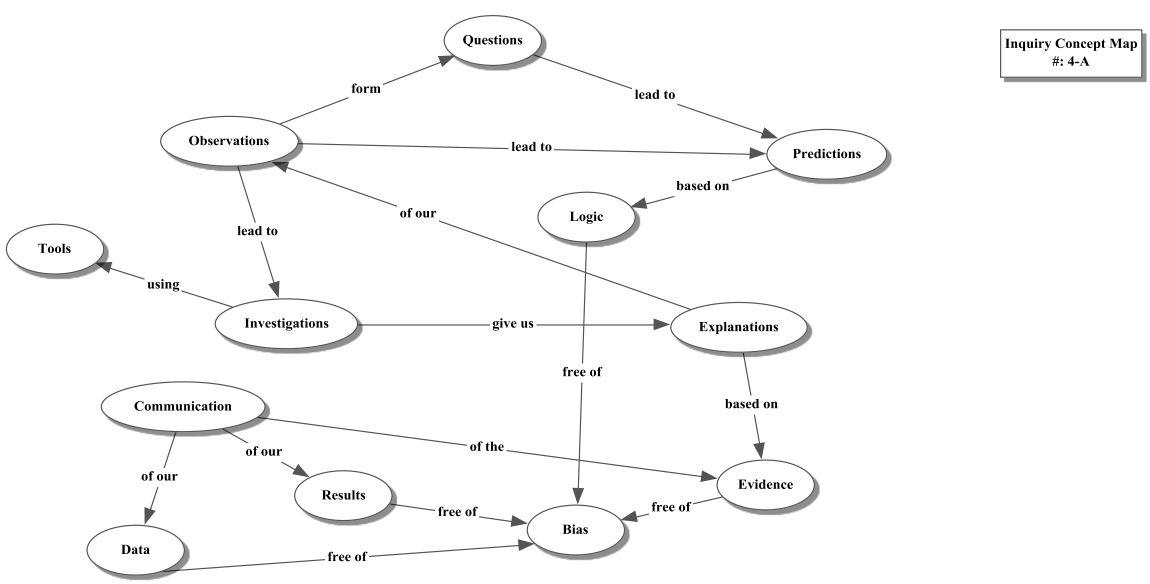
12 Concepts related to Scientific Inquiry	
Explanations	Evidence
Investigations	Data
Tools	Communication
Results	Questions
Logic	Observations
Predictions	Bias

Appendix B – Concept Maps

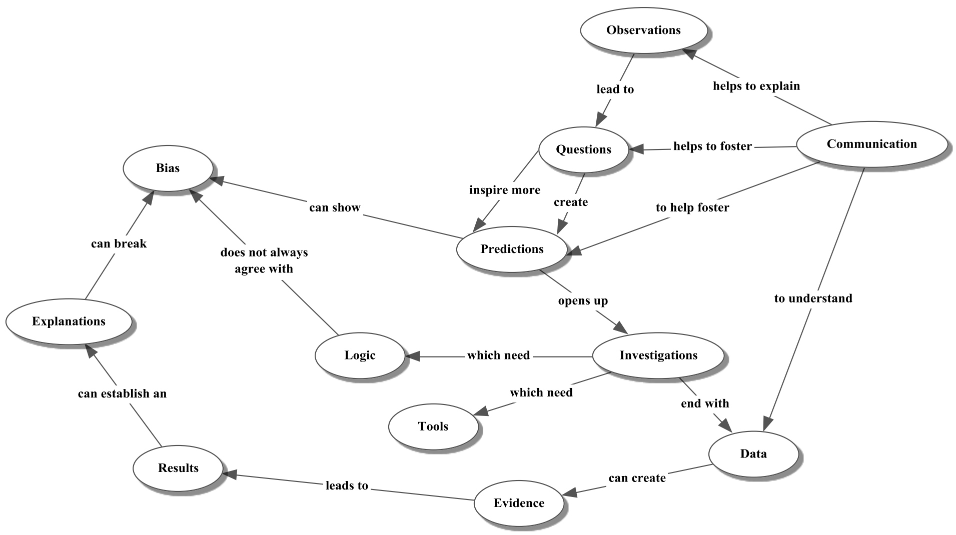




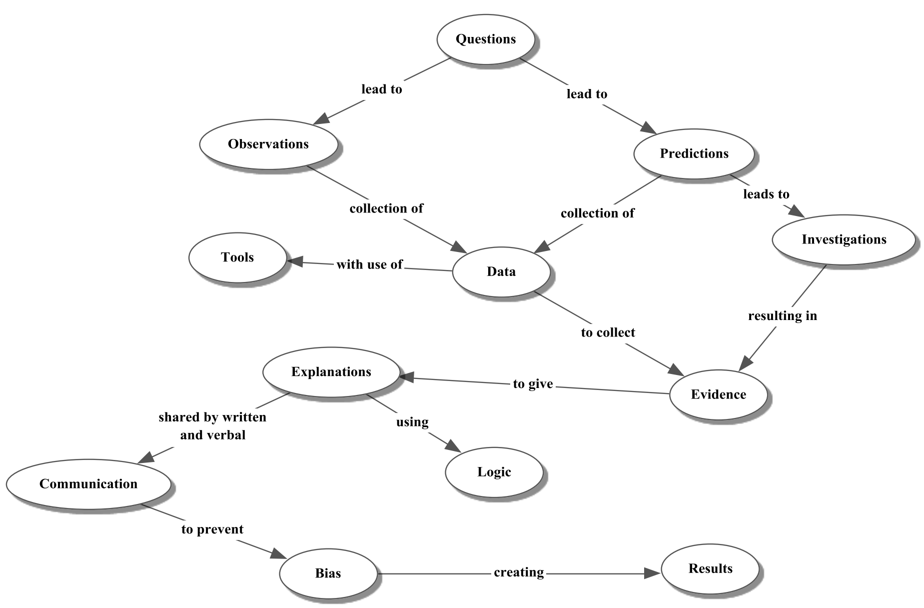

Inquiry Concept Map
#: 3-A
Bias
may influence
can influence
Observations
leads to
Questions
can provide
prompt
may influence
Data
facilitate
Explanations
supported by
helps alleviate
provide
information for
require
may produce
used to collect
inform
analyzed to
provide
produce
Predictions
can reform
Results
help form
Tools
conducted to
reach
shared with
scientific
community
through
used in
Investigations
contributes to
supports
guides
Evidence
Communication
governs
guides
Logic
informs

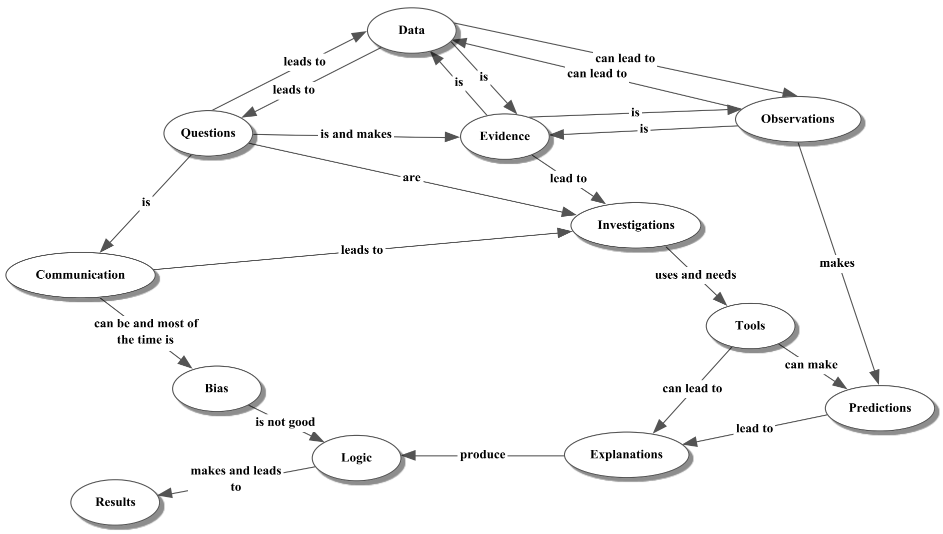

Questions
Inquiry Concept Map
#: 4-A
form
lead to
Observations
lead to
Predictions
based on
of our
Logic
lead to
Tools
using
Investigations
give us
Explanations
free of
based on
Communication
of the
of our
of our
Results
free of
Bias
free of
Evidence
Data
free of

Inquiry Concept Map
#: 5-A

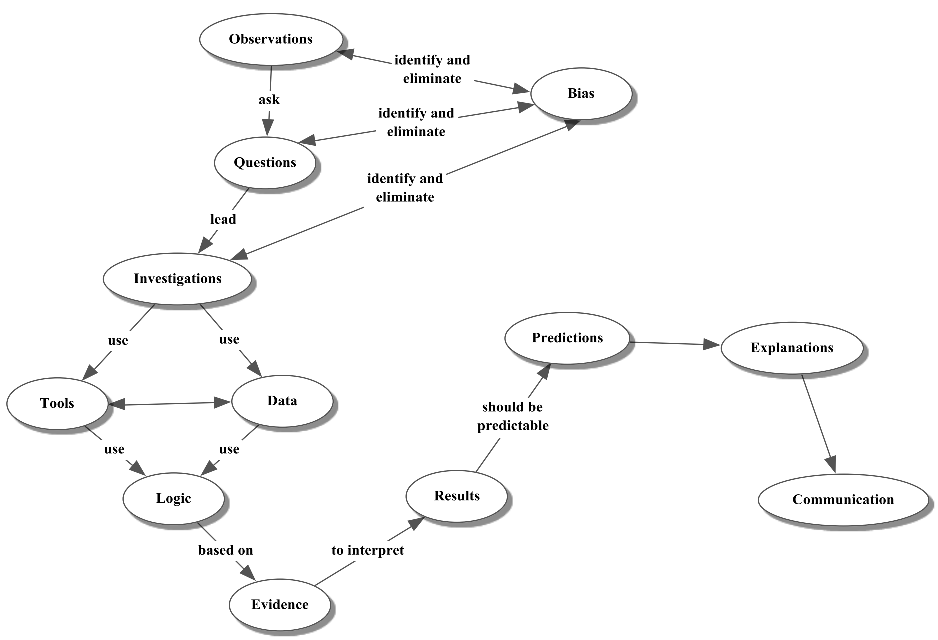


Inquiry Concept Map
#: 6-B

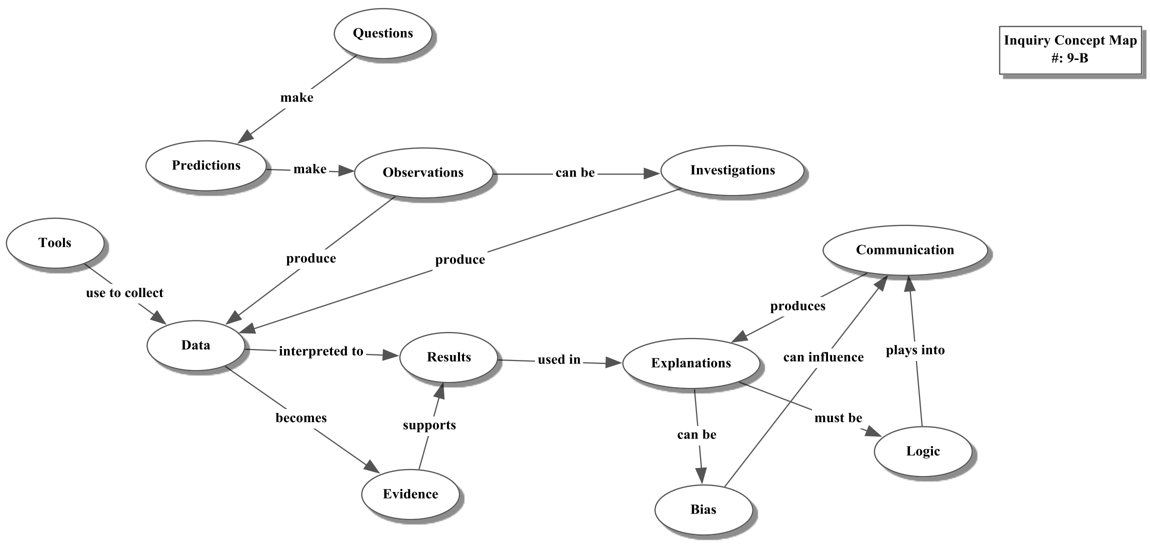


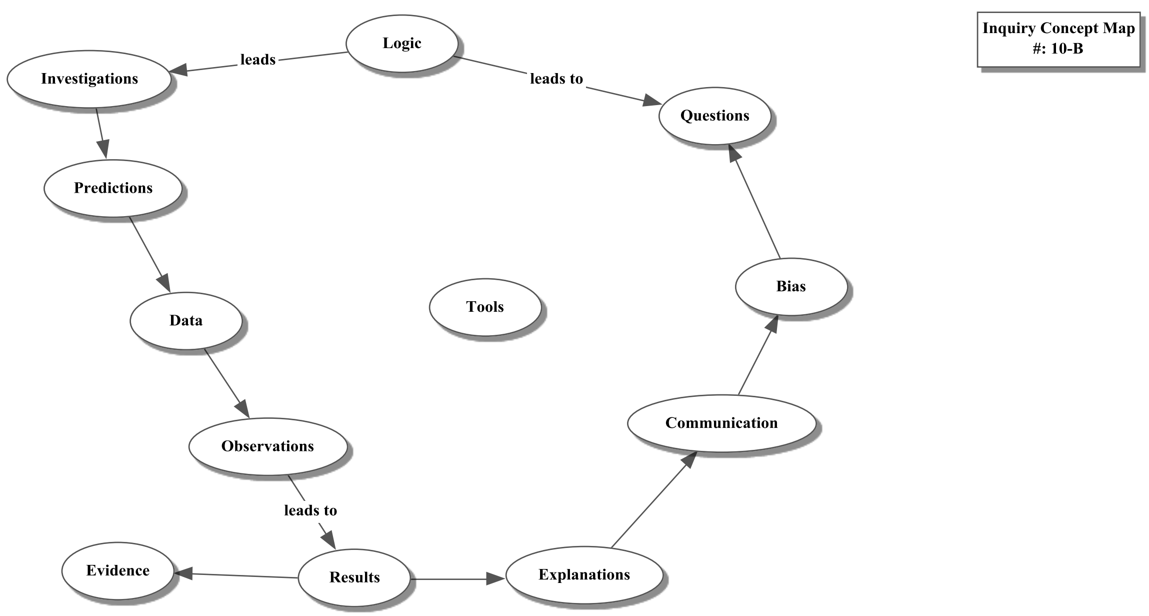


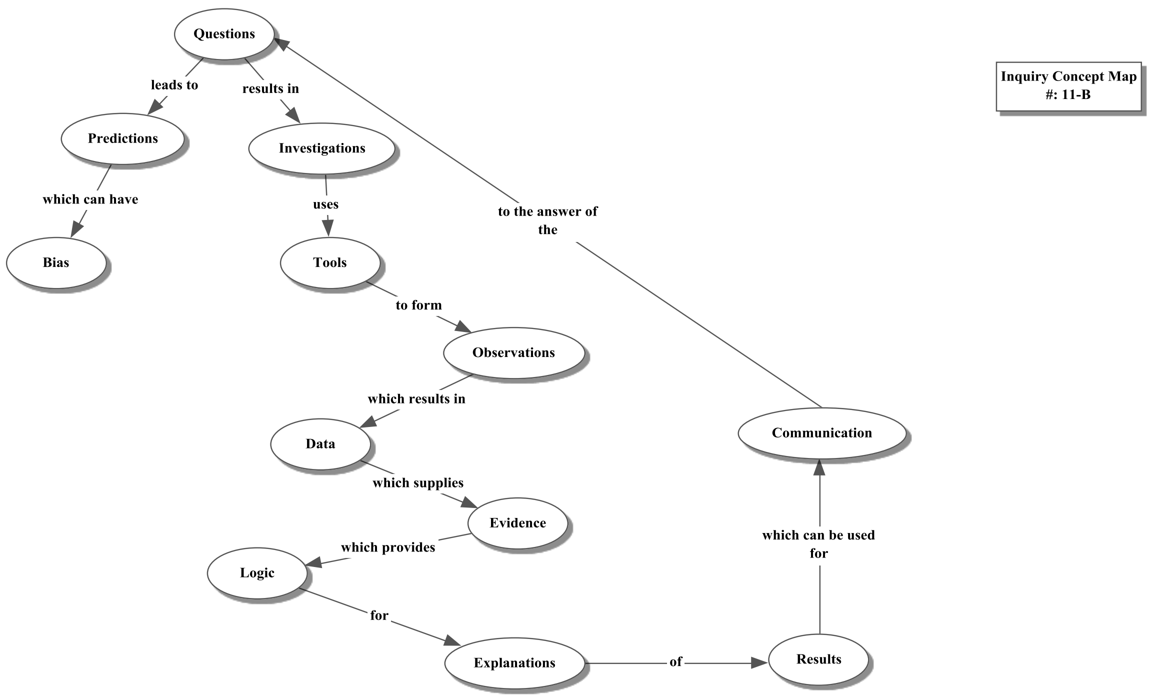
Inquiry Concept Map
#: 7-B

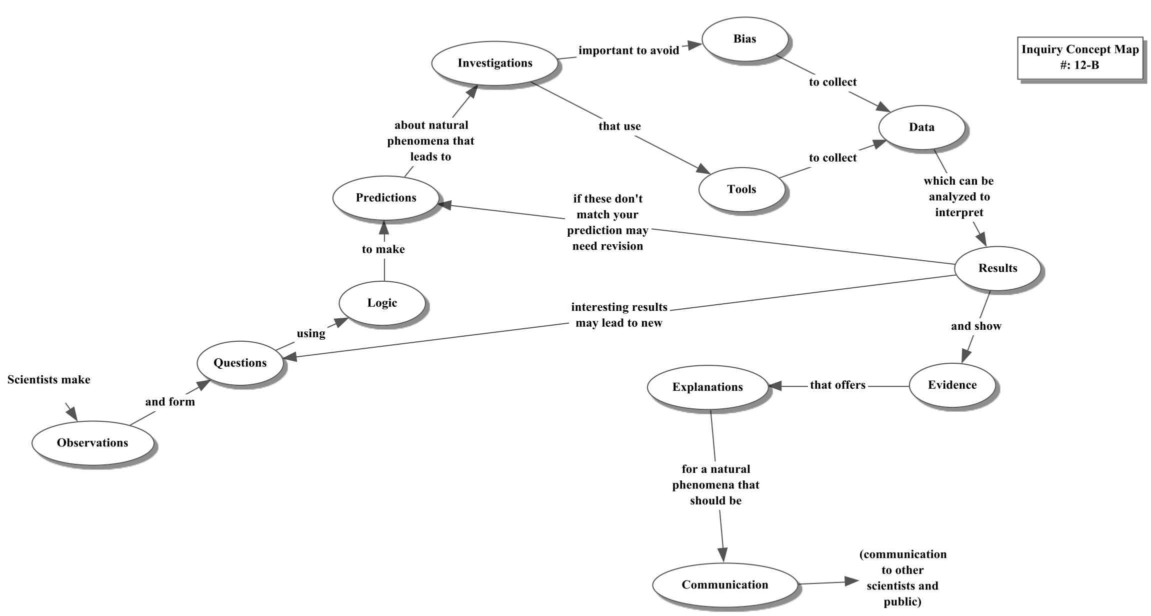


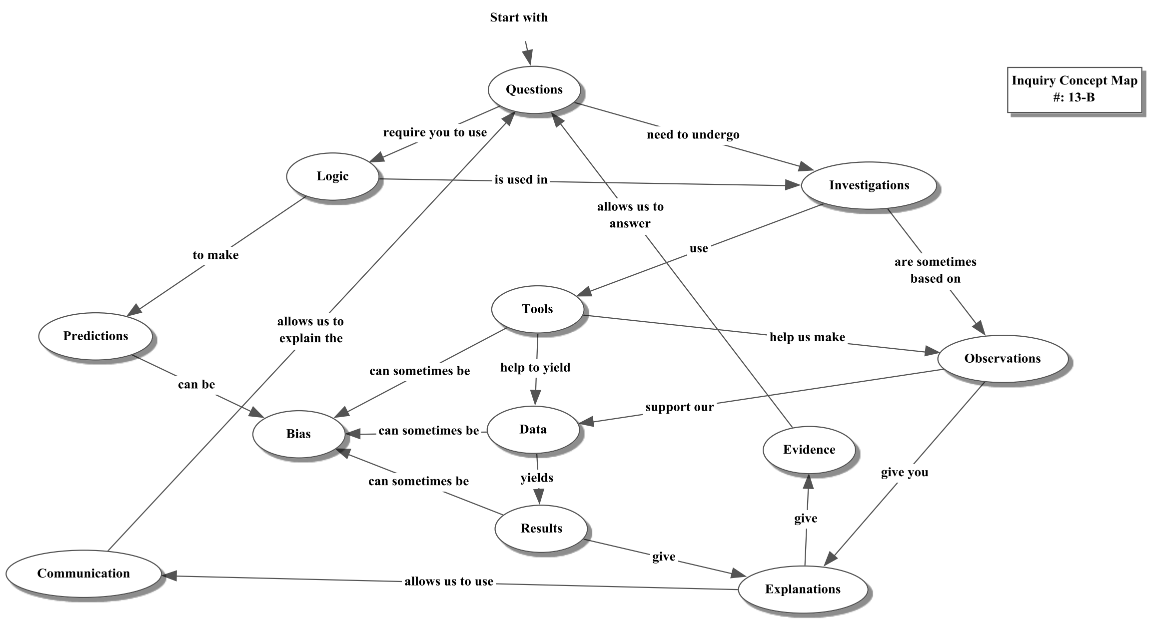
Inquiry Concept Map
#: 8-B

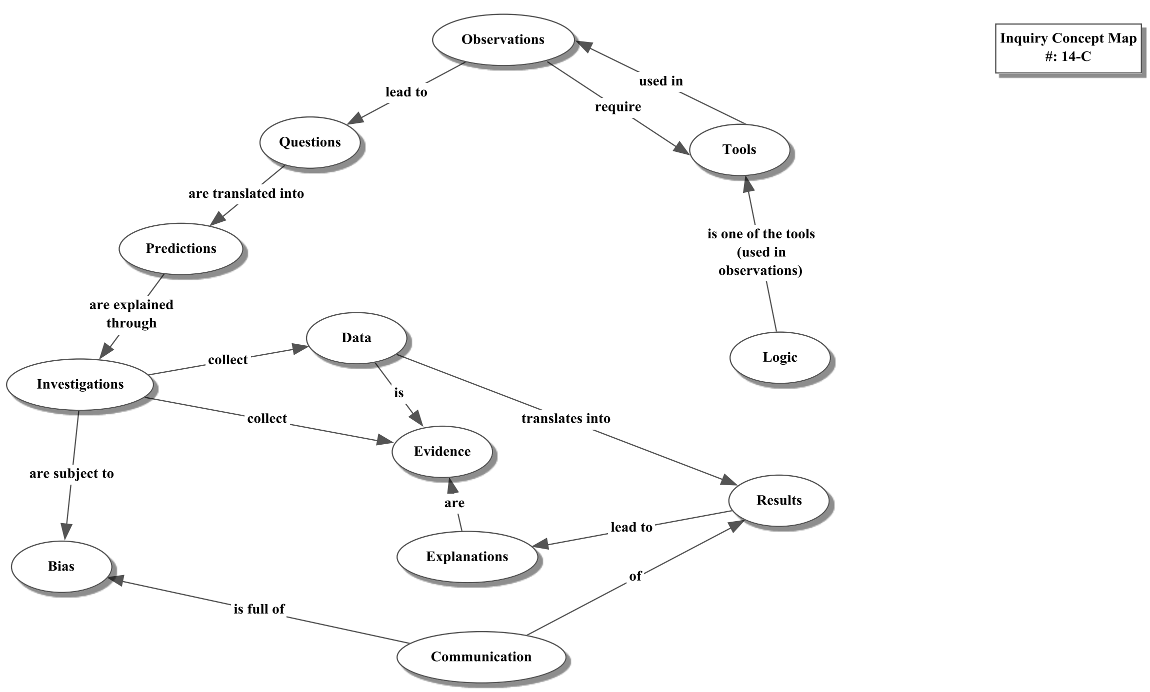

Inquiry Concept Map
#: 9-B
Questions
make
Predictions
make
Observations
can be
Investigations
Tools
produce
produce
Communication
use to collect
produces
Data
interpreted to
Results
used in
Explanations
can influence
plays into
becomes
supports
can be
must be
Logic
Evidence
Bias

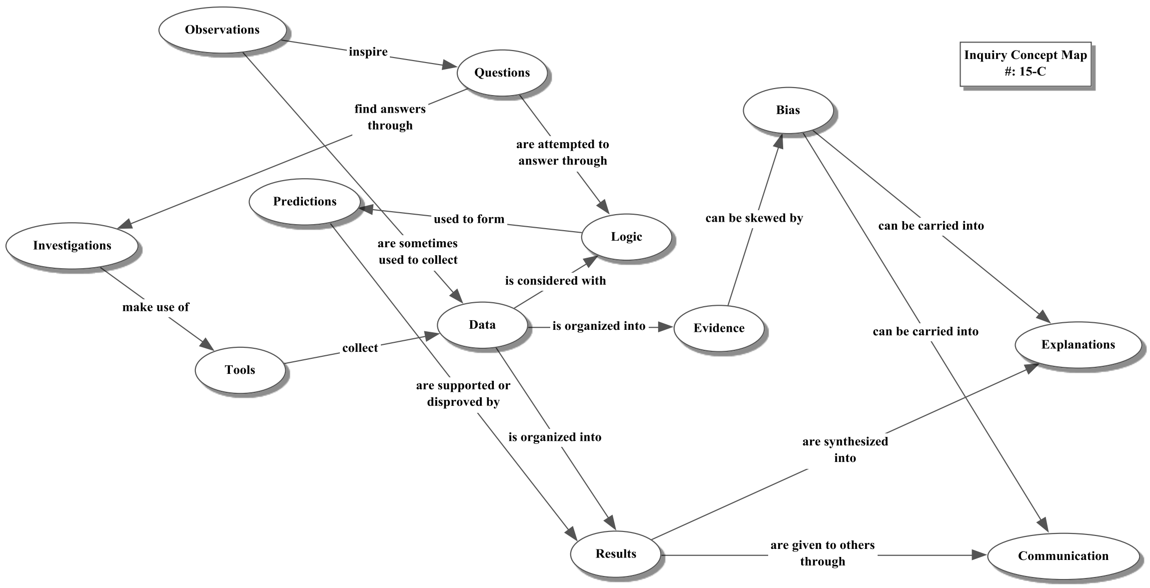

Inquiry Concept Map
#: 10-B
Logic
leads
Investigations
leads to
Questions
Predictions
Bias
Data
Tools
Communication
Observations
leads to
Evidence
Results
Explanations

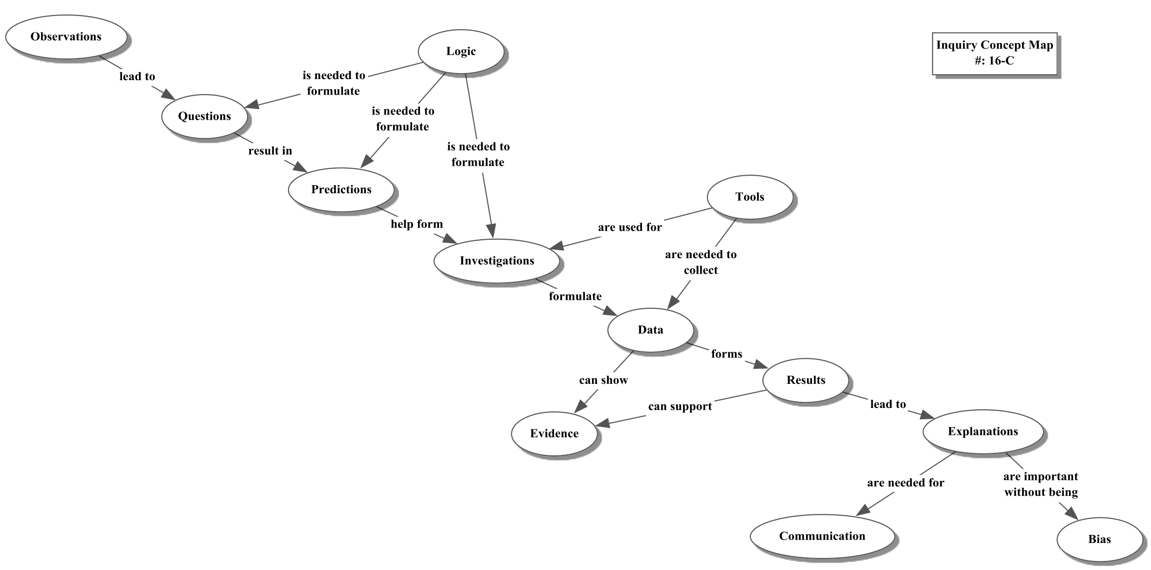

Inquiry Concept Map
#: 11-B
Questions
leads to
results in
Predictions
Investigations
which can have
uses
to the answer of the
Bias
Tools
to form
Observations
which results in
Data
Communication
which supplies
Evidence
which provides
which can be used for
Logic
for
Explanations
of
Results

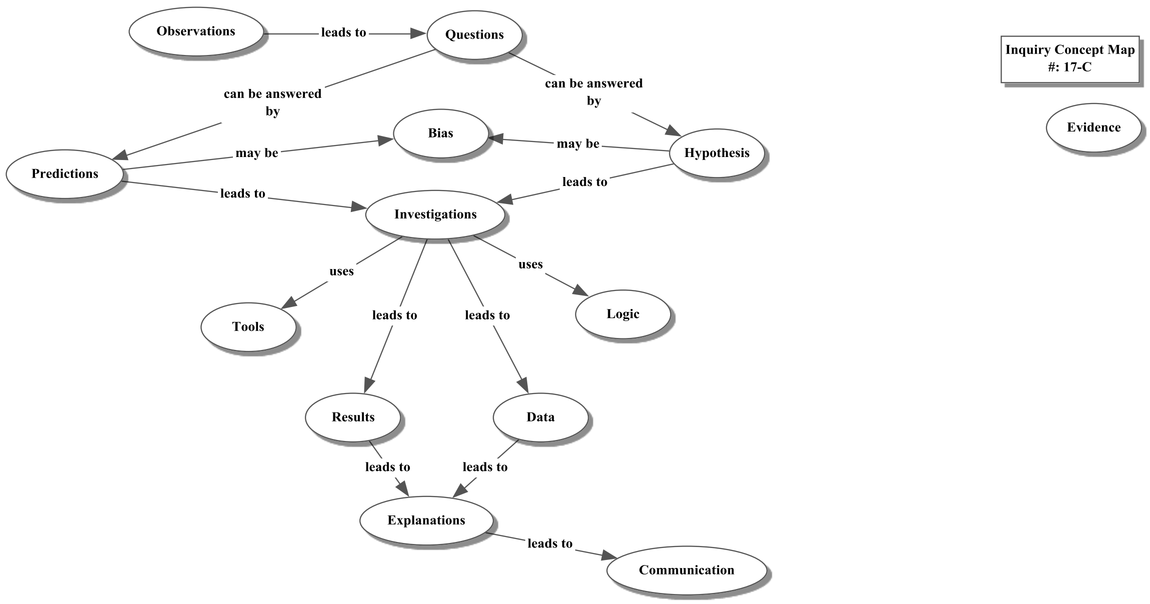

Inquiry Concept Map
#: 12-B
Bias
Investigations
important to avoid
to collect
about natural phenomena that leads to
that use
Data
to collect
Tools
which can be analyzed to interpret
Predictions
if these don't match your prediction may need revision
Results
to make
Logic
interesting results may lead to new
and show
using
Questions
Scientists make
Explanations
that offers
Evidence
and form
Observations
for a natural phenomena that should be
Communication
(communication to other scientists and public)

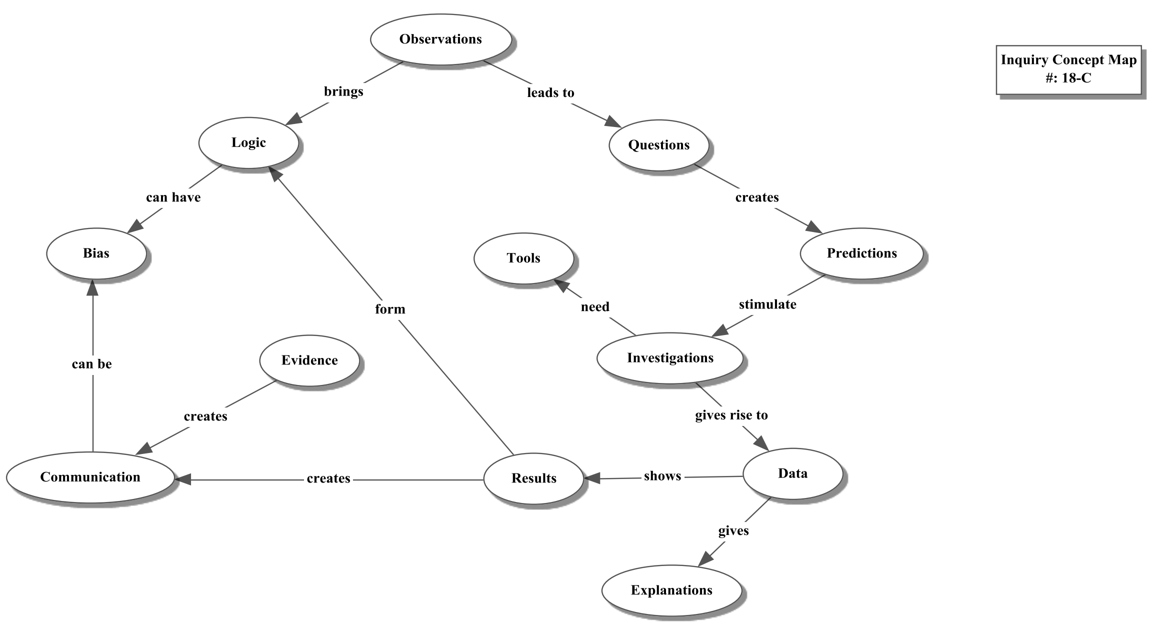

Inquiry Concept Map
#: 13-B
Start with
Questions
require you to use
need to undergo
Logic
is used in
Investigations
allows us to
answer
to make
use
are sometimes
based on
Tools
Predictions
allows us to
explain the
help us make
Observations
can sometimes be
help to yield
can be
support our
Bias
can sometimes be
Data
Evidence
can sometimes be
yields
give you
give
Results
give
Communication
allows us to use
Explanations


Inquiry Concept Map
#: 14-C
Observations
used in
lead to
require
Questions
Tools
are translated into
Predictions
is one of the tools
(used in
observations)
are explained
through
Data
Logic
collect
Investigations
is
collect
translates into
Evidence
are subject to
are
Results
lead to
Explanations
Bias
of
is full of
Communication

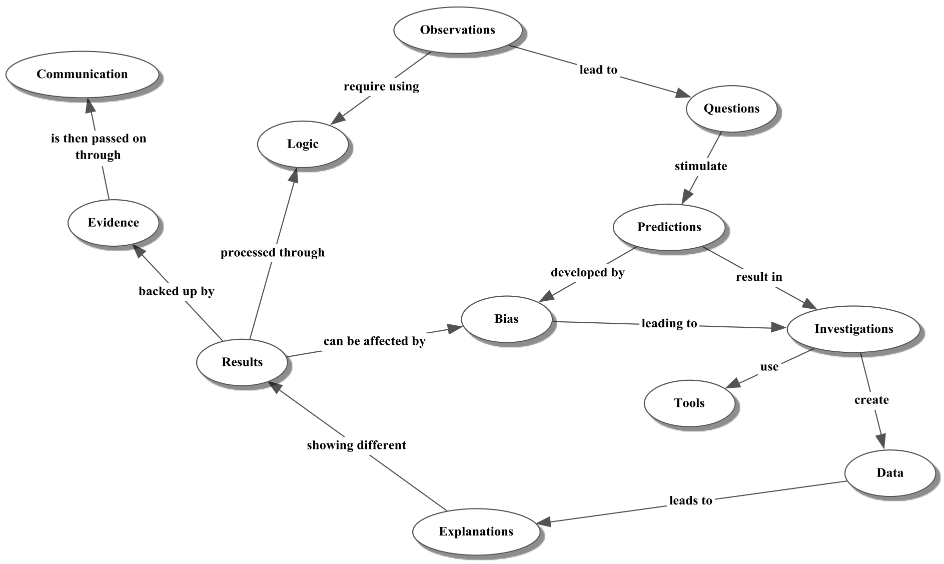

Inquiry Concept Map
#: 15-C
Observations
inspire
Questions
find answers through
are attempted to answer through
Bias
Predictions
used to form
Logic
can be skewed by
can be carried into
Investigations
are sometimes used to collect
is considered with
make use of
Data
is organized into
Evidence
can be carried into
Explanations
Tools
collect
are supported or disproved by
is organized into
are synthesized into
Results
are given to others through
Communication


Inquiry Concept Map
#: 16-C
Observations
lead to
Logic
is needed to formulate
Questions
is needed to formulate
is needed to formulate
result in
Predictions
Tools
help form
are used for
Investigations
are needed to collect
formulate
Data
forms
can show
Results
can support
lead to
Evidence
Explanations
are needed for
are important without being
Communication
Bias

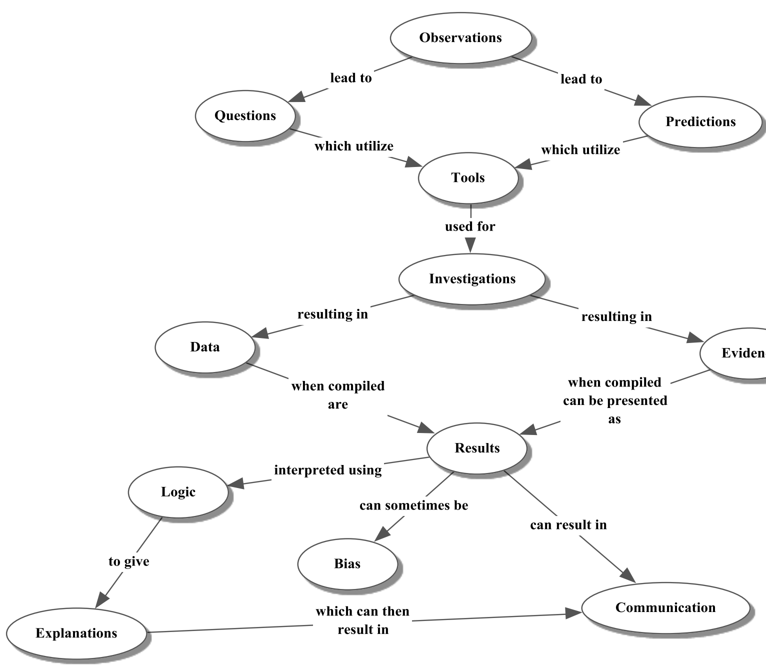

Inquiry Concept Map
#: 17-C
Observations
leads to
Questions
can be answered by
can be answered by
Predictions
may be
Bias
may be
Hypothesis
leads to
leads to
Investigations
uses
uses
leads to
leads to
Tools
Logic
Results
Data
leads to
leads to
Explanations
leads to
Communication
Evidence

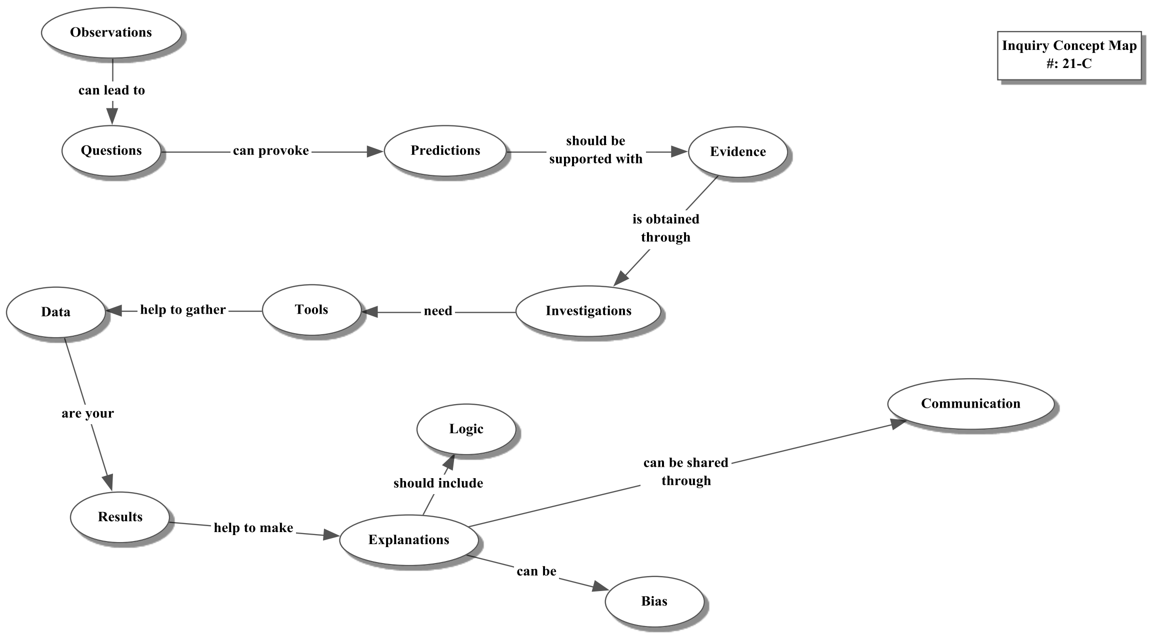

Inquiry Concept Map
#: 18-C
Observations
brings
leads to
Logic
Questions
can have
creates
Bias
Tools
Predictions
form
need
stimulate
can be
Evidence
Investigations
creates
gives rise to
Communication
creates
Results
shows
Data
gives
Explanations

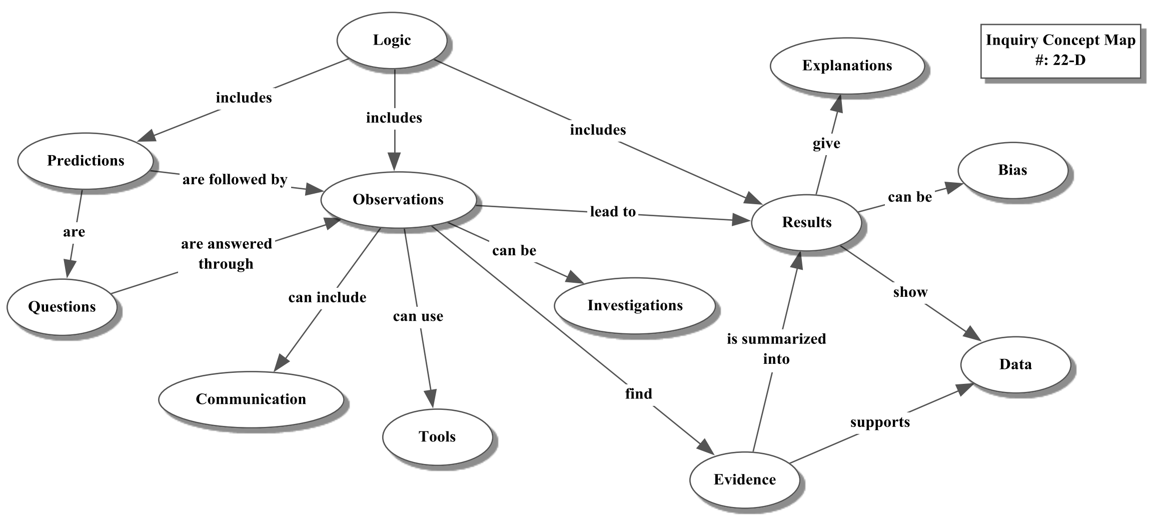
Inquiry Concept Map #: 19-C

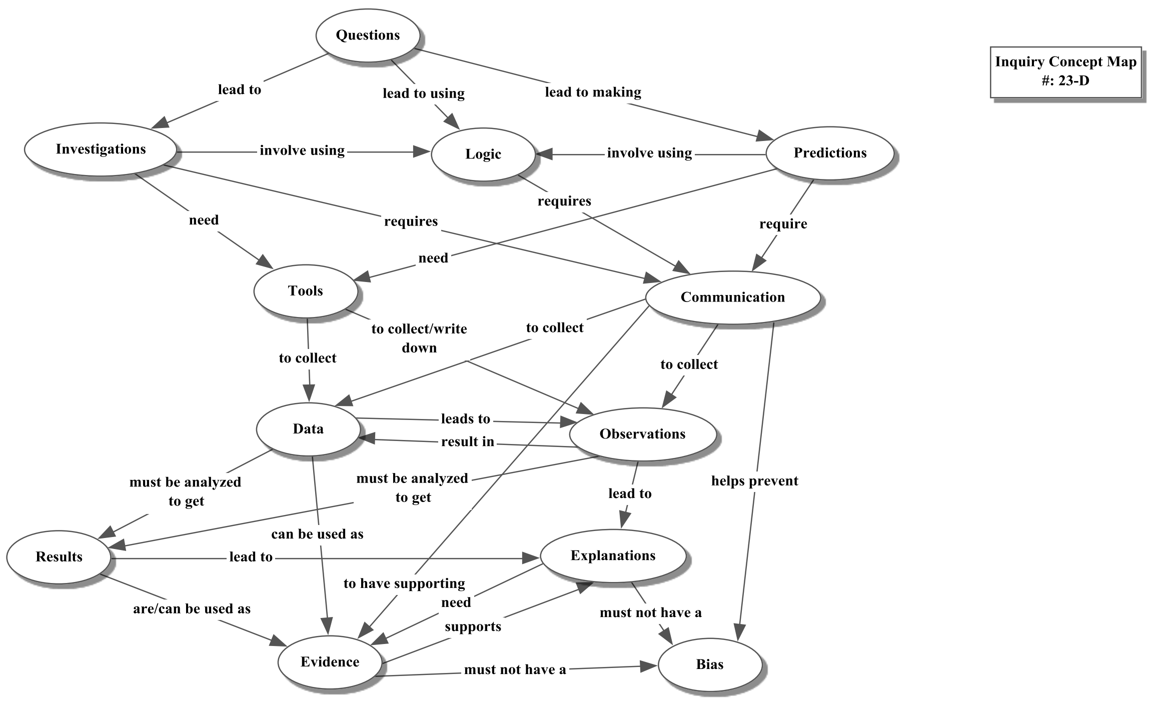


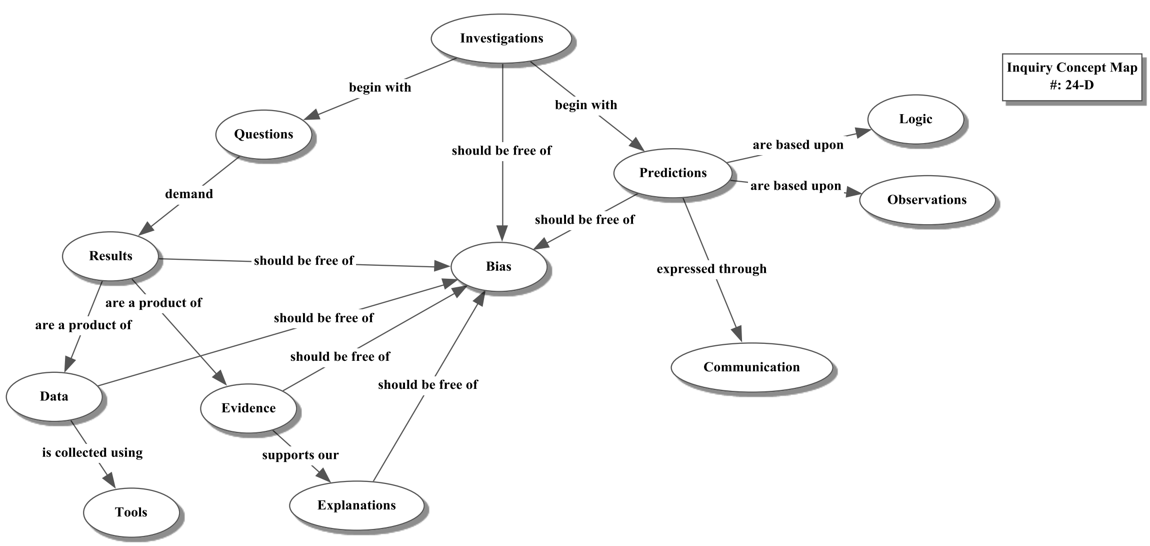
Inquiry Concept Map #: 20-C

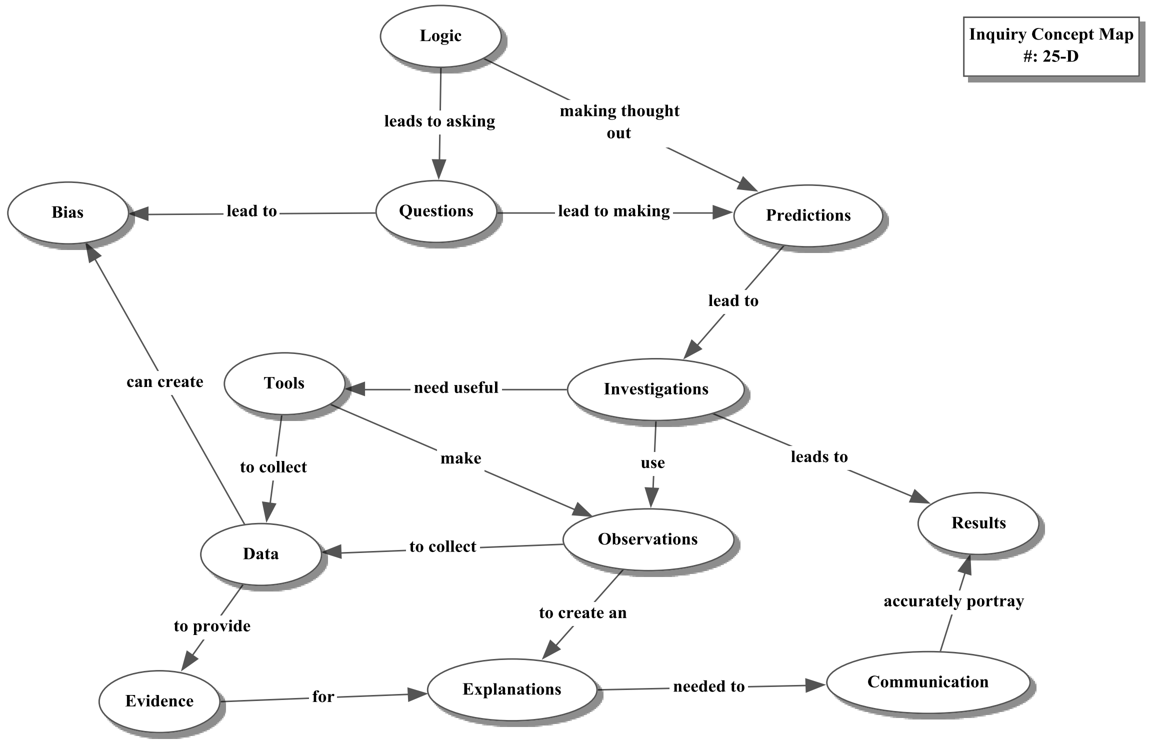


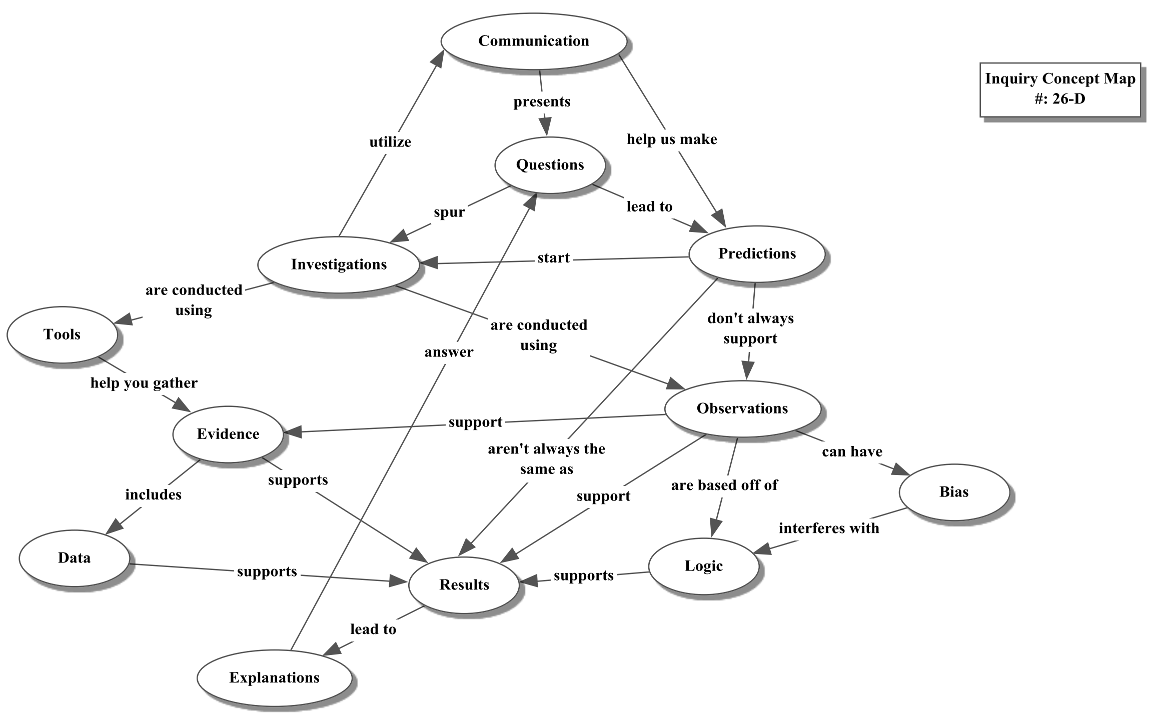

Observations
can lead to
Questions
can provoke
Predictions
should be supported with
Evidence
is obtained through
Investigations
need
Tools
help to gather
Data
are your
Results
help to make
Explanations
should include
Logic
can be shared through
Communication
can be
Bias
Inquiry Concept Map #: 21-C

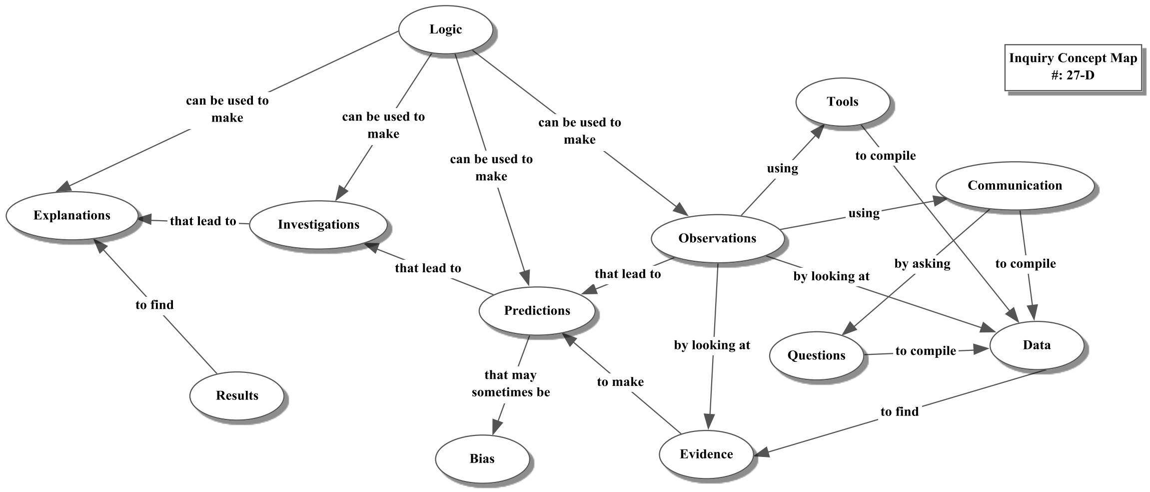

Logic
includes
includes
includes
Predictions
are followed by
Observations
are
Questions
are answered through
can include
Communication
can use
Tools
can be
Investigations
find
Evidence
lead to
Results
give
Explanations
can be
Bias
show
Data
is summarized into
supports
Inquiry Concept Map #: 22-D

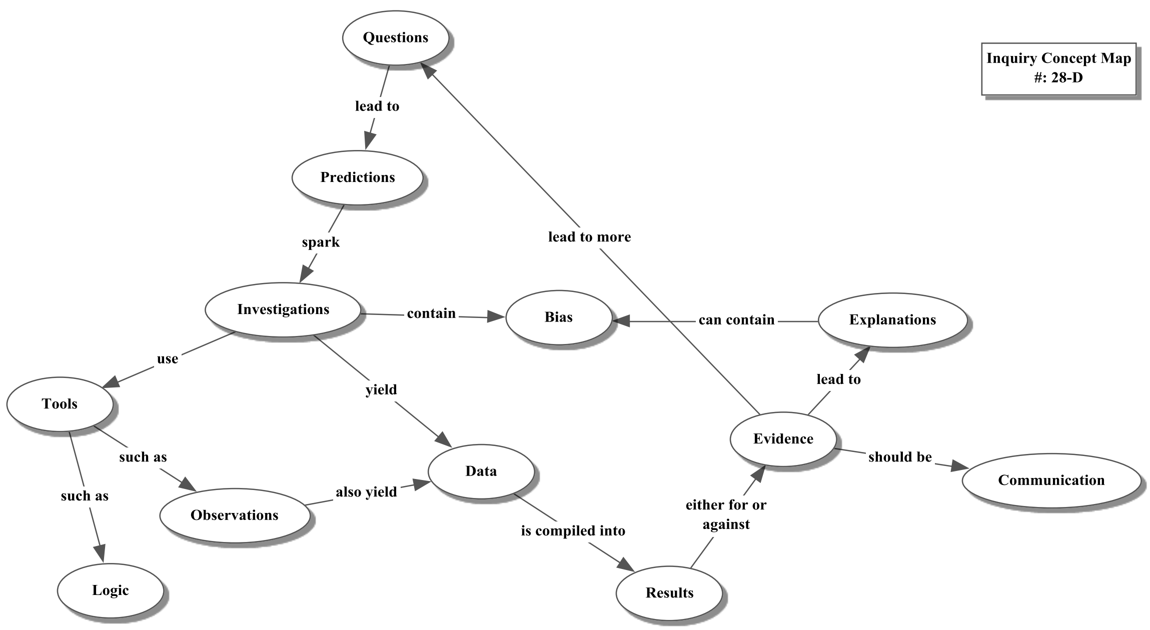

Inquiry Concept Map
#: 23-D
Questions
lead to
lead to using
lead to making
Investigations
involve using
Logic
involve using
Predictions
need
requires
requires
require
need
Tools
Communication
to collect/write
down
to collect
to collect
to collect
Data
leads to
result in
Observations
must be analyzed
to get
must be analyzed
to get
lead to
helps prevent
can be used as
Results
lead to
Explanations
to have supporting
need
are/can be used as
supports
must not have a
Evidence
must not have a
Bias


Inquiry Concept Map
#: 24-D
Investigations
begin with
begin with
Questions
should be free of
Logic
Predictions
are based upon
are based upon
Observations
demand
should be free of
Results
should be free of
Bias
expressed through
are a product of
are a product of
should be free of
should be free of
should be free of
Data
Evidence
Communication
is collected using
supports our
Tools
Explanations

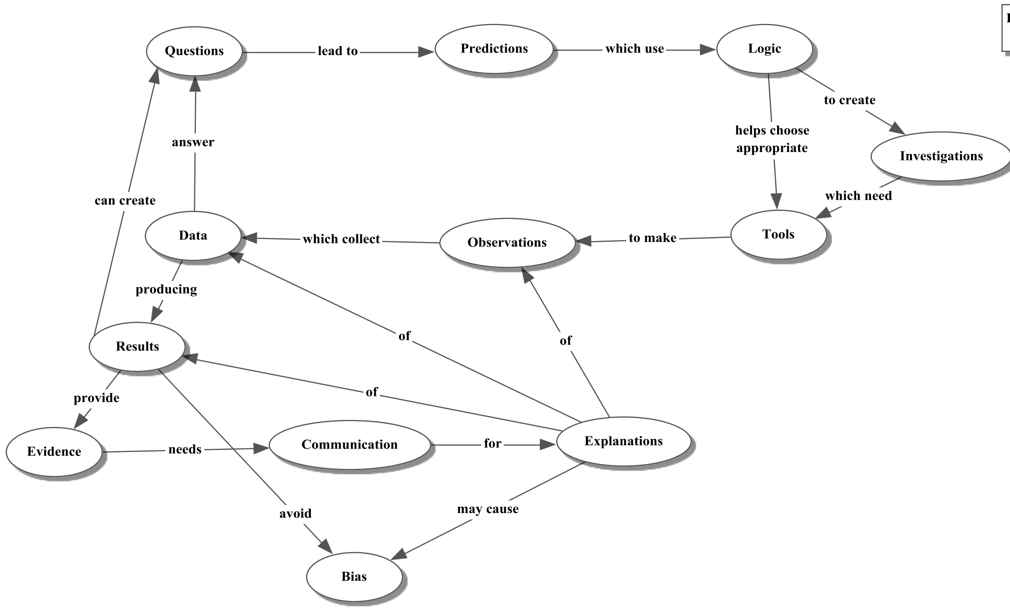

Inquiry Concept Map
#: 25-D
Logic
leads to asking
making thought out
Questions
lead to
Bias
lead to making
Predictions
lead to
Investigations
need useful
Tools
can create
to collect
make
use
leads to
Results
Observations
to collect
Data
to provide
to create an
accurately portray
Evidence
for
Explanations
needed to
Communication


Inquiry Concept Map
#: 26-D
Communication
presents
utilize
help us make
Questions
spur
lead to
Investigations
start
Predictions
are conducted using
Tools
are conducted using
answer
don't always support
help you gather
Observations
Evidence
support
aren't always the same as
can have
includes
supports
support
are based off of
Bias
interferes with
Data
supports
Results
supports
Logic
lead to
Explanations


Logic
Inquiry Concept Map
#: 27-D
can be used to make
can be used to make
can be used to make
can be used to make
Tools
to compile
using
Communication
Explanations
that lead to
Investigations
using
Observations
that lead to
by asking
to compile
by looking at
that lead to
Predictions
to find
by looking at
Questions
to compile
Data
that may sometimes be
to make
Results
to find
Bias
Evidence


Questions
Inquiry Concept Map
#: 28-D
lead to
Predictions
spark
lead to more
Investigations
contain
Bias
can contain
Explanations
use
lead to
yield
Tools
Evidence
such as
should be
Communication
Data
such as
also yield
either for or against
Observations
is compiled into
Logic
Results

Inquiry Concept Map
#: 29-D



Inquiry Concept Map
#: 30-D