View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by DigitalCommons@USU

Utah State University

DigitalCommons@USU

All Graduate Theses and Dissertations

Graduate Studies

5-2016

Epistemic Beliefs of Middle and High School Students in a Problem-Based, Scientific Inquiry Unit: An Exploratory, Mixed Methods Study

Jiangyue Gu
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Educational Psychology Commons, Instructional Media Design Commons, and the Science and Mathematics Education Commons

Recommended Citation

Gu, Jiangyue, "Epistemic Beliefs of Middle and High School Students in a Problem-Based, Scientific Inquiry Unit: An Exploratory, Mixed Methods Study" (2016). *All Graduate Theses and Dissertations*. 4674.
https://digitalcommons.usu.edu/etd/4674

This Dissertation is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

UtahStateUniversity
MERRILL-CAZIER LIBRARY

EPISTEMIC BELIEFS OF MIDDLE AND HIGH SCHOOL STUDENTS IN A PROBLEM-BASED, SCIENTIFIC INQUIRY UNIT: AN EXPLORATORY, MIXED METHODS STUDY

by

Jiangyue Gu

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Instructional Technology and Learning Sciences

Approved:

Brian Belland, Ph.D. Major Professor	Mimi Recker, Ph.D. Committee Member
Andy Walker, Ph.D. Committee Member	Steven Camicia, Ph.D. Committee Member
Cathy Maahs-Fladung, Ph.D. Committee Member	Mark R. McLellan, Ph.D. Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2016

Copyright © Jiangyue Gu 2016

All Rights Reserved

ABSTRACT

Epistemic Beliefs of Middle and High School Students in a Problem-Based, Scientific Inquiry Unit: An Exploratory, Mixed Methods Study

by

Jiangyue Gu, Doctor of Philosophy

Utah State University, 2016

Major Professor: Brian. R. Belland, Ph.D.
Department: Instructional Technology and Learning Sciences

Epistemic beliefs are individuals' beliefs about the nature of knowledge, how knowledge is constructed, and how knowledge can be justified. This study employed a mixed-methods approach to examine: (a) middle and high school students' self-reported epistemic beliefs (quantitative) and epistemic beliefs revealed from practice (qualitative) during a problem-based, scientific inquiry unit, (b) How do middle and high school students' epistemic beliefs contribute to the construction of students' problem solving processes, and (c) how and why do students' epistemic beliefs change by engaging in PBL.

Twenty-one middle and high school students participated in a summer science class to investigate local water quality in a 2-week long problem-based learning (PBL) unit. The students worked in small groups to conduct water quality tests at in their local watershed and visited several stakeholders for their investigation. Pretest and posttest versions of the Epistemological Beliefs Questionnaire were conducted to assess students' self-reported epistemic beliefs before and after the unit. I videotaped and interviewed three groups of students during the unit and conducted discourse analysis to examine their epistemic beliefs revealed from scientific inquiry activities and triangulate with their self-reported data.

There are three main findings from this study. First, students in this study self-reported relatively sophisticated epistemic beliefs on the pretest. However, the comparison between their self-reported beliefs and beliefs revealed from practice indicated that some students were able to apply sophisticated beliefs during the unit while others failed to do so. The inconsistency between these two types of epistemic beliefs may due to students' inadequate cognitive ability, low validity of self-report measure, and the influence of contextual factors. Second, qualitative analysis indicated that students' epistemic beliefs of the nature of knowing influenced their problem solving processes and construction of arguments during their inquiry activities. Students with more sophisticated epistemic beliefs acquired knowledge, presented solid evidence, and used it to support their claims more effectively than their peers. Third, students' self-reported epistemic beliefs became significantly more sophisticated by engaging in PBL. Findings from this study can potentially help researchers to better understand the relation between students' epistemic beliefs and their scientific inquiry practice.

(201 pages)

PUBLIC ABSTRACT

Epistemic Beliefs of Middle and High School Students in a Problem-Based, Scientific Inquiry Unit: An Exploratory, Mixed Methods Study

by

Jiangyue Gu, Doctor of Philosophy

Epistemic beliefs are individuals' beliefs about the nature of knowledge, how knowledge is constructed, and how knowledge can be justified. Recent science education reform highlights a goal of helping students (a) understand the nature of scientific knowledge and how scientists conduct scientific inquiry, and (b) be able to engage in scientific inquiry. To help students learn the nature of science, research on epistemic beliefs should be integrated with research on scientific inquiry to better understand students' beliefs regarding scientific inquiry.

This study employed a mixed-methods approach to examine: (a) middle and high school students' self-reported epistemic beliefs (quantitative) and epistemic beliefs revealed from practice (qualitative) during a problem-based, scientific inquiry unit, (b) How do middle and high school students' epistemic beliefs contribute to the construction of students' problem solving processes, and (c) how and why do students' epistemic beliefs change by engaging in PBL. Twenty-one middle and high school students participated in a summer science class to investigate local water quality in a 2-week long problem-based learning (PBL) unit. The students worked in small groups to conduct

water quality tests at multiple sites in their local watershed and visited several stakeholders to collect evidence for their investigation. Pretest and posttest versions of the Epistemological Beliefs Questionnaire (Elder, 1999) were conducted to assess students' self-reported epistemic beliefs before and after the unit. I videotaped and interviewed three groups of students to record their performances during the unit. I coded the transcripts from three groups and conducted discourse analysis to examine students' epistemic beliefs revealed from their scientific inquiry activities and triangulate with their self-reported data.

There are three main findings from this study. First, students in this study self-reported relatively sophisticated epistemic beliefs on the pretest. However, the comparison between their self-reported beliefs and beliefs revealed from practice indicated that some students were able to apply sophisticated beliefs during the unit while others failed to do so. The inconsistency between these two types of epistemic beliefs may due to students' inadequate cognitive ability, low validity of self-report measure, and the influence of contextual factors. Second, qualitative analysis indicated that students' epistemic beliefs of the nature of knowing influenced their problem solving processes and construction of arguments during their inquiry activities. Students with more sophisticated epistemic beliefs acquired knowledge, presented solid evidence, and used it to support their claims more effectively than their peers. Third, students' self-reported epistemic beliefs became significantly more sophisticated by engaging in PBL. Findings from this study can potentially help researchers to better understand the relation between students' epistemic beliefs and their scientific inquiry practice.

ACKNOWLEDGMENTS

It is a humbling experience to acknowledge those people who have helped me along the journey for my Ph.D. I am indebted to so many for encouragement and support.

I would like to express my deepest gratitude to the members of my doctoral committee: Dr. Brian Belland, Dr. Mimi Recker, Dr. Andrew Walker, Dr. Steven Camicia, and Dr. Cathy Maahs-Fladung. Thank you for your expertise, time, support, and encouragement throughout this process. I want to especially thank my chair, Dr. Belland. Thank you for your constant support and intelligent guidance of my work in the past 5 years. You have spent a tremendous amount of time and effort on my dissertation from the initial research proposal to the final editing, which I genuinely appreciate. I would also like to thank Dr. Recker for always encouraging me and sharing your wisdom with me. Your incredible guidance and critical feedback greatly improved the quality of my dissertation. Dr. Walker, thank you for sharing your expertise of problem-based learning and methodology with me. Your critical feedback helped me refine the research design of this study. Dr. Camicia, thank you for your valuable suggestions and guidance of qualitative analysis, which greatly improved my qualitative research skills. Finally, I want to give thanks to Dr. Maahs-Fladung for patiently answering my methodological questions and providing me with valuable suggestions. Thank you for often taking time to talk to me and give me life advice. It was a great pleasure to have all of you on my committee. The comments from each of you made my dissertation much stronger than what I originally wrote.

I would like to thank the two teachers and the students of the classes I studied. I greatly appreciate your participation and willingness to be videotaped and interviewed in this study. Your collaboration was central to the success of my dissertation.

I would also like to express particular thanks to the faculties and students in the Department of Instructional Technology and Learning Sciences. Dr. Fields, Dr. Feldon, and Dr. Tofel-Grehl, thank you all for your guidance and collaboration on the research projects we have worked together. I want to thank my friends for always standing by me during my tough times and good times. I would not have achieved so much without your help and encouragement. I will always cherish the time we spent together at Utah State University.

Last, but certainly not least, I want to dedicate this dissertation to my family. Thank you for encouraging me in all of my pursuits and inspiring me to follow my dreams. Your unconditional love was worth more than I can express on paper.

Jiangyue Gu

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Problem Statement

In a recently released framework of K-12 science education, the National Research Council (NRC) emphasized that all American high school graduates should not only have adequate knowledge and skills of science to enter the career of their choice, but also be capable of engaging in public discussion on social-scientific issues and continue to learn science outside of school (NRC, 2012). To achieve these goals, educators should move beyond a focus on content knowledge and process skill and toward a goal of helping students engage in scientific inquiry; this in turn may help students understand the nature of scientific knowledge and how scientists conduct scientific inquiry (NRC, 2007).

Challenges in Developing Sophisticated Understanding of Science

Since the 1990s, engaging students in scientific inquiry has been advocated in K-12 science education to promote both students' ability to engage in scientific inquiry and their understandings of the nature of science (NRC, 1996). However, research has consistently shown that simply engaging in scientific inquiry is not sufficient to support K-12 students' development of sophisticated understanding of the nature of science (Khishfe & Abd-El-Khalick, 2002; Sandoval & Reiser, 2004). This may be due to two factors. First, inquiry tasks commonly used in school incorporate an oversimplified, algorithmic form of scientific reasoning, which does not reflect the epistemic aspect of authentic scientific inquiry. Such tasks may lead students to hold suboptimal epistemological understanding: namely, that science inquiry is simple, certain, and can be conducted by following prescribed stepwise methods (Chinn & Malhotra, 2002; Khishfe & Abd-El-Khalick, 2002). Second, it is not clear if and how students' epistemological understandings of science and their inquiry activity relate (Greene, Azevedo, & Torney-Purta, 2008; Hofer, 2006). As a result, it has remained unclear that how to support students' development of sophisticated understanding of science during scientific inquiry.

Possible Solution

Over the past few decades, a line of research on individuals' epistemic beliefs—beliefs about the nature of knowledge, how knowledge is constructed, and how knowledge can be justified (Hofer & Pintrich, 1997; Muis, Bendixen, & Haerle, 2006)–has been pursued by psychologists and educators. Research on epistemic beliefs in the context of science education can help educators examine how students understand the nature of science and how they construct scientific knowledge. Hence, to help students learn the nature of science, research on epistemic beliefs should be integrated with research on scientific inquiry to better understand students' beliefs regarding scientific inquiry (Sandoval, 2005; Wu & Wu, 2010). Another reason for the push to integrate research on scientific inquiry with that on epistemic beliefs is a perceived need to better assess students' epistemic beliefs in the context of scientific inquiry. The traditional approach to assessing individuals' epistemic beliefs mostly relies on self-report measures and has been criticized for its decontextualized manner (Louca, Elby, Hammer, & Kagey,

2004) and poor validity (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008). To better measure epistemic beliefs, the assessment should be situated in a specific context to investigate both practice and expressed beliefs because students can hold general beliefs about science but their beliefs will be framed by specific scientific practice (Hammer, Elby, Hofer, & Pintrich, 2002; Hofer, 2006).

As one inquiry-based instructional approach, problem-based learning (PBL) provides opportunities for students to engage in scientific inquiry by investigating scientific problems and providing solutions (Belland, 2009). In PBL, students often work in small groups to provide problem solutions to authentic, ill-structured problems; in this way, students can engage in scientific inquiry in the manner of real scientists and be responsible for their learning (Hmelo-Silver, 2004). Engaging students in PBL could be one way for researchers to examine students' epistemic beliefs in the context of scientific inquiry. By doing so, researchers can better understand how students' epistemic beliefs and their scientific inquiry practice interrelate and how to better support students' development of epistemological understanding of science.

The Present Study

In the recent literature, few studies assess middle and high school students' epistemic beliefs based on their performance during scientific inquiry. Several researchers (Barzilai & Zohar, 2012; Mason, Boldrin, & Ariasi, 2009) have started to examine middle school students' epistemic beliefs based on how they search for, evaluate, and integrate information during online inquiry tasks. Yet, the duration of these studies is fairly short (e.g., one class period) to capture if there is any change of students' epistemic beliefs (Ferguson & Bråten, 2013; Knight & Mattick, 2006). As a result, in the current literature, it is not clear how and why students' epistemic beliefs change over time. In short, it remains unclear (a) what epistemic beliefs middle and high school students hold during scientific inquiry, (b) how students' epistemic beliefs and their scientific inquiry practices relate, and (c) whether and how their epistemic beliefs change during scientific inquiry. To fill the gap in the literature, this study aimed to examine middle and high school students' epistemic beliefs in the context of PBL to explore how their epistemic beliefs relate with their practice and how their epistemic beliefs change over time.

CHAPTER II

LITERATURE REVIEW

Terminology of Epistemic Beliefs

Epistemology is a branch of philosophy that addresses questions about the nature of human knowledge and justification of knowing (Muis et al., 2006). In the field of educational research, researchers are concerned about epistemology at the individual level—the theories and beliefs individuals hold about how one comes to know, how knowledge can be justified, and how these theories and beliefs influence individuals' cognitive processes (Hofer & Pintrich, 1997). Unfortunately, this research area lacks a unified terminology of the central constructs (Greene et al., 2008; Hofer, 2004a) as researchers employ diverse terms (e.g., *epistemic beliefs*, *epistemological beliefs*, *personal epistemology* and *epistemic cognition*) when they refer to the beliefs people hold regarding the nature of knowledge and knowing. As Kitchener (2002, p. 92) pointed out, etymologically, "epistemology is the theory (logos) of knowledge (episteme), the theory of the epistemic." Hence, *epistemic beliefs* refer to individuals' beliefs about knowledge and knowing whereas *epistemological beliefs* or *personal epistemology* refers to "beliefs about *the study* of knowledge and knowing" (Greene et al., 2008, p. 143), or "beliefs about *the field* of epistemology" (Murphy, Edwards, Buehl, & Zeruth, 2007, p. 4). Therefore, the term *epistemic beliefs* reflects the students' beliefs about knowledge and knowing (Murphy et al., 2007). In my dissertation, I chose to use the term *epistemic beliefs* to refer to beliefs and theories individuals hold about the nature of knowledge and knowing. When referring to other research, I kept the terms (e.g., epistemological beliefs, personal epistemology) the researchers chose in their studies.

Theoretical Frameworks of Epistemic Beliefs

Developmental Approach

Jean Piaget used the term genetic epistemology in his theory of cognitive development, which generated interest in epistemology among developmental psychologists (Buehl & Alexander, 2001; Hofer & Pintrich, 1997). Influenced by this line of research, the work of Perry (1968, 1970) among undergraduate students established the foundation of the field of personal epistemology. On the basis of in-depth interviews of male college students, Perry (1970) developed a scheme of students' intellectual development that included four classifications of students' perspectives of knowledge and learning: dualism, multiplicity, relativism, and commitment. As students transition from one perspective to another, they shift from a perspective that knowledge consists of simple, certain facts to one that holds that knowledge is a complex, tentative, entity that is derived from reasoning and empirical inquiry.

Influenced by Perry (1970), most researchers at that time believed that individuals' epistemic beliefs develop through a stage-like, developmental sequence (Baxter Magolda, 1992; Hofer & Pintrich, 1997) explored gender influence on epistemological beliefs; whereas, King and Kitchener (1994) assessed the effect of epistemic beliefs on thinking and reasoning. As such, a developmental perspective of personal epistemology has been formed as it views how students' epistemic positions develop through the course of life within certain trajectories (e.g., King & Kitchener, 2004; Kuhn, Cheney, & Weinstock, 2000). The developmental approach asserted that personal epistemic beliefs develop from a naïve position to a more sophisticated position through a few stages with qualitative differences (Greene et al., 2008). Among the developmental models (e.g., Baxter Magolda, 2004; Kuhn, 1991; Perry, 1970) of epistemic beliefs, different levels in each model can be commonly labeled along three levels: (1) absolutism/objectivism, (2) multiplism/subjectivism, and (3) evaluativism/ objectivism-subjectivism (Greene et al., 2008). The first level of epistemological beliefs is "absolutism/objectivism" in which individuals hold an absolutist view of knowledge—that knowledge is either right or wrong and can be known with certainty. The second level of epistemological beliefs is "multiplism/subjectivism" in which individuals believe knowledge consists of subjective, uncertain opinions which can be equally right (Buehl & Alexander, 2001). The last level of epistemological beliefs is "relativism/evaluativism," according to which knowledge is evolving and needs to be critically judged based on criteria such as critical thinking and evidence (Kuhn et al., 2000).

Multidimensional Approach

Since the late 1980s, a few researchers started to conceptualize students' epistemic beliefs as multidimensional as they believed individuals' epistemic beliefs systems are too complex to be undimensional. Based on the conflicting results from the research of Perry's framework, Schommer (1990) first proposed that epistemic beliefs consist of independent dimensions. Initially, she posited five dimensions of epistemic beliefs: the structure, certainty, and source of knowledge, and the control and speed of knowledge acquisition (Schommer, 1990). As these dimensions are relatively independent of one another, individuals' epistemic beliefs can develop at different rates in each dimension (Schommer-Aikins, 2004). Another contribution of Schommer's works was that she developed a questionnaire with 63 items and initiated a more quantitative approach to investigate and verify the proposed dimensions. Although in a few empirical studies the first four dimensions appeared to be confirmed based on the results of factor analysis (e.g., Schommer, 1993a), the Schommer's (1990) epistemological beliefs questionnaire has been criticized for having several methodological problems such as loadings, internal reliability, and the use of factor coefficients (Buehl & Alexander, 2001; DeBacker et al., 2008)

In a detailed review of epistemological theories, Hofer and Pintrich (1997) questioned Schommer's (1990, 1993a) conceptualization of epistemological beliefs as they believed the control and speed of knowledge acquisition are factors of students' beliefs about intelligence rather the nature of knowledge and learning. By reviewing various models and definitions of epistemic beliefs, Hofer and Pintrich stated that the construct of epistemic beliefs only consists of individuals' beliefs about the *nature of knowledge* and the *nature or processes of knowing*. Under the category *nature of knowledge*, Hofer and Pintrich identified two dimensions: (1) *the certainty of knowledge* (ranging from knowledge is absolute truth to knowledge is tentative and evolving); and (2) *the simplicity of knowledge* (ranging from knowledge exists as discrete facts to knowledge is highly interrelated concepts. There are two dimensions under *nature of knowing*: (1) *the source of knowledge* (ranging from external authority to knowledge is constructed with interaction; and (2) *the justification for knowing* (ranging from relying on observation, expertise and authority, to applying rules of inquiry and personal evaluation and integration of expert's view (Hofer, 2000).

Integrated Approach

In an integrated model of both developmental approach and multidimensional approach, Greene et al. (2008) proposed to use three dimensions to categorize the positions of individuals' epistemic beliefs in a development trajectory in both ill-structured and well-structured domains. Compared with the multidimensional approach, the first dimension—*simple and certain knowledge*—consists of two dimensions (*certainty of knowledge* and *simplicity of knowledge*) in Hofer (2000)'s model because factor analysis showed that these two dimensions merged together (Hofer, 2000). The other two dimensions—justification by authority and personal justification - can be considered two positions in the dimension of *justification of knowing* in Hofer's model. Hence, Greene et al.'s model included two constructs that are very similar to Hofer's model: *simple and certain knowledge* and *justification of knowing*. Based on the position of students' epistemic beliefs in each dimension, students' epistemic beliefs can be categorized into four types. For example, according to Greene and colleagues' model, middle and high school students are expected to exhibit dogmatism or skepticism positions in ill-structured domains and realism positions in well-structured domains. Realists believe that knowledge is certain and simple, justification can rely on authority or one's own experience, but there should be no disagreement regarding knowledge. Dogmatists and skeptics both agree that knowledge is not simple and certain, as one might see in a direct "copy" of reality. Dogmatists rely on justification from authority, whereas skeptics rely on personal experience (Greene et al., 2008). In the integrated model, rationalists believe that knowledge is tentative and evolving, and justification should be based on the evidence from both experience and reasoning (Greene et al., 2008). That is, their justifications do not rely on either authority or personal experience alone.

Hofer's multidimensional model and Greene and colleagues' integrated model both conceptualized epistemic beliefs through two independent dimensions—*certainty/ simplicity of knowledge* and *justification of knowing* that emphasize whether individuals believe knowledge is certain and objective and whether justification of knowing rely on external authority or personal evaluation. Although the developmental models suggest that individuals' epistemic beliefs develop in an integrative fashion, individuals' epistemic beliefs can be categorized into three levels from their positions on two dimensions: *objectivity/subjectivity of knowledge* (whether knowledge is certain and objective or uncertain and subjective), *justification of knowledge* (whether knowledge can be evaluated by argument and evidence). The dimension *objectivity/subjectivity* of knowledge is similar to the dimension *certainty/simplicity* of knowledge in the multidimensional model and integrated model, as absolutists view knowledge as objective entity with certain whereas multiplists and evaluativists both are aware of the uncertain, subjective nature of knowing (Kuhn et al., 2000). The dimension *justification of knowledge* is related to *justification of knowing* as the former involves whether knowledge can be justified, and the latter is about how knowledge is justified.

Epistemic Beliefs in K-12 Science Education

In the past few decades, there has been a growing interest in scientific inquiry in K-12 science education in the United States. Recently, engaging students in scientific practices, along with engineering practices, are still explicitly highlighted as one of the major foci of K-12 science education (NRC, 2012). Students who are proficient in science should “(1) know, use, and interpret scientific explanations of the natural world, (2) generate and evaluate scientific evidence and explanations, (3) understand the nature and development of scientific knowledge, and (4) participate productively in scientific practices and discourse” (NRC, 2007, p.2). These strands of proficiency represent a shift of learning goals from content knowledge and process skills to understandings of the nature of science and the ability to engage in scientific inquiry.

As some researchers pointed out, simply engaging in scientific inquiry is not sufficient to help students develop understanding of the nature of science (Khishfe & Abd-El-Khalick, 2002). Indeed, many school inquiry practices do not reflect the epistemic aspect of authentic science practices (Capps & Crawford, 2012; Chinn & Malhotra, 2002). By engaging in these over-simplified forms of inquiry, students begin to think of science as the accumulation of simple facts rather than the construction and revision of models and theories about the world (Sandoval, 2005). Thereby, educators need to emphasize the epistemic aspect of scientific inquiry to help students to understand and better conduct inquiry as it represents the processes scientists ask questions, collect and interpret data, draw conclusions, construct and validate knowledge.

Influence of Epistemic Beliefs in K-12 Education

Academic Performance

Sophisticated epistemic beliefs can positively influence students' learning strategies and outcomes (Kienhuesl, Bromme, & Stahl, 2008). In a study of Schommer (1993b), among 400 high school students, she found that all four epistemological factors in her epistemology beliefs questionnaire (fixed ability, simple knowledge, quick learning, and certain knowledge) were significant predictors of students' GPAs. By regressing GPAs on these four factors, it showed that the more that students believed in quick learning, simple knowledge, certain knowledge, and fixed ability, the lower GPAs they earned (Schommer, 1993b, p. 409). By using a Spanish version of Schommer's Epistemological Beliefs Questionnaire in a large sample, Cano's (2005) study partially supported Schommer's findings as three factors in Schommer's model showed significant impacts on academic performance among middle and high school students in Spain.

Argumentative Reasoning

From a developmental perspective, several researchers started to examine in the influence of epistemic beliefs on students' argumentation ability in everyday reasoning tasks. According to a developmental model of epistemological understanding (Kuhn, 1991), individuals who hold an evaluativist view balance objective and subjective views of knowledge by acknowledging that knowledge is continually constructed and uncertain, but it can be critically evaluated based on criteria such as critical thinking and evidence. As a result, evaluativists in various age groups were more likely than others to have higher argumentative reasoning skills such as the use of counterargument and alternative theory generation (Kuhn, 1991) and evaluativists in eighth grade produced higher quality arguments, counterarguments, and rebuttals (Mason & Scirica, 2006).

Online Learning Strategies

As using online information becomes more and more important in the 21st century, several researchers became interested in the role of epistemic beliefs in the process of internet-based learning. The studies indicated that middle school students' epistemic beliefs influence the processes and strategies they use during internet-based learning. Evaluativist middle school students significantly outperformed absolutists on their strategies to integrate online information and be aware of potential bias of information sources (Barzilai & Zohar, 2012). Middle school students can also express reflections about the nature of knowledge and the knowing on the four factors of epistemic beliefs proposed by Hofer and Pintrich (1997) during their learning processes, which in turn may influence their online learning processes. As a result, the more middle school students believed that scientific knowledge is tentative and evolving, and can be justified by evidence, the more likely they evaluated knowledge as subject to change due to future research, and justified information by comparing information from multiple sources and scientific evidence (Mason et al., 2009).

Cognitive and Metacognitive Processes

From a cognitive psychology perspective, some researchers argued that students' epistemic beliefs about knowledge and knowing play an important role among various cognitive and metacognitive processes during learning. Muis (2007) proposed an integrated theoretical model to incorporate epistemic beliefs within a self-regulated (SRL) learning framework in which epistemic beliefs influence each phase of SRL. For example, students who believe that knowledge is complex and highly interrelated may set higher learning standards such as comprehension, elaboration, and critically integration of information which in turn, may lead to higher performance (Greene, Muis, & Pieschl, 2010). While achieving these higher learning standards, students' advanced epistemic beliefs affect their critical interpretation of scientific knowledge and facilitate their cognitive processes of recognizing, comparing, reasoning and judging two competing views of certain scientific knowledge (Mason & Boscolo, 2004). Students' epistemic beliefs also influence their conceptual understanding of scientific knowledge. For example, high school students who hold immature beliefs about knowledge and knowing were less likely to achieve conceptual change during the learning process of scientific knowledge (Qian & Alvermann, 1995). In sum, as students' epistemic beliefs affect various aspects of learning, educators need to help students develop optimal epistemological beliefs. This in turn may help students succeed in scientific inquiry and other aspects of learning.

Assessment of Epistemic Beliefs

Issues of the Current Assessment Approach

Although psychologists and educators have been making efforts to examine individuals' epistemic beliefs, in the recent literature several challenges regarding the assessment of epistemic beliefs have emerged (Muis et al., 2006). First, because Schommer (1990) initiated a quantitative approach to assess individuals' epistemic, most studies of epistemic beliefs relied mostly on self-report measures. However, recent research indicated that some of the epistemic beliefs assessments have low internal consistency and poor factor structure (DeBacker et al., 2008; Greene et al., 2008). For instance, a few dimensions (e.g., beliefs about quick learning and fixed ability of learning) in some multidimensional self-report measure were not epistemic in nature, which fundamentally rest the measures on a poor factor structure (Hofer & Pintrich, 1997). In addition, validity of epistemic self-report instruments may be threatened due to students' differential interpretation of the meaning of items in the self-report measures (Muis et al., 2012). Second, in the literature, there is a growing consensus that epistemic beliefs are not entirely domain general, rather, epistemic beliefs are different at domain-general, domain-specific, or context-specific levels (Buehl, Alexander, & Murphy, 2002; Hofer, 2006; Muis et al., 2006). Hence, it is challenging to use self-report instruments in a decontextualized manner to measure epistemic beliefs at multiple levels of specificity. When students engage in scientific inquiry, contextual factors of a specific setting may influence and shape epistemic beliefs differently (Hofer, 2006). In that sense, measuring students' epistemic beliefs in a decontextualized questionnaire is insufficient to examine how and why their beliefs are affected by a specific context (Gill, Ashton, & Algina, 2004, Gottlieb & Institute, 2007; Hammer et al., 2002). Therefore, other measures based on observational data or trace data may be more accurate to assess students' epistemic beliefs that may be salient to self-report measures (Greene et al., 2010).

Although there are several methodological drawbacks of using self-report measure in research on epistemic beliefs, self-report measures still have a few merits. First, the convenience and low cost of the self-report measures made it more efficient to study epistemic beliefs in a large scale. Second, self-report measures may present epistemic beliefs in a more salient way to students as such beliefs maybe difficult to articulate in action (Strømsø & Bråten, 2010). Third, in spite of the lack of accuracy when self-report measures are used to study students' complex epistemic beliefs in action, self-report measures they may still provide an estimate of the tendency of students' learning activities (Muis, Winne, & Jamieson-Noel, 2007). Given these considerations, it is still worthwhile to use self-report measures in research on epistemic beliefs and more researchers call for a mixed-method approach to assess epistemic beliefs at different levels of specificity in future work (Bråten, Strømsø, & Samuelstuen, 2008; Greene et al., 2010). Coupled with self-report data, the use of observational data or trace data provides researchers a more comprehensive way to study epistemic beliefs by which to triangulate results (Winne, Jamieson-Noel, & Muis, 2002).

Another issue of the current assessment of epistemic beliefs is that few recent studies focus on the epistemic beliefs of middle and high school students; to the contrary, most studies used adults as participants. Therefore, it remains unclear that what epistemic beliefs adolescents hold about science and how their epistemic beliefs influence their scientific inquiry practices. Although the metacognitive ability that is necessary for students to evaluate and justify knowledge based on evidence may develop after early adolescence (Hofer & Pintrich, 1997), middle school students can hold advanced epistemic beliefs (Kuhn et al., 2000; Mason & Scirica, 2006). High school students are able to make epistemic judgments and metacognitively monitor their learning processes (Hofer, 2004b). As a result, high school students with higher levels of epistemic beliefs are more likely to critically compare and evaluate online information obtained from various sources (Mason & Boldrin, 2008). Hence, assessing middle and high school students' epistemic beliefs is critical to understand how their epistemic beliefs influence their learning processes. Last, as several empirical studies indicated, epistemic beliefs are domain-specific (Buehl et al., 2002) or at least both domain general and domain-specific (Muis et al., 2006). Students' epistemic beliefs can differ according to domain (e.g., mathematics and psychology). Indeed, as epistemic beliefs can be influenced by contextual factors (Hofer, 2006), to understand how epistemic beliefs influence students' learning processes, epistemic beliefs should be studied within a context (Elby & Hammer, 2001; Louca et al., 2004). As researchers are interested in students' epistemic beliefs in science and how their beliefs impact the way they learn science, students' epistemic beliefs should be examined during scientific inquiry practices. The duration of most current studies examining students' epistemic beliefs based on their performance during scientific inquiry is fairly short (e.g., one class period). As a result, it is not clear how and why students' epistemic beliefs change over time (Ferguson & Bråten, 2013).

New Directions of the Assessment

A variety of approaches have been utilized to assess metacognition including questionnaires, inventories, interviews, self-report measures, and think-aloud methodology, may also be adopted in studies of epistemic beliefs (Hofer, 2004b; Muis, Kendeou, & Franco, 2011). Think-aloud methodology is based on the premise that verbal behavior can be observed and analyzed because “the cognitive processes that generate verbalizations are subset of the cognitive process that generates any kind of recordable response or behavior” (Ericsson & Simon, 1984, p. 9). Because students’ epistemic beliefs are activated and situated within contexts that influence the process of knowledge construction, using the think-aloud approach allows researchers to better examine metacognitive aspects of students’ epistemic beliefs (Hofer, 2004a). Hofer first applied the think-aloud method in a series of studies in which high school and college students were asked to write a research paper that summarized information about a scientific topic. The think-aloud method was also utilized to examine students’ epistemic beliefs during their practice of online searching (Mason & Boldrin, 2008). Other approaches such as retrospective interviews can also be used to examine students’ epistemic reflections to investigate how their epistemic beliefs influence their learning processes (Mason & Boldrin, 2008). To address the issues in current assessment of students’ epistemic beliefs of science, researchers should use multiple methodologies and measures to examine students’ epistemic beliefs within context. In short, a mixed methods approach may be necessary to fully examine individuals’ epistemic beliefs (Greene et al., 2008).

Epistemic Beliefs and Problem-Based Learning

As discussed earlier, to better understand students’ epistemic beliefs of science, assessment of epistemic beliefs should be situated in the context of scientific inquiry. As one inquiry-based instructional approach, PBL could provide a context to engage students in scientific inquiry. In PBL, students often work in small collaborative groups to solve ill-structured, open-ended problems (Gijbels, Dochy, Bossche, & Segers, 2005). Because ill-structured problems have no single right or wrong answers (Jonassen, 1997), students can try out different solution paths to solve the problem. Also, as the problems are situated in the real world or are similar to real-world problems, students can engage in scientific inquiry in the manner of real scientists and feel more responsible for their learning (Hmelo-Silver, 2004). Because epistemic beliefs are crucial to solving ill-structured problems (Kitchner, 1983), having students engage in authentic, ill-structured problem solving provides a great opportunity for researchers to examine students' epistemic beliefs.

Compared to direct instruction, in PBL, learning is more student-centered and less teacher-directed: students need to represent the problem, identify what they need to know, acquire relevant information, apply relevant information to create possible solutions to solve problems (Barrows, 1996). To justify their problem solutions, students also need to provide evidence and a corresponding rationale to support their problem solutions (Belland, Glazewski, & Richardson, 2010). To create an effective evidence-based argument in a PBL unit, there are several critical steps: represent the problem, analyze the audience, develop claim, search for and evaluate evidence, and link evidence to the claim (Belland, Glazewski, & Richardson, 2008). As discussed earlier, students' epistemic beliefs influence their motivation (Ricco, Schuyten Pierce, & Medinilla, 2009), self-regulated learning (Greene et al., 2010; Muis, 2007), and online learning strategies (Barzilai & Zohar, 2012), all of which are critical to problem solving. Therefore, by investigating the processes of problem solving (such as search for evidence, justify problem solutions), researchers can better understand students' epistemic beliefs (such as how they acquire knowledge, and how they justify scientific knowledge).

Conclusion

This literature review examined the current state of the conceptualization of epistemic beliefs and the research of students' epistemic beliefs in K-12 education, and provided directions for future research in this area. Examining students' epistemic beliefs in a decontextualized way is not sufficient to understand the social and contextual aspect of students' epistemic beliefs. Correlations between students' epistemic beliefs and academic performance and other aspects of learning still fail to explain how and why students' epistemic beliefs influence their learning and practice in scientific inquiry. As research on epistemic beliefs progresses, students' epistemic beliefs need to be examined in the context of scientific inquiry to investigate the complex nature of epistemic beliefs and how epistemic beliefs and scientific inquiry practices interrelate.

Research Objectives

This study aims to examine middle and high school students' epistemic beliefs during a problem based, scientific inquiry unit. Specifically, I explored in what way students' epistemic beliefs influence their problem solving processes, and how and why their epistemic beliefs change during the PBL unit. In this study, I employed a mixed methods research design (Johnson & Onwuegbuzie, 2004) to investigate middle and high school students' self-reported epistemic beliefs and their epistemic beliefs revealed during PBL. By doing so, researchers can better understand students' epistemic beliefs in the context of scientific inquiry, and how students' epistemic beliefs and their scientific inquiry practice interrelate.

Objectives

The first research objective of this study is to explore middle and high school students' epistemic beliefs. Most existing epistemic beliefs assessments were designed to be used among adults, which leaves few instruments available to assess adolescents' epistemic beliefs (Greene et al., 2008). Recent research suggests that assessing students' epistemic beliefs should not rely solely on self-report measures (Greene et al., 2008; Muis et al., 2006), and the assessment of students' epistemic beliefs should be situated in a specific context (Hammer et al., 2002; Hofer, 2004a). Researchers should investigate both students' expressed, articulated beliefs, and beliefs shown during practices (Hofer, 2006; Sandoval, 2005). Hence, in this study I adopted a mixed methods approach to assess both students' expressed beliefs (quantitative) and beliefs revealed from practice (qualitative) during a problem-based, scientific inquiry unit. By employing a mixed methods approach, I sought triangulation of the results from different data sources to examine different facets of middle and high school students' epistemic beliefs.

Students' epistemic beliefs can play an important role in self-regulated learning (Greene et al., 2010), evaluating and integrating online resources (Barzilai & Zohar, 2012), and text comprehension (Bråten, Britt, Strømsø, & Rouet, 2011). Therefore, the second research objective of this study is to explore how do middle and high school students' epistemic beliefs contribute to the construction of students' problem solving processes during PBL.

The basic assumption of the development of epistemic beliefs is that individuals' epistemic beliefs develop from a "naïve" level to a more sophisticated level (Kuhn et al., 2000). However, most developmental models of epistemic beliefs focus on examining the developmental trajectory of individuals' epistemic beliefs over a fairly long period of time, which does not provide specific information about how epistemic beliefs change. Hence, the last objective of this study is to examine whether engaging in scientific inquiry in a PBL unit will promote the development of more sophisticated epistemic beliefs among middle and high school students.

Research Questions

The research questions for this study were as follows.

1. a) What are middle and high school students' self-reported epistemic beliefs about science?

   b) What epistemic beliefs are revealed from scientific inquiry practice in a PBL unit?

2. How do middle and high school students' epistemic beliefs contribute to the construction of their problem solving processes?

3. a) Do middle and high school students' epistemic beliefs change during a PBL unit?

   b) If so, how and why do these changes occur?

CHAPTER III

METHODS

Setting and Participants

Setting

This study was conducted in conjunction with a summer science program offered by Mountain High School (note: all names have been changed) in June 2014. Mountain High School is a public school located in the Intermountain West region of the U.S. In the 2013-2014 school year, Mountain High School had 72 teachers and 1,707 students enrolled in grades 9-12. Though Mountain High School was not eligible for Title I funding, 72% of the students qualified for free and reduced lunch program. The school reported 68% of students to be Caucasian, 24% to be Hispanic, 4% to be Asian/ Pacific Islander, and 3% to be of other ethnic backgrounds.

Context. The summer science program offered by Mountain High School was designed to engage students in science learning in and out of the classroom in a 2-week period. The program started at 9 AM and ended at 5 PM each day. In part because Mountain High School was situated at the foothills of a mountain range and at the border of a national forest, the science program adopted an exploratory approach in which students learn science by exploring the nearby outdoor natural environment. In prior years, class activities included identifying bird and tree species, examining local river water quality, and collecting specimens (e.g., fossils) through field trips and lab experiences. Although the summer program was not free (the registration fee was $30 per student), it had sponsors to cover most of the cost and provided free lunch for each student during the 2-week period. Two teachers, Mr. Scott and Mr. Davis, worked 8 years together to facilitate and teach this science program. Neither had experience facilitating PBL units. Mr. Scott, who had 20 years' experience of teaching high school science, took leadership in developing the curriculum and facilitating the program. Mr. Davis had 30 years' experience teaching high school science. Mr. Davis was less involved in developing the instructional approach and providing instructional support to students than Mr. Scott. Mr. Davis conducted much of the "logistics work" such as ordering lunch, arranging school buses, and gathering supplies.

Rationale for selection of setting. The focus of this study was to explore middle and high school students' epistemic beliefs during scientific inquiry. The summer class program provided an excellent context for this study for three reasons. First, the summer class program enabled students to conduct scientific inquiry in real-world settings. Students engaged in science learning in potentially authentic contexts that are relevant to their daily lives. Second, teacher-led instruction was minimal as students often worked in small groups to conduct observations, ask questions to stakeholders, and take notes during field trips, which is aligned with PBL approach that often requires self-regulated learning (Hmelo-Silver, Duncan, & Chinn, 2007; Jonassen, 2011). Third, Mr. Scott mentioned that he wanted to integrate creating evidence-based arguments into the program as it is an essential skill for students. He liked the idea of giving students a central question to answer through a PBL unit and planned to implement it in future. Therefore, the design of the PBL unit fit the teacher's need to improve the summer program.

Sampling strategy. This study employed a mixed methods design in which sampling strategy needed to be considered regarding both qualitative and quantitative approaches. From the perspective of the quantitative method, to ensure the sample size was large enough to assess if there was any impact of PBL on students' epistemic beliefs, a priori power analysis was conducted. In a previous study, the effect size of the impact of PBL on average-achieving and higher-achieving seventh-grade students' epistemic beliefs was 0.57 (Belland, Gu, Kim, Turner, & Weiss, 2015). Based on the effect size, alpha level (.05) and power (.80), the minimum sample size was determined to be 22 using g*Power (Faul, Erdfelder, Lang, & Buchner, 2007). As the teacher estimated that there would be approximately 18-25 students in this program based on his past years' experience, I recruited all students registered in this summer program to participate in this study. For qualitative analysis, I used purposeful sampling, which is a widely used technique in qualitative research to identify and select information-rich cases for in-depth analysis most effectively (Patton, 2002). Specifically, among all the purposeful sampling strategies, I chose opportunistic or emergent strategies to take advantage of events and opportunities for additional data collection, which is commonly used in conducting ethnographic fieldwork (Palinkas et al., 2013). Because the students in this study spent most of their time outdoors, I purposefully selected three groups of students who could potentially provide rich information during their fieldtrips as the case study groups. The students in these case study groups often stayed together during the field trips, which in turn provided more conversation and interactions to analyze. In addition, because the objective of the qualitative analysis was to explore emergent themes of students' epistemic beliefs in practices rather than to make generalization, focusing on three out of six of groups of students was sufficient for qualitative analysis purposes.

Participants

As the summer science program was meant to recruit middle and high school students in the local area, participants included students from various schools and grades. There was no specific requirement for students to register. Mr. Scott mentioned that students often register for this summer program because they want (or their parents want them) to do "something outdoor" during summer, so the participants were not necessarily higher-achieving students in science. Twenty-four students registered for the program and signed the assent portion to participate in this study, and their parents signed the consent forms. Three students dropped out of the summer program 3 days before it ended and did not complete the posttest. During the preceding regular school year, each of the 24 participants was enrolled in a local middle school or high school at the 7-11th grade level. Eleven students came from Mountain High School, while the remaining students came from six different middle and high schools. Participants included 11 female students and 13 male students. Four students were Hispanic, two were African American, and the rest were Caucasian. Some participants already knew each other well as they came from the same school or they were friends or relatives (there were three pairs of students who were cousins). Therefore, based on Mr. Scott's anticipation of how well they can work together or know each other, he assigned the students into six groups (3-4 students per group) to work together during the unit. Because 21 students completed the unit, the sample size was smaller than the proposed sample size of 22. I conducted a sensitivity analysis to make sure the power statistics are relatively the same. Based on the effect size of 0.23, alpha level of 0.05, and power of 0.8, the critical value of *Z* statistic is the same as the results based on the sample size of 22. Hence, a sample size of 21 still ensured enough power for data analysis.

Research Design

This study adopted a mixed methods research design (Johnson & Onwuegbuzie, 2004) (see details in Table 1).

The first research question (RQ 1) was: (a) what are middle and high school students' self-reported epistemic beliefs about science, and (b) what epistemic beliefs are revealed from scientific inquiry practice in a PBL unit. That means the research objective is to examine both students' expressed beliefs (quantitative) and beliefs revealed from practice (qualitative) during a problem-based, scientific inquiry unit. Therefore, I

Table 1

Research Design

Research questions	Research design	Research objectives	Methods
RQ1	Sequential mixed methods design (QUAN→QUAL)	Self-reported epistemic beliefs	Quantitative
		Epistemic beliefs revealed from practice	Qualitative
RQ2	Qualitative design	How do epistemic beliefs contribute to the construction of problem solving	Qualitative
RQ3	Sequential mixed methods design (quan→ QUAL)	Do students' epistemic beliefs change	Quantitative
		How and why do epistemic beliefs change	Qualitative

employed a sequential mixed methods design with an equal emphasis on qualitative and quantitative approaches (QUAN → QUAL; Johnson & Onwuegbuzie, 2004) to address RQ 1. Students' self-reported epistemic beliefs were assessed before the PBL unit. Qualitative data were collected through the PBL unit to identify epistemic beliefs revealed through students' actions during the PBL unit. In this way, I conducted both qualitative and quantitative data collection and analyses separately, and then compared the results to examine how these two types of epistemic beliefs related.

The second research question (RQ 2) addressed how middle and high school students' epistemic beliefs contribute to the construction of their problem solving processes. Suggested by the literature (e.g., Greene et al., 2010; Strømsø & Bråten, 2009), analyzing observational data with a qualitative approach may be more profitable to assess the dynamic process of how students acquire knowledge from different sources. Given this consideration, I employed a qualitative approach to address RQ2 by conducting a multiple case study (Yin, 2009) with three groups of students. Since the students worked as group during the unit, they naturally formed three case study groups. To conduct case study during the unit, I employed an ethnographic approach through participating, observing, and conducting in-depth interviews to investigate how the participants understood the nature of science and engage in problem solving during a PBL unit. Among several qualitative research traditions, the ethnographic approach is a way to capture a holistic picture that reveals how people describe and structure their world by participating and observing how it unfolds (Flick, 2007). In this case study to address RQ2, guided by an ethnographic approach, I was able to employ the method of participant observation to study students' actions and accounts in real life contexts for an extended period of time (Hammersley & Atkinson, 2010) to explore how their epistemic beliefs contribute to the construction of their problem solving processes.

The third research question (RQ 3) was: (a) do middle and high school students' epistemic beliefs change during a PBL unit, and (b) if so, how and why do these changes occur. Addressing RQ 3 required a quantitative approach to examine if there is any change of students' epistemic beliefs during the unit and a qualitative approach to explore the reasons behind the potentially changes. Hence, I employed a sequential mixed methods design that weighted the qualitative approach over quantitative approach (quan → QUAL) to answer RQ 3. The quantitative research phase followed a one-group pretest-posttest design (Creswell, 2003) to examine whether students' epistemic beliefs changed over time during the PBL unit. Students' self-reported epistemic beliefs were assessed before and after they engage in the PBL unit, and qualitative data were collected during the PBL unit. The results of quantitative analysis informed the qualitative data analysis to explain how and why students' epistemic beliefs change. Qualitative analysis informed me whether and how students' epistemic beliefs varied across different contexts during a PBL unit.

Unit

To develop the summer program curriculum, I met with Mr. Scott three times from March to May 2014. The summer program often focuses on one theme each year. I proposed water quality investigation as the theme of the program and Mr. Scott agreed on it as he often led students to conduct water quality tests during field trips in the past a few years. Mr. Scott said he wanted to assign a topic for students to build evidence-based arguments. As Mr. Scott said they often conduct water quality tests during the summer program in previous years, after several discussions Mr. Scott and I decided to make water quality be the theme of this year's science program. To incorporate PBL in this program, we decided to choose "*Is there a water quality problem in Green Valley*?" as the driving question for students to address. As the summer program focused on exploring the outdoor environment, students went on one or multiple field trips each day. Several field trips were designed for students to collect water quality data at several locations in the local watershed or interview various stakeholders (e.g., waste water treatment plant workers, water scientists) about local water quality. The remaining field trips often focused on one specific learning activity (e.g., invasive species control, collecting fossils, identifying trees species). Students worked in small groups (3-4 students) during the program. At the end of each day, students returned to the classroom to organize their notes and write in their science journals. At the end of the program students presented their findings about water quality as groups—*if there is water quality problem in Green Valley or not*. Their presentations were graded and the group that scored highest was designated as the winning team.

Data Collection

In this study, quantitative data collection included the completion of an epistemic beliefs pretest and posttest to assess students' self-reported epistemic beliefs. I collected three major types of qualitative data: (1) videotaped all the case study groups through the PBL unit, (2) collected students' science journals, (3) interviewed all the case study groups. See Table 2 for data collection and analyses procedures.

Quantitative Data

A questionnaire about early adolescents' epistemic beliefs in science—*Epistemological Beliefs Questionnaire* (Elder, 1999) was used to examine students' self-

Table 2

Data Collection Methods and Analysis Strategies

Research questions	Measurement/data Collection	Analyses
RQ1: What are middle and high school students' epistemic beliefs about science?	Pretest and posttest (Epistemological Beliefs Questionnaire, 20 minutes, all participants)	Descriptive analysis and Mann Whitney *U* test
	Video observations (through the unit, case study groups)	Coding and discourse analysis
RQ2: How do middle and high school students' epistemic beliefs contribute to the construction of their problem solving processes?	Video observations (through the PBL unit, case study groups)	Coding and discourse analysis
	Science journals (case study groups)	Coding and discourse analysis
	Post interview (case study groups)	Coding and discourse analysis
RQ3a: Do students' epistemic beliefs change?	Pretest and posttest (Epistemological Beliefs Questionnaire, 20 minutes each, all participants)	Wilcoxon signed-rank test
	Video observations (through the PBL unit, case study groups) Post interviews (case study groups) Science journals (case study groups)	Coding and discourse analysis
RQ3b: How and why do these changes occur?	Video observations (through the PBL unit, case study groups) Post interviews (case study groups)	Coding and discourse analysis

reported epistemic beliefs before and after the PBL unit with permission (see Appendix A). The questionnaire was designed to examine students' epistemic beliefs from four dimensions: (1) *Certainty*—whether knowledge is certain, (2) *Developing*—whether knowledge is changing and evolving, (3) *Authority*—whether knowledge comes from authority, and (4) *Reason*—whether justification of knowing comes from reasoning and logical reasoning. These four dimensions were consistent with the four dimensions in the multidimensional framework of epistemic belief that discussed before. The original questionnaire has 33 items (e.g., "all questions in science have one right answer") on a 5-point Likert scale. In this study I am more interested in examining whether students agree or disagree with the statements in the questionnaire rather than identifying the nuance of their attitude between "agree" and "strongly agree," I collapsed the 5-point scale to a 3-point scale (1 = disagree; 2 = neutral; 3 = agree). A pilot study conducted among seventh-grade students with the 3-point scale indicated good reliability (Cronbach's alpha = 0.85).

Qualitative Data

Videotaped observations. The case study groups selected for qualitative analysis were videotaped throughout the PBL unit. As the students spent the most of the time outdoor during the PBL unit, I videotaped the segments from field trips when: (1) Mr. Scott addressed water quality related issues to students, (2) stakeholders or guest speaker addressed water quality issues to students, (3) students asked questions about water quality issues, and (4) students discussed water quality issues amongst themselves. During the in-class segment for students to analyze water quality data, for each case study group, I placed a camera facing all group members with an external microphone placed close to the students to record their utterances, facial expressions, body movements, etc. I participated in the entire PBL unit to observe students and provided help to them if necessary.

Students' presentations. At the end of the unit, all students made presentations as groups to present their findings about local water quality. All presentations were videotaped.

Semistructured post interviews. After the unit, I interviewed the case study groups separately. The interview questions focused on students' approaches to create arguments, acquire knowledge, judge and evaluate the quality of knowledge (e.g., "how did you find evidence to support your claims") and their opinions about science (e.g., "What methods do scientists use to do research"). See Appendix B for the complete interview protocol. Each interview lasted 20 minutes.

Science journals. All students were asked to write in a science journal every day to record what they learned and their reflections about the learning content. Although there was no length requirement of their journals, the teachers read through students' journals every day after class and gave different amounts of reward points to them based on the quality and length of their journals. At the end of the PBL unit, the student with the most reward points received a prize. After the PBL unit, I made a copy of all their science journals.

Procedures

On Day 1, most participants came in with their parents and their parents signed the consent form and students signed the assent after I explained the purpose of this study. For a few students whose parents did not come with them on Day 1, the teacher contacted their parents immediately for parental permission (Appendix E). All of them gave the permission for their children to participate in the study and signed the consent form and brought the form to me the following day. After all participants registered for the class, Mr. Scott began the class by introducing the schedule of the summer program and explaining this year's theme "Is there a water quality problem in Green Valley." Then I administered the pretest (epistemic beliefs questionnaire), which took 20 minutes. All participants completed and returned the pretest to me. Then Mr. Scott and I spent 2 hours to introduce the water quality topic to help students be familiar with: (1) concept of watersheds, (2) indicators of water quality, (3) local rivers and wetlands, (4) procedure of water quality tests, and (5) state water quality standards. In the afternoon of Day 1, Mr. Scott and I helped students conduct water quality tests in a local river that goes through Mountain High School campus to demonstrate water quality test procedures. For the rest of the afternoon, all participants went on a field trip to the city environmental department to visit the storm water management system and conducted a water quality test of storm water from drainpipe.

On Day 2, Mr. Scott, Mr. Davis, and I led students on three field trips. First, the students visited the city water tanks systems and interviewed two staff members about how the water tanks systems work and quality of local drinking water. Second, students went to the source of city drinking water—a local spring and conducted a water quality test of the spring water. Third, the students went to a local river recreation area to learn how to do electro-fishing. Meanwhile, students conducted water quality tests and interviewed a water scientist about local water quality.

On Day 3, Mr. Jones, another science teacher from Mountain High School, gave a lecture about the evolution and change of the regional geological environment and taught the students how to identify several types of fossils. In the afternoon, the students went on a field trip to the nearby mountain to collect fossils and conducted a water quality test of a creek in the mountain.

On Day 4 and Day 5, Mr. Scott took students to visit a local wildlife preservation ranch. The rangers and a few entomologists introduced a program to control invasive species that threaten the Intermountain region. They also explained how water quality could influence wild animals and plants to the students. During the field trip the students had a chance to conduct water quality tests of a creek in the ranch.

On Day 6, the students spent the entire morning canoeing in a nearby wetland area that is downstream of their local river. Mr. Scott introduced several plant, bird, and fish species that live in the wetland and invited students to conduct water quality tests. After the students returned to the classroom in the afternoon, Mr. Scott led a lecture unit to demonstrate how to create a data sheet to organize the water test data they collected, and explained how to interpret water quality data. Then I assigned one laptop to each student for them to create their data sheet and search for online information about water quality until the class ended.

On Day 7, students went on a field trip to the neighboring national forest. Mr. Scott taught the students how to identify tree and other plant species. As a preparation and exercise activity for the final presentation, Mr. Scott proposed a question "*Is the forest healthy or dying*" to all students and asked them to use evidence to support their answers. Students were divided into two groups based on their answers, and then started to collect evidence to support their claims. After half an hour, the students from each side debated with each other and presented their findings. Mr. Scott commented on the debate with an explanation of how to collect evidence and how to use evidence to support their claims. Then the students conducted a water quality test from a creek in the forest.

On Day 8, the students visited a biochemistry lab to learn about a transgene project. In the afternoon, students returned to the classroom to create and update their water quality data sheet and search for more information about water quality as groups until the class ended.

On Day 9, students went on four field trips to visit the city wastewater treatment plant, hog farms, chicken farms, and the city landfill. During these field trips, students had a chance to learn about how these different stakeholders use water and treat wastewater and interviewed them about local water quality.

On Day 10, Mr. Scott helped students plant trees along the local riverbank. After all the students returned to the classroom, I administered the posttest (epistemic beliefs questionnaire), which took students 20 minutes to complete. Except for the three students who dropped out of the summer program on Day 8, all students completed and returned the posttest to me. Then the students had one hour to prepare their final presentation. In the afternoon, students presented their findings by groups. Mr. Scott, Mr. Davis, and I graded each group's presentation separately and gave a total score for each group. I announced the group who got the highest score as the winning team. After the presentation, I interviewed the three case study groups separately.

Data Analyses

Mixed Methods Analyses

As the two mixed methods designs in this study both applied sequential mixed methods design, the data collection and analyses of both designs were presented as two distinct quantitative and qualitative phases (Creswell, 2003). The mixed methods analyses included two parts to address RQ1 and RQ3 separately. To address RQ1, by applying data triangulation, the themes emerged from qualitative analysis was compared with students' responses in their pretest and posttest to examine the similarity/difference between students' self-reported epistemic beliefs and their epistemic beliefs revealed from practice during scientific inquiry. To address RQ3, the quantitative analyses identified the change of students' self-reported epistemic beliefs. Then, the qualitative analysis verified whether these changes occur during the PBL unit and explored the possible reasons for these changes.

Quantitative Analyses

Quantitative analyses were conducted to address RQ1 and RQ3. To address RQ1 (What are middle and high school students' epistemic beliefs about science?), I first conducted descriptive data analysis. Items with a negative valence were reverse coded such that high scores represented sophisticated epistemic beliefs. Then, I calculated means and standard deviations, as well as the five-number summary of the students' self-reported epistemic beliefs scores in each dimension of their epistemic beliefs. The means of each dimension reflected students' epistemic beliefs in each dimension. Next, quantitative data were examined to see if they met the assumptions for the paired *t*-test statistical analyses (e.g., normality). The data set was not normally distributed and no outliers (defined as data that are three standard deviations above or below the mean were identified. To examine if there was any difference between students' subgroups, I chose to use Mann-Whitney *U* test as it is often used to examine independent samples with non-normally distributed data (Cohen, 2007). I chose to use Wilcoxon Signed Ranks Test to examine the change of students' epistemic beliefs scores from pretest to posttest because: (1) it is an equivalent non-parametric test to the paired *t* test when data do not meet the assumption of normality, and (2) the Likert scaling is often interpreted as ordinal rather than interval level data (Cohen, 2007).

Qualitative Analyses

Qualitative analyses in this study addressed the research questions 1-3: (1) What are middle and high school students' epistemic beliefs about science, (2) How do middle and high school students' epistemic beliefs revealed from practice influence their problem solving processes, and (3) Whether and how do middle and high school students' epistemic beliefs change during a PBL unit.

Methodology. I adopted the case study method to explore and describe how students conduct and understand scientific inquiry in the context of PBL. The case study methodology enables researchers to conduct a holistic, in-depth investigation of a bounded system or multiple bounded systems over time through detailed, in-depth data collection from multiple sources of information (Creswell, 2012; Feagin, Orum, & Sjoberg, 1991; Yin, 2009). In this study, students worked as small groups to conduct scientific inquiry and present their findings, which naturally formed several bounded systems—cases. As mentioned earlier, I purposefully selected three cases (three groups of students) that could potentially provide rich information as the case study group. Students' activities and interaction within these three small groups were collected and analyzed as separate cases. As such, I conducted a descriptive, multiple-case study (Yin, 2009) to describe cases and find any similar or contrasting themes among these cases within the holistic context of this study.

To conduct in-depth investigation of the cases in this multiple cases study specifically, I conducted discourse analysis to explore in what way middle and high school students understand and conduct scientific inquiry in a PBL unit. Discourse, according to Burr (2003), referred to "a set of meanings, metaphors, representations, images, stories, statements and so on that in some way together produce a particular version of events" (p. 64), therefore, discourse includes the language and "non-language stuff"—ways of acting, feeling, and interacting that allow people to make meaning (Gee, 2011). Discourse analysis involves analyzing the patterns of people's accounts in talk or texts in a specific context of social life to understand their course of actions, opinions, communicative events and so on (Jørgensen & Phillips, 2002; Wooffitt, 2005). As such, I conducted discourse analysis to analyze language students use and other relevant ways individuals interact within certain contexts. This was done with the goal of uncovering their understandings of scientific knowledge and the process of scientific inquiry.

Theoretical framework. In this study, as students worked in groups and interacted with the teacher and the researchers to engage in social learning, the social constructionism epistemology guided the qualitative analyses to examine the social interaction in different contexts, such as the approach students adopted to interact with different stakeholders and how the teacher prompted the students to conduct investigations in different contexts. More importantly, as social process is not given or established by nature (Hibberd, 2005), social groups can "choose to replace old conventions, theories, ideologies, practices and bodies of knowledge with new ones" (p. 3). In this study, social constructionism was useful in that students worked together to choose their own path to solve problems rather than follow direct instruction.

Social constructionism is "the view that all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context" (Crotty, 1998, p. 42). Compared to constructionism, social constructionism is concerned with how knowledge is constructed and understood with a social rather than an individual focus. Social constructionists view knowledge as created through an interactional and rhetorical process within a social system through discourse, thus, knowledge is influenced by social force (Elder-Vass, 2012). Therefore, social constructionism emphasizes how people use language to construct reality of their social system in their everyday interactions (Berger & Luckmann, 1991). In other words, language is not a means to convey thoughts and feelings, rather, language is a tool with which people can construct thoughts and concepts—language structures the way people experience the world (Burr, 2003). As one of the most widely used approaches within social constructionism, discourse analysis emphasizes sociocultural and contextual aspects as it involves asking questions about how language is used to construe the meaning of a specific context, and how the contextual aspects simultaneously give meaning to that language (Gee, 1999). As such, social constructionism guided me to analyze the language students and other relevant individuals use to interact within certain contexts to uncover their understanding of scientific knowledge and the process of scientific inquiry. I analyzed the words students use to describe certain information they find from the Internet to understand how they thought of the credibility of the information. More importantly, social constructionism also guided me to analyze how the social culture aspects influence the way students construct and articulate their thoughts about scientific inquiry. As the students' interaction was analyzed across different contexts (field trip, in-class activities, and interviews), I examined the difference between the languages they used within these contexts and how contextual aspects gave different meanings to the language.

As this study involved many outdoor activities, I addressed the language used by the students and other relevant individuals, and also non-language instances that happened during the study. As social constructionism is concerned with the nature and construction of knowledge (Berger & Luckmann, 1991), it guided me to examine the language students used to understand how certain words, thoughts, concepts become a shared knowledge within their social groups and how the shared knowledge comes to have significance in their problem solving processes. For instance, I examined the language students used to create argument to understand what counted as "evidence" to them, what did they mean when they said they "knew" something, etc., and more importantly, how did the language they use influenced their approaches to construct knowledge and solve problems. According to social constructionism, the way people make sense of and understand their world are historically and culturally situated (Burr, 2003), thereby, the influence of non-language instances in the specific social-culture context in this study were also taken into account. For example, a previous study showed that, with the presence of the teacher, students are more likely to make claims and justify with evidence (Belland, Gu, Kim, et al., 2015). As such, I also examined how the nonlanguage instances such as presence of teachers, learning environment, and relationships between groupmates influenced the learning process during the PBL unit.

By using discourse analysis, I focused on *situated meanings* and *cultural models* (Gee, 1999) to examine the interactions between students and other relevant individuals in different contexts within this study. As it is often negotiated between individuals through their social interaction, a situated meaning reflects how people assemble specific meanings for certain words in a specific context (Gee, 1999). Cultural models can explain why certain words have various situated meaning among or cross different social groups (Gee, 1999). By focusing on situated meaning and cultural models, discourse analysis was applied to uncover the meaning of the language used in different contexts in this study, and why the languages have certain meanings among different social groups (such as students group, and students with a teacher). People use language and other semiotic systems to construct and/or construe the situation network in certain ways through seven building tasks: significance, practice (activities), identities, relationships, politics, connections, and sign systems and knowledge (Gee, 2011). Among these seven building tasks, I focused on the practice building task and sign system and knowledge building tasks. The practice building tasks involves how people use certain pieces of language to get recognized as engaging in a certain sort of practice or activity (Gee, 2011). Examining practice building tasks that enable me to uncover what specific language students use when they engage in scientific inquiry. The sign systems and knowledge building task involves "how people use language to create, change, sustain, and revise language itself and other sign systems and their ways of making knowledge claims about the world" (Gee, 2011, p. 20). By focusing on the sign and knowledge building, I examined how students perceive and communicate their ways of knowing across different contexts.

Process. Following the recommendations of the six steps of qualitative analysis (Creswell, 2003), the "generic" coding methods proposed by Saldaña, (2013), and the qualitative analysis procedure proposed by Miles and Huberman (1994), I followed the following steps to conduct qualitative analysis.

Step 1: Organize and prepare data for analysis. Video of classroom activities and post interviews of all case study groups were transcribed. I took a time log of video recordings from field trips and took notes of meaningful segments. Students' science journals were scanned as electronic files and sorted for each student in the case study groups.

Step 2: Read through all data. I read through all transcripts and written documents once to get general ideas of what participants did and said during the PBL unit, and got a general impression of possible themes revealed from the data. This step helped me to generate concepts to make sense of what was happening in the cases documented by the data (Hammersley & Atkinson, 2010). Then, I wrote analytic memos to document and reflect on the emergent patterns and concepts I noticed (Saldaña, 2013).

Step 3: First cycle coding process. I developed an initial coding scheme based on the literature review, the research questions, and the process of students' practice during a PBL unit. The initial coding scheme was designed to analyze students' performance and utterances during their problem solving process and their epistemic beliefs revealed during the unit. Therefore, the initial coding scheme include seven top level categories in regard of several critical steps during PBL (gather information, evaluation information, justify their claims, reflect and revise their claims), epistemic beliefs, interests of science, and reflections of the unit. Since I aimed to explore students' epistemic beliefs revealed from their practices, rather than apply the existing dimensions of epistemic beliefs in the literature directly, I did not include specific codes to code students' epistemic beliefs in the initial coding scheme. Instead, I created one top-level code that includes two sub-categories: nature of knowledge and justification of knowing to code related students' performance and utterances. Before applying the initial coding scheme, I conducted an open test coding by code two randomly selected excerpts of transcripts from each group, and revised and added more subcategory codes. During the first cycle of coding. I coded the entire data set and revised the coding scheme as needed. For example, since the study involved many fieldtrips, I revised the coding scheme by creating several specific codes for different contexts and created specific codes for different types of performance and utterances (e.g., asking questions, taking notes, making observations) and applied it to the entire data set.

Step 4: Second cycle coding process. I applied a second cycle coding process to reorganize and reanalyze data coded through the first coding cycle to develop a coherent synthesis of the data corpus (Saldaña, 2013). During the second cycle of coding, I used an open, axial coding method to categorize the data and explore how the categories and subcategories are related to each other (Saldaña, 2013). Codes that were conceptually similar merged together and new codes were created during the second cycle coding process. For instance, under the code of epistemic beliefs, three themes (simplicity and certainty of knowledge, source of knowledge, understanding of science) merged across cases as they present three subcategories of beliefs of the nature of knowledge during the unit. Hence, I created codes based on these categories and added subcodes as needed. I also revised and recreated codes for learning activities and language in each context (e.g., field trips, classroom observations, journals) to better reflect different situations across contexts. For example, the approaches students adopted in different contexts were different. During field trips, students often asked questions to stakeholders, conduct observation to acquire information. While in classroom, they often conduct online search, and discuss with group members to acquire information. Therefore, the codes under each context were revised to adjust to specific context during the second cycle of coding. See the final version of the coding scheme in Appendix C.

Step 5: Generate descriptions, categories, and themes. In this step, I used the coding process to develop a description of social context and the participant, and generated categories for analysis. In this process, first, I searched for and generated potential themes of how students solve the problem, and what epistemic beliefs they hold during the problem solving process. Second, for each case study group, I displayed the most relevant themes within each group in a time-ordered matrix to arrange themes by in sequence to see students' problem solving process and understand how their epistemic beliefs change over time (Miles & Huberman, 1994). In this step, I also performed discourse analysis guided by social constructionism (please see theoretical framework section for more details). In doing so, I focused on situated meaning and cultural models to understand the meaning of the language students use across different contexts and over time.

Step 6: Explain the data. In this step, I explained the themes and categories I uncovered and made causal connections between them to interpret (1) how and why the students made sense of the problem solving process in their particular way, (2) the interrelationship between their epistemic beliefs revealed from practice and their self-reported epistemic beliefs, and (3) how and why their epistemic beliefs changed during the PBL unit. Based on the themes I developed, I wrote narrative passages to interpret the meaning of the themes by using descriptions, illustrations, quotations, discussion with interconnecting themes (Saldaña, 2013). I also used a table to present and explain the meaning of themes across different contexts. Themes from three case study groups were presented in a content analytic summary table (Miles & Huberman, 1994), which helped me to compare the different groups. The cross-case analysis helped me to form more general themes of students' epistemic beliefs and their problem solving approach. Guided by social constructionism, the cross-case analysis was also used to uncover the specific social culture context under which students' epistemic beliefs changed. By conducting discourse analysis, I explored what systems of knowledge and ways of knowing were relevant for each group of students by examining the practice building tasks and the sign system and knowledge building tasks through which they went. I explored the practice and language that students use to acquire knowledge and justify their knowing across different contexts. I verified the findings by triangulating with multiple data sources from independent measures (Miles & Huberman, 1994).

According to Gee (1999), validity in discourse analysis is based on four criteria: convergence, agreement, coverage, and linguistic details. To foster validity of the discourse analysis used in this study, first, I examined whether the answers of different aspects of discourse can converge in a way to provide a compatible and convincing answers. Second, as the researcher, I was highly involved with interactions with students during the PBL unit, which helped me to acquire insights on their social language in certain contexts. Third, as multiple types of data were collected, I had access to more details to explain the causes and consequences of certain situation being analyzed. Last, as almost all activities in this study were video recorded, the videotapes provided more valid and detailed information of linguistic structure used in this study.

Ethical Considerations

I submitted this study protocol to the USU Institutional Review Board (IRB) for approval (see consent/assent form in Appendix D). This process ensured that the rights and welfare of participants in the research were protected. Prior to the study, students and their parents signed the parental consent/assent forms. The consent/assent forms explained to the students and their parents/guardians (1) the purpose of the study, (2) the process of data collection and analyses, and (3) how their confidentiality and privacy interests would be protected. Students whose parents signed the consent portion and who themselves signed the assent portion participated in this study. Because three students dropped out of the summer program, their information and data were not included in this study and destroyed. The video recording was accessible only by myself. I used pseudonyms for the teacher and students in my dissertation and will continue to use pseudonyms in any future reports or publications to protect their confidentiality.

CHAPTER IV

RESULTS

Quantitative Results

Preliminary Analysis

Epistemic beliefs scores among all participants. I used SPSS 21 to test the reliability (Cronbach's Alpha) of the results of the pretest and posttest. The reliabilities of the pretest and posttest were 0.89 and 0.91, respectively. Means and standard deviations of pretest and posttest scores are presented in Table 3.

Because 21 students participated in the study, the sample size was smaller than the proposed sample size of 22 participants. I conducted a sensitivity analysis to make sure the power statistics were relatively the same. Based on the effect size of 0.23 and power of 0.8, the critical value of the *Z* statistic was the same as if the sample size were 22. Hence, a sample size of 21 still ensures enough power for data analysis.

Table 3

Pretest and Posttest Scores in Each Dimension

		Pretest			Posttest		
Dimension	*N*	Sum	Mean	*SD*	Sum	Mean	*SD*
Certainty (8 items)	21	19.90	2.49	0.46	20.29	2.53	0.33
Developing (6 items)	21	16.57	2.76	0.27	16.67	2.78	0.30
Authority (10 items)	21	26.14	2.61	0.37	27.24	2.72	0.32
Reason (9 items)	21	24.24	2.70	0.34	24.81	2.76	0.23
Total	21	86.86	2.63	0.33	89.00	2.70	0.25

Note. In the questionnaire, possible total scores range from 33 to 99.

According to the *Epistemological Beliefs Questionnaire* (Elder, 1999), high scores on the *Certainty* dimension mean that participants viewed scientific knowledge as consisting of complex concepts with subjectivity. High scores on the *Developing* dimension means students believe scientific knowledge evolves over time as new discoveries are made. High scores on the *Authority* dimension mean that students tended to disagree with that external authorities such as teachers, scientists and books are the ultimate source of scientific knowledge. High scores on the *Reason* dimension mean participants believed knowledge is derived from reasoning, thinking, and testing. Table 4 represents the distribution of mean scores on each dimension on the pretest and posttest. I created four intervals ($1 < M \leq 1.5$, $1.5 < M \leq 2$, $2 < M \leq 2.5$, and $2.5 < M \leq 3$) based on the range of the mean scores. Under each interval, I listed the frequency counts and the associated percentages of the participants whose responses fell into the range.

Table 4

Distribution of Mean Scores in Each Dimension

	Range of mean scores							
	$1 < M \leq 1.5$		$1.5 < M \leq 2$		$2 < M \leq 2.5$		$2.5 < M \leq 3$	
Dimensions	Count	%	Count	%	Count	%	Count	%
Pretest								
Certainty	2	9.5	0	0	10	47.6	9	42.9
Developing	0	0	1	4.8	4	19	16	76.2
Authority	0	0	2	9.5	7	33.3	12	57.1
Reason	0	0	2	9.5	2	9.5	17	81
Posttest								
Certainty	0	0	2	9.5	8	38	11	52.4
Developing	0	0	1	4.8	4	19	16	76.2
Authority	0	0	2	9.5	2	9.5	17	81.0
Reason	0	0	0	0	3	14.3	18	85.7

Epistemic beliefs scores by grade level. To examine if students' epistemic beliefs scores vary by their grade level, I divided all participants into a middle school subgroup and a high school subgroup. Participants' epistemic beliefs scores by grade level were presented in Table 5. Using a Mann-Whitney *U* test, the results showed that there was no statistically significant difference between middle school and high school participants on the pretest, $U = 37.00$, $z = -0.90$, $p = 0.37$, $ES = 0.13$, or the posttest, $U = 41.50$, $z = -0.56$, $p = 0.58$, $ES = 0.083$. In addition, the results showed that there was no statistically significant difference on each dimension score by grade level on pretest or posttest.

Epistemic beliefs scores by gender. To examine gender difference on students' epistemic beliefs, their pretest and posttest scores by grade were presented in Table 6. Using a Mann-Whitney *U* test, the results showed that although there was no statistically significant difference by gender on the pretest ($U = 40.50$, $z = -1.02$, $p = 0.31$, $ES = 0.49$) or the posttest ($U = 43.50$, $z = -0.81$, $p = 0.42$, $ES = 0.55$), female students scored higher than male students on both pretest and posttest with medium to large effect sizes. In addition, the results

Table 5

Pretest and Posttest Scores by Grade Level

		Pretest			Posttest		
Grade level	*n*	Mean	*SD*	Mean rank	Mean	*SD*	Mean rank
Middle School (7-8)	7	86.00	8.54	9.29	89.43	5.22	9.93
High School (9-12)	14	87.29	11.95	11.86	88.79	9.60	11.54
Total	21	86.86	10.73		89.00	8.25	

Note. In the questionnaire, possible total scores range from 33 to 99.

Table 6

Pretest and Posttest Scores by Gender

		Pretest			Posttest		
Gender	*n*	Mean	*SD*	Mean rank	Mean	*SD*	Mean rank
Male	11	84.10	13.03	9.55	86.60	10.61	9.85
Female	10	89.36	7.93	12.32	91.18	4.90	12.05
Total	21	86.86	10.73		89.00	8.25	

Note. In the questionnaire, possible total scores range from 33 to 99.

showed that there was no statistically significant difference on each dimension scores by gender on pretest or posttest.

RQ1a: Middle and High School Students' Self-Reported Epistemic Beliefs about Science

As shown in Table 3, the mean scores of the pretest in each dimension were equal or larger than 2.5 on a 3-point scale. That means on average, the participant self-reported relatively high scores on the pretest. As shown in Table 4, for the pretest mean scores on the *Certainty* dimension, the majority of participants agreed that scientific knowledge was uncertain and consisted of complex, contextual, and highly integrated concepts. For the pretest mean scores on the *Developing* dimension, the majority of participants stated that knowledge was changeable and evolving. For the pretest mean scores on the *Authority* dimension, the majority of participants did not agree that external authorities are the ultimate source of knowledge. For the last dimension—*Reason*—most participants agreed that knowledge comes from reasoning, thinking, and testing on the pretest. Hence, except for a few students, most participants' self-reported epistemic beliefs are relatively sophisticated on the pretest, in that they perceived scientific knowledge as complex, uncertain, highly integrated and evolving, and agreed that scientific knowing stems mostly from logical reasoning and testing. Thus, generally speaking, before the unit started, the participants self-supported relatively sophisticated epistemic beliefs in science.

RQ3a: Do Students' Epistemic Beliefs Change during a PBL Unit?

A Wilcoxon Signed-Rank Test was conducted to examine the mean difference between pretest scores and posttest scores. Three students dropped out of the summer program. Thus, 21 students' test scores were included in the analysis. The results showed a significant increase from pretest (M = 86.86, SD = 10.73) to posttest scores (M = 89.00, SD = 8.25), Z = -1.981, p = 0.048, ES = 0.23. When comparing pretest and posttest scores at the individual level, one finds that for eleven students, posttest scores were higher than pretest scores; four students got the same scores on the pretest and the posttest; for six students, posttest scores were lower than pretest scores. Overall, the mean scores in all dimensions increased from pretest to posttest (see Table 1). When examining pre-post gains among each dimension, only scores in the *Authority* dimension significantly increased from pretest (M = 26.14, SD = 3.75) to posttest (M = 27.24, SD = 3.21), Z = -2.48, p = 0.013, ES = 0.31.

Qualitative Results

Atmosphere of the Summer Program

The summer program provided by Mountain High School was available for middle and high school (grades 6-12) students in the surrounding area. Hence, some students had not known each other before they registered for the program. Once Mr. Scott assigned them to small groups, most students soon got along with their groupmates and tended to work closely with their groupmates even when scattered during field trips. As a result, the students worked in small groups during the entire program instead of working as groups only in the classroom.

Mr. Scott mentioned that he wanted to encourage the students to learn more about the way scientists conduct inquiry. At the first day of the program, Mr. Scott asked all students to read a description of scientist off a display board on the wall of classroom.

A scientist is:
Observant, Curious, Careful, Precise,
Ethical, Skeptical, Analytical, & Nice,
Open-minded, Honest, Responsible, & can Write!

He explained these characteristics to the students and asked them to memorize all of them, and students who recited all of them by the end of the first day received a treat. During the summer program, Mr. Scott often asked the students to recite these descriptions of scientists, and asked them to adopt these characteristics in their learning activities. For example, when students were testing water quality, he would often remind students to be observant, careful, and precise in their investigation.

Mr. Scott was passionate about teaching environmental science to the students during the field trips. As advisor, he led a team of Mountain High School that won a state natural resource knowledge competition for high school students in 2010. He wanted to encourage students' interest in environmental science and recruit more students to participate in the competition in future. During the field trips, Mr. Scott often asked students to observe the surroundings and taught them various environmental science topics. During the program, some students became interested in certain topics and took notes even when they were not required to do so. For instance, a few students became highly interested in identifying plant species so they were eager to learn characteristics of various plants and collect plant leaves as specimens. When interviewing stakeholders, at first Mr. Scott often encouraged the students to ask questions about water quality. As the PBL unit progressed, the students became more self-directed in interviewing stakeholders and conducting investigations of water quality by themselves. The program cultivated a positive and supportive learning atmosphere in which the students were curious to find out if there were water quality issues in their local area.

Group 1

RQ1b: Epistemic beliefs revealed from scientific inquiry practice. Group 1 consisted of three boys, Jake, Adam, and Taylor. All three were set to enter ninth-grade in Fall 2014. Jake scored 91 and 91, Adam scored 97 and 96, and Taylor scored 98 and 97 on pretest and posttest, respectively (the highest possible score is 99), which indicated that their self-reported epistemic beliefs were relatively sophisticated. Adam was the son of Mr. Scott, and Adam and Jake were cousins. Adam and Taylor both came from Mountain High School; therefore, they all knew each other well before the summer class and worked together closely during the entire class. Based on my observation, Jake, Taylor, and Adam all participated actively in field trips. An examination of their science journals showed that all of them made detailed notes from field trips. They were more engaged in the inquiry activities compared to other groups as they stayed on task most of time, even when the teacher was not around.

Nature of knowledge. In Elder's *Epistemological Beliefs Questionnaire*, two dimensions—*Certainty* and *Developing*—involve the nature of knowledge aspect of epistemic beliefs. In this paper, I discussed the results on these two dimensions together as factor analysis (Hofer, 2000; Qian & Alvermann, 1995) indicated that these two dimensions merged together as one dimension. Achieving high scores on these two dimensions mean that participants think that scientific knowledge consists of complex concepts with subjectivity and evolves over time as new discoveries are made. Jake scored 2.7 and 3.0, Adam scored 2.8 and 3.0, and Taylor scored 3.0 and 3.0 on average (on a three-point scale) on the *Certainty* and *Developing* dimensions on the pretest and posttest respectively, showing that they hold sophisticated epistemic beliefs about the nature of knowledge in that they viewed knowledge as a continuum that changes over time rather than absolute truth exists with certainty. During the conversation below in the post interview, such beliefs were also evidenced.

Researcher: Do you think scientific knowledge is certain and objective?
Adam: No.
Taylor: No.
Adam: It can be changed.
Taylor: Just look at a timeline…
Adam: As technology moves on we get better equipment, better tests and

theories and stuff.

Taylor: The evidence of that is just look at a timeline. Look at what has changed.

Researcher: Okay. The more we do research the more evidence we will have, so we will know more things about…

Adam: Yeah.

Researcher: Okay. So do you think scientific knowledge will change over time?

Adam, Jake, and Taylor: Yes.

As the students noted, they believed that knowledge evolves as technology advances, which is consistent with their responses on the pretest and posttest. In addition, during the post interview, when asked about what scientists do in their fields, the students also expressed their understandings of how scientists use different scientific methods to conduct research in their professional fields.

Researcher: In your opinion, what do scientists do in their professional fields? Like in general, what do they do?

Taylor: They're careful and observant. They have to be precise.

Adam: They research.

Taylor: Yeah, scientists do research.

Jake: They study in their field. Like if they're in a field that's about fish, like brown trout, they don't study about elephants. They specifically study….

Taylor: Yeah, they do experiment and try to look for different things. Come up with new ways…

Adam: Use evidence to support their claim.

Taylor: Thinking and looking. Always progressing. Progressing… type of things.

Researcher: Okay, so do you think all the scientists use the same method to do research? Or they may use different methods?

Adam: Different.

Taylor: It just depends on…

Adam: On their field.

Taylor: They have different ways of measuring, testing. A rocket scientist isn't going to test, well it might, but it's not going to test the pH of a river a couple miles away next to a big city, it's probably going to test the fuel, how the fuel will react to something, you know, like to the air or…

During the conversation above, by using the phrases "progressing," "precise," and "new ways," their discourse revealed their beliefs about how scientists doing research to continue exploring new research topics. As Taylor and Adam pointed out that scientists do research in their specific fields by using different scientific methods, it was evidenced that they understood the diversity of scientific methods—one notion of "*practical epistemologies*" proposed by Sandoval (2005) that are essential for students to effectively engage in scientific inquiry and evaluate scientific claims.

Nature of knowing. Students' epistemic beliefs of the nature of knowing were discussed below under the *Source of knowledge* and *Justification of knowing* dimensions separately.

Source of knowledge. In Elder's *Epistemological Beliefs Questionnaire*, receiving high scores on the *Authority* dimension means that students disagreed that external authorities (e.g., teachers, scientists, and books) are the ultimate source of scientific knowledge. Jake scored 2.5 and 2.6, Adam scored 3.0 and 3.0, and Taylor scored 3.0 and 2.9 on the *Authority* dimension on the pretest and posttest, respectively, showing that they hold sophisticated epistemic beliefs about the source of knowledge. That means they started to view themselves as knower that can construct knowledge in interaction with others rather than only acquiring knowledge that resides in external authority. However, their inquiry practices revealed that they hold mixed beliefs of the source of knowledge. I discuss the sophisticated and naïve side of their epistemic beliefs of the source of knowledge separately below.

The sophisticated aspect of their epistemic beliefs revealed from practice is that they constructed scientific knowledge by conducting water quality investigations on their own. During the field trips, the students always made sure to record the water quality test data accurately in their journals. As a result, other students sometimes came to ask them for water quality data. To help students interpret the test data they collected, Mr. Scott often drew a map of their local river on the whiteboard and marked all the sites where they did water tests. Following Mr. Scott's suggestion, Adam and Taylor both drew the map on their journals to which they could refer later. The students recorded detailed information from water quality tests and used it as part of their evidence to support their claims. During the post interview, they noted that they valued "the information from tests" because they are "facts" rather than "things like your opinions," which showed that the water quality tests they conducted also served as a source of knowledge to them. In other word, they acquired knowledge that comes from the water quality tests and investigations they conducted on their own as it revealed the "facts" of water quality.

The students in Group 1 also showed naïve epistemic beliefs of the source of knowledge as they tended to accept knowledge from external authorities without understanding the meaning of it. Although the students had already conducted several water tests in the past five days and made detailed notes from field trips, they did not understand the meaning of the water quality indicators they tested. For instance, on Day 6 when they started to conduct online search of water quality information, Jake asked Taylor and Adam that "what is dissolved oxygen" but none of them knew the answer.

Although they recorded many water tests data during field trips, they did not know what "DO" and "pH" stood for. They accepted concepts such as dissolved oxygen and pH without understanding the meaning of them, indicating that they did not play active roles as knowers to comprehend and construct knowledge by interacting with others. Later, they decided to "Google" the meaning of all the water quality indicators on the Internet. When Adam found out the definition of pH is "a measure of hydrogen ion concentration" and mumbled to himself, Mr. Scott heard him and asked him if he understood what that means. Still, although he said he did not understand it, he believed he was done searching for information about pH. His discourse showed that, to Adam, he "acquired" knowledge of the definition of pH from outside by searching for it on the Internet and taking notes.

Similarly, when dealing with the information from stakeholders, the students also tended to accept it without integrating it with other information. For example, in Jake and Adam's journals, both of them wrote, "Jake (a stakeholder from the local drinking water plant) said that Green valley [drinking water] is one of the most healthiest [sic] water in the U.S. because most of the water is from spring water" and they used it as part of their evidence. As Jake said during the post interview, he believed "some of our most strong [sic] evidence is by asking other stakeholders that we visited." However, as this piece of information was about drinking water quality, it could not support their claims about surface water quality, which showed that they used the information from external authorities without fully comprehend the meaning of it.

To sum up, the examples presented above indicated that, two types of epistemic beliefs were revealed through their interaction in knowledge construction. Their discourses showed that they started to construct knowledge as knowers, as they understood the value of making investigation and conducting water quality tests to gather facts about water quality. But at the same time, they still relied heavily on accepting and recording knowledge from external authorities (stakeholders, the Internet), which positioned themselves as passive receivers of knowledge from external authorities.

Justification of knowing. In Elder's *Epistemological Beliefs Questionnaire*, receiving high scores on the *Reason* dimension means that students believe knowledge is derived from reasoning, thinking, and testing, which represents sophisticated epistemic beliefs of *justification of knowing* in Hofer's model (2000). According to the results from pre and posttest, Jake scored 2.8 and 3.0, Adam scored 2.9 and 3.0, and Taylor scored 2.9 and 2.9 on the *Reason* dimension on the pretest and posttest, respectively, showing that they believed justification of knowing comes from applying rules of inquiry and making personal evaluations and integrations of the views of the experts. Their inquiry practice revealed that to some extent they justified their knowing from reasoning and testing as they made personal interpretations and evaluations of the data they collected as their evidence. However, they only used information from stakeholders who said there is no water quality problem as their evidence, even though other stakeholders disagreed with this conclusion. It indicated that their use of authorities was still naïve as they failed to evaluate and integrate information from different perspectives. As a result, their beliefs of justification of knowing were still at a suboptimal level, as they did not fully make personal justifications by applying rules of inquiry, making evaluations and integrations of expert's views during their inquiry.

The sophisticated aspect of their justification of knowing revealed from practice is that they applied rules of inquiry and made personal interpretations and evaluations of the data they collected as their evidence. For example, on Day 6, Adam made a table to record test water data in one column and compare them with State water quality standards listed in another column. On Day 8, the students spent one hour to analyze the data they collected through the PBL unit. During the conversation below, Taylor and Jake discussed their findings from water quality data.

Jake:	What are you comparing right now, Taylor?
Taylor:	So I just took this (pointed to the screen) and I just match every single one of this to this (water quality standards), and 8 of 11 are perfect.
Jake:	Oh, I did that too.
Taylor:	8 out of 11 are perfect, storm water has a little bit low DO, other than that are fine. And then, turbidity for Greenville and Collinston are high.

The conversation showed that Jake and Taylor both applied rules of inquiry and made personal justification of the water quality problems by comparing water test data against the state standards. They found three sites with water quality problems. Adam also participated in the conversation and wrote, “out of the 11 tests, 8 of them are perfect for our water quality” in his science journal.

The students also identified trends in water quality data. Jake wrote, “the closer the water gets to the city, the more turbidity is in the water, the closer the water gets to the city, the lower [the] dissolved oxygen” in his science journal. On Day 8, Jake came to talk to Taylor about his findings of the trends of water quality. He said: “Taylor, so all of them are kind of same, except turbidity. When we look at the map, those ones [turbidity] are starting to going up when it gets close to Green Valley. So that means…the higher up to the mountain, the clearer the water is. So back to our claim, we could put…we have good water quality because when it is draining down the mountain, it is clean. But what makes it off the chart is human waste." This conversation showed that Jake was able to identify trends in water quality by comparing water quality data gather from multiple sites along the river. More importantly, his discourse revealed that he made a personal justification by interpreting that the water quality problem was due to human waste rather than natural causes based on his own interpretation of the trends of data.

In addition, the students also made personal justifications to consider if the water quality problem was serious. On Day 8, since the dissolved oxygen level in local storm water was found to be 0.5 ppm below the state standard (minimum 6.5 ppm), Taylor asked Mr. Scott that: "If it is 0.5 below, is it a huge difference? Is that gonna change much?" Mr. Scott told him "it might not be dead dead, but it is below the minimum. It means you will be struggling. You will be expecting the system to be dying if it does not change." It should be noted that this particular water sample they took was from a storm water sewer at their local storm water management facility. Although Mr. Scott said in general having low dissolved oxygen level could be a serious problem for a system, Taylor decided that the dissolved oxygen problem in storm water was not serious because "there is no fish in storm water," and "it is not in a serious range, it is only 0.5 below the standards, so it is close to the standards." The decision Taylor made indicated that, besides comparing water test data against to the State standard, Taylor also considered the specific beneficial uses of storm water and decided that low dissolved oxygen level was not a serious problem because it was not meant for fish to live in it. Overall, their discourse in these examples showed that the students to some extent were able to make personal justifications of their knowing by analyzing and interpreting data they collected.

However, as stated earlier, the students failed to consider different opinions from the stakeholders they visited, which revealed the naïve side of their epistemic beliefs. The only one piece of information from the stakeholders they used was that the drinking water in Green Valley is of good quality. Although the water quality tests they conducted focused on surface water, they did not mention any information from other stakeholders about surface water quality, which indicated that they did not evaluate or integrate information from stakeholders with different perspectives. As they believed there was no water quality problem in Green Valley, they simply chose one piece of information from the stakeholders to support their claim and ignored the voices from other stakeholders. As a result, their inquiry practice also revealed that they were not able to fully make justifications by applying rules of inquiry and personal evaluation and integration of expert's views during their inquiry.

RQ2: How do students' epistemic beliefs contribute to the construction of their problem solving processes. In Group 1, students' epistemic beliefs influenced the approaches they adopted to collect and integrate evidence to support their claims.

Using multiple types of evidence to support their claims. The students' inquiry practice revealed that they hold mixed beliefs of the source of knowledge as they accepted knowledge directly from external authorities, but at same time, they also self-constructed knowledge by conducting their own investigations. Guided by such mixed beliefs, they used information from authorities and their own investigations to support their claims during their problem solving processes. In their final presentation, they used information from water quality tests, online search, and stakeholders as their evidence. For example, during the post interview, when asked about their approach to investigate water quality in Green Valley, they noted that they used the water quality data as well as information from multiple sources as evidence.

> Jake: We did a lot of research, and asked a lot of questions and compared our water quality stuff with the ideal [water quality] for Green Valley and with our actual results. And then after that we made our claim. And our claim is that the water quality in Green Valley is good.
>
> Researcher: Okay, so you did the water quality tests first, and then you compared to the standards, then you made a claim.
>
> Jake: I think probably most of our evidence we looked up on webpages.
>
> Taylor: Where we got all the standards from, something to compare it to.
>
> Jake: I think that's where we got a good half of our evidence from, but I think some of our most strong evidence is by asking other stakeholders that we visited.
>
> Taylor: And by doing water testing.

The conversation above demonstrated that the students valued information from multiple sources (water quality tests, the Internet, and stakeholders) and used them as their evidence to support their claims. In their final presentation, they claimed that water quality in Green Valley was good based on three types of evidence. First, they stated that they compared all water quality test data to the state standards and found that "eight out of eleven tests fit the range" of the state standards. They noted that although turbidity readings were higher than the state standards at two sites, they believed water quality in Green Valley in general was good because the two sites were "down [at] the lowest point of the valley." The turbidity levels in these two sites were higher because they collected the dirt washed off from the higher points of the valley. Second, they noted they found fish and macroinvertebrates (e.g., mayflies, caddisfles, and stoneflies) at most water quality test sites, which indicated that water quality was good enough for aquatic life. Third, they stated that drinking water quality in Green Valley was also good because the specialists in local water utility (one of the stakeholders) said "the drinking water in Green Valley is one of the finest in the state." As stated earlier, the sophisticated side of their epistemic beliefs revealed from practice is that they constructed knowledge by conducting investigation of the water quality issues on their own. Guided by such beliefs, they used water quality data and their observations as evidence to support their claims, which strengthened their arguments. Meanwhile, they also held naïve epistemic beliefs related to the source of knowledge in that they accepted knowledge from external authorities without understanding the meaning of it. Therefore, influenced by such beliefs, they also used the stakeholder's opinions of drinking water quality as their evidence although it cannot directly support their claims about surface water quality.

Difficulties integrating conflicting information from authorities. Group 1's naïve epistemic beliefs related to justification of knowing revealed from practice may be linked with their failure to evaluate and integrate different opinions from the stakeholders they visited. Influenced by such beliefs, they were not able to address and integrate conflicting views from the stakeholders and use them to back up their claims. During the post interview, when asked about what information can be used as evidence, Taylor said, "If you ask enough stakeholders in the area on your topic you'll usually get a group that either supports what you think or doesn't support what you think and you can take the majority of that and start digging deeper to find out what [is happening]." It showed that Taylor realized that knowledge from different authorities can be in conflict. However, when they were trying to integrate these conflicting pieces of information, they did not "dig deeper" to find out what is happening. As Taylor said during the post interview, "we have to know the sides first, then we can research, and then we have to choose a side." In the end, they simply chose the opinions from one side of the stakeholders that there is no water quality problem in Green Valley. Therefore, they failed to justify why dissolved oxygen and turbidity problems in the three sites did not indicate a water quality problem in Green Valley and whether any stakeholders may be affected. Although some stakeholders noted that there were water quality problems in Green Valley, this did not make it into the group's presentation.

Interestingly, during the post interview when asked about how they dealt with conflicting information, the students mentioned that they would evaluate the source of information first and then use the information:

Researcher: So if you find two websites that provide opposite information about something, what do you do?

Taylor: If one of the websites is Wikipedia and the other website is a government site, then we trust the government site.

Taylor: Yeah. You have to look at the source. You might have to do some research for what the source is. If it's one that's Wikipedia, anybody can go in and screw around with it, then that's probably not the most reliable site.

Researcher: Yeah, so what about a personal blog or…?

Adam: I probably wouldn't.

Jake: I would go to an official website.

Taylor: If you could find out who wrote the post and do some research to find their credentials, then their…

Adam: If they're qualified then their…

Taylor: If they're qualified, you know, if they're a doctor and a teacher at a university and on this subject then maybe you might consider that. But if it's a 14-year-old doing a project and has to reply to something…. so you might have to do some research on who is actually saying that.

Above, the students noted that they would evaluate the credibility of the source of information before they use the information. Specifically, they valued authorities (government, teachers at university) over other sources of information. Therefore, as they said, they would trust information that comes from authorities. However, when different authorities provided conflicting information to them, they struggled with integrating such.

One possible reason why the students in Group 1 struggled to integrate conflicting information is a belief that knowledge resides in authorities. This, in turn, may have made it difficult for them to perceive the need to actively evaluate and integrate information from authorities. During the conversation below they noted their approach to dealing with conflicting information.

Researcher: So when you talked to some guest speakers or stakeholders, some of them had different opinions about water quality. So what did you do in that situation? Do you think that all of them could be right?

Taylor: You also have to consider what they're testing because some of the people are testing our drinking water, some of them are testing just what is growing in the river.

Researcher: Or some of them are talking about our wastewater.

Taylor: Yeah, some are about how to take waste…our wastewater plant. They all have different things they specialize in. And you have to look at all of those and get the bigger picture of overall do we have a water quality problem. I mean, we might have a problem in one certain field of this water, like in general….

Adam: In general it might not be too bad.

The conversation demonstrated that to the students the disagreement between different authorities (stakeholders) is mainly due to the different subjects the stakeholders specialize in. They did not realize that the disagreement among stakeholders may also due to their different perspectives, which in turn may make it difficult for them to evaluate and integrate stakeholder's views by considering their perspectives. Therefore, they ignored the disagreement between stakeholders and chose one side. Hence, their presentation was weakened by the fact that they did not fully address and integrate conflicting information. As the students believed justification of knowing comes from authorities, it was challenging for them integrate or make personal justifications related to inconsistent opinions of authorities. Hence, influenced by their naïve aspect of epistemic beliefs of nature of knowing, the students failed to comprehend and integrate conflicting information and use them as evidence to support their claims.

RQ3b: How and why do students' epistemic beliefs changes. As stated earlier, in Group 1, Adam scored 97 and 96, Jake scored 91 and 91, and Taylor scored 98 and 97 on the pretest and posttest, respectively (the highest possible score is 99). Thus, the results showed that the students' self-reported epistemic beliefs stayed consistent during the PBL unit. This result may due to the "ceiling effect" since the students received almost full scores in both pretest and posttest. An examination of their video recordings from field trips and in-class activities also showed that their epistemic beliefs revealed from practice stayed consistent during the PBL unit. Nevertheless, their reflections during the post interview indicated that they still benefited from participating in the scientific inquiry unit as they experienced the complex process to conduct investigations and use evidence to support their claim.

During the unit, as students had first-hand experiences conducting water quality tests and visiting different stakeholders, they had opportunities to reflect on their inquiry practices and compare such with authentic scientific inquiry practices. For instance, in a conversation during the post interview, the students mentioned that the water quality tests they conducted were not strictly controlled and authentic scientific inquiry practices should be done in a more accurate and precise way.

Researcher: So what are some methods you have observed during the summer class that were used by the scientists?

Taylor: Oh. Well, they used a lot more fancy equipment than we do. And they have to be pretty precise.

Researcher: You mean like we dipped the test paper into…

Taylor: Yeah we dipped the test paper but didn't even measure how long we dipped…

Taylor: If we wanted [to be] more accurate, say a pH test for example, we have to have a specific time to wait in there, a specific time before we look at it, and then write it down instead of just dipping it, then waiting for 10 seconds one time, 20 seconds for another, immediately one time. We could have had it more controlled. And that's what these guys do; they have to make sure their experiments are more controlled. They have to be more precise.

Researcher: So they're measuring all kinds of things more accurately?

Adam: Yeah.

Taylor: No room for error.

Adam: It could ruin their career.

Taylor: Kind of like a rocket. You don't want your rocket to blow up.

The conversation showed that the students realized that scientific inquiry is a complex process that involves using advanced equipment and strict methods to get accurate and precise results. Their discourse also implied that they believed that scientists often adopt more "controlled" or advanced methods during their scientific inquiry to make sure they can acquire more accurate and precise understandings of the nature world. As they learned more about water quality during the PBL unit, they also realized that water quality is a complex concept that can be investigated from multiple perspectives. During the post interview Taylor said, “The tests, they might not be the most high-tech and we kind of specialized in the chemical aspect of it, but I’m guessing there are a lot more things you can test that we didn’t, that show water quality. But I guess for this [PBL unit], that will do.” This statement demonstrated that, Taylor understood that besides the water quality tests they conducted, there are other types of tests that can be used to investigate water quality. The examples above implied that by experiencing scientific inquiry in the PBL unit, the students were exposed to the complexity of the nature of knowledge and the method of making it. Thus, they started to understand that scientists need to be “careful,” “observant,” and “precise” to conduct scientific inquiry to explore the complex nature world as Taylor said during the post interview.

Group 2

RQ1b: Epistemic beliefs revealed from scientific inquiry practice. Group 2 consisted of three girls—Kate, Emily, and Linda. Their grade levels varied as Kate, Emily, and Linda were set to enter 7th grade, 9th grade, and 12th grade in Fall 2014 respectively. Kate was the granddaughter of Mr. Davis and she and Emily were cousins. Therefore, although they came from two different middle schools, they spent most of the time together during the entire unit. Linda came from Mountain High School and she enrolled in the same summer class in 2013. As she was familiar with the learning activities from the summer class in the previous year, she was eager to help other students during the field trips such as helping them to conduct water quality tests, or teaching other students about the species of plants. Due to a family trip, Linda had been absent from Day 6 to Day 9 for the summer class. Kate scored 69 and 81, Emily scored 87 and 87, and Linda scored 92 and 93 on the pretest and posttest respectively (the highest possible score is 99), which indicated that their self-reported epistemic beliefs were varied.

Nature of knowledge. According to Elder's *Epistemological Beliefs Questionnaire*, reporting high scores in *Certainty* and *Developing* dimensions mean that participants view scientific knowledge consists of complex concepts with subjectivity and evolves over time as new discoveries are made. Kate scored 2.1 and 2.0, Emily scored 2.5 and 2.5, and Linda scored 2.8 and 3 on average in *Certainty* and *Developing* dimensions on pretest and posttest respectively. The results showed that Kate held a neutral view on whether knowledge exists with certainty or can change over time. Emily and Linda held relatively sophisticated epistemic beliefs that viewing knowledge consists of complex concepts that evolve over time.

Their epistemic beliefs of the nature of knowledge were also reflected in their responses during a conversation in the post interview. When asked if they think scientific knowledge is certain and objective, they all responded "yes," which was inconsistent with their responses in the pretest and posttest. Linda noted that she believed that scientific knowledge is certain and objective because "in order for it to be science it's got to have data, which solidifies it. If you just base everything on opinions, then things can go wacko." Her discourse indicated that to Linda, scientific knowledge is certain and objective because it was based on "data" rather than "opinions." That meant she believed data represent the absolute and objective truth. Nevertheless, she did not understand that data can be uncertain and subjective as the methods of acquiring and analyzing data is often influenced by the subjectivity of researcher (Ratner, 2002).

Later, during the conversation below, when asked if they think scientific knowledge can change over time, the students all responded that they believed knowledge can change.

Researcher: Do you think scientific knowledge will change over time?

Emily: Yeah.

Linda: Yeah.

Kate: Yeah.

Researcher: Why and how?

Emily: Scientists can just go deeper into the subject and find more things about it.

Linda: Learn new ways of doing things. Find hidden factors… and how things work and change.

Kate: Maybe new tools they can use.

Linda: Yeah, I mean everyone thought the world was flat because they couldn't see that it was round. So they were like, "The horizon is the edge of the earth" because they can't see anything beyond it so they thought if I can't see it, then it doesn't exist. But now we know that the earth is round because we learned more ways of doing things and we've actually sent people into space who have seen the Earth. I mean, we thought that was wrong before that.

As shown in the conversation above, the students said that by using new tools and new methods, scientific knowledge can change over time as new discoveries are made. That meant that they understood that scientific knowledge evolves over time as scientists continue studying the world. However, this opinion to some extent conflicts with their beliefs of the certainty of scientific knowledge, as captured by the pretest and posttest.

That being said, if scientific knowledge evolves over time, it implies that scientific knowledge cannot exist with absolute certainty. Therefore, I asked them follow up questions during the conversation below.

Researcher: (Immediately after Linda's response in the conversation presented above) But does that make the scientific knowledge nowadays is uncertain? Because maybe tomorrow we will have a new understanding of something. So does that mean scientific knowledge could be uncertain and it can change?

Emily: It can change, yeah. It definitely can…

Linda: It's still certain and objective because you've got to look at things, you've got to get the data. And you get it and it's certain as far as you know. If it's uncertain then it's unpredictable.

Researcher: For example, think about the water quality problem. Different scientists may have different opinions on the water quality problem. So some said there is a water quality problem and some said there isn't, do you think that is objective or subjective?

Emily: I don't know how to answer that.

Linda: I guess you can look at the data and two people could see it differently….

Researcher: You mean the data is objective? So it's just how you interpret it?

Linda: Yeah. Like the glass is half full, the glass is half empty depending on how you look at it.

Researcher: Depends on how you interpret the data?

Linda: Yeah.

From Linda's response, we can see that she stuck to the idea that scientific knowledge is certain and objective because it is based on data. She acknowledged that different scientists may interpret a same thing differently based on their different perspectives, but she maintained that data is objective. It showed that she believed knowledge exists with certainty and can be represented by objective data. However, she failed to realize that scientific knowledge is acquired and accumulated by human beings, which certainly is influenced by how people acquire and interpret them from different perspectives. Emily and Linda did not talk much during the conversation presented above. Later in the post interview, I asked them how they dealt with different opinions from the stakeholders.

> Researcher: When we talked to the stakeholders, some of them had different opinions about the water quality, right? So what would you do in that situation? Could all of them be somewhat right? Or…?
>
> Emily: We would probably go back and look at, like go deeper into the situation, into the information and see. Like if half say that it's good and half say that it's bad then just probably go on the Internet and see what the websites say and just go deeper into it.

Emily stated that she would search for more information on the Internet to "go deeper into it," which was not evidenced in their inquiry practices. Since they all agreed with that scientific knowledge is certain and objective, it may be difficult for them to understand that knowledge can be interpreted from different perspectives—the subjectivity of knowledge. Hence, when presented with opposite information from the stakeholders, Emily never said they would consider the conflicting information from different perspectives. In fact, during the entire PBL unit, both Emily and Kate stuck to the idea that there was a water quality problem in Green Valley because some stakeholders said so. They ignored the other stakeholders who said there was no water quality problem and did not present such information in their presentation. Hence, overall, the discourse in Group 2 demonstrated that they believed that knowledge is certain and objective, but it can evolve over time as new discoveries made.

Nature of knowing. Students' epistemic beliefs of the nature of knowing were discussed below under the *Source of knowledge* and *Justification of knowing* dimensions separately.

Source of knowledge. Kate, Emily, and Linda scored 2.3 and 2.5, 2.8 and 2.8, 2.5 and 2.6 on the *Authority* dimension of the pretest and the posttest, respectively, showing that their beliefs about the source of knowledge leaned toward a sophisticated level. That meant they started to view themselves as knowers who can construct knowledge in interaction with others rather than only acquiring knowledge from external authorities. However, their inquiry practices revealed that they tended to use stakeholders as their only source of knowledge rather than their own investigations, which represented their naïve epistemic beliefs of the source of knowledge.

Group 2 members did not record any water quality test data from the field trips in their science journals. As a result, they did not compare water quality data with the state standards. Instead, they only used the information from stakeholders as their evidence to support their claims about water quality. Following suggestions from Mr. Scott, Kate made a table in her science journal to organize her notes from different stakeholders they visited. She made three columns to record the names of the stakeholders, their occupations, and evidence about water quality she learned from them. However, she did not record much information from the stakeholders. In the table, she wrote only “no pollution” next to storm water inspector and “water in valley is bad, the water in the mountain is good” next to the fish biologist. Emily did not record much information from the stakeholders in her journal either. Since Linda did not turn in her journal on the last day, I did not have access to her science journal. The science journals from Kate and Emily indicated that they did not acquire and recorded sufficient information for them to investigate the water quality issues on their own.

In Day 8, the students spent one hour in a computer lab to analyze water quality data and search for online information to construct their arguments. Instructed by Mr. Scott and myself, Emily made a graph in her science journal to present the water quality data at all sites [water quality data were provided to them on the whiteboard], which showed that the turbidity levels at Greenville and Collinston were much higher than the readings at other sites. Unfortunately, she did not make use of this graph to further explore the changes of the water quality along the river. As neither Kate nor Emily recorded any information about the state water quality standards, they never compared water quality data to the standards as their evidence to support their claims.

Due to insufficient evidence they collected during the PBL unit, they did not present much solid evidence during their presentation. In their presentation, they stated that: "We think that there is a water quality problem in Green Valley because the two rivers—Green River and Black Creek meet together and all the pollutants mix together and just become all bad and gross." The logic of their argument was not sound for three reasons: (1) they did not explain why having two rivers meet together would make the water quality bad, (2) they did not present any evidence of pollutants in the two rivers, and (3) they never used any water quality standard to demonstrate that the water quality is "bad and gross." Later in their presentation, they used information from a stakeholder to support their argument:

> Gerry Thomas (fish biologist) said that the water quality in the valley is worse than the water quality in the mountains because in the mountains the water comes out of the ground and becomes a spring, but when the Green river and the Black creek meet, all of the trash and animal feces come together and make very bad water quality.

However, according to the video recording, Gerry Thomas had never said water quality was bad, he only said the water quality in the valley is worse than the water quality in the mountains. Kate misunderstood the stakeholder's opinion so she simply put "water in valley is bad, the water in the mountain is good" in her journal and used it as evidence to support her claim. Thus, students used information from stakeholders as their source of knowledge directly without understanding the real meaning of it. They also stated water quality is bad because "Jake [a stakeholder from local drinking water plant] said that if a bug falls in the water it will break down the bug and by the time it comes to you, you will never know you drink it." In fact, what Jake said was that they use chlorine to sterilize spring water before it is distributed to consumers, and if a bug falls in the water, it will be broken down during this process. Hence, they used the information from stakeholders in a superficial way so that the evidence could not support their claim about water quality problem. Although they were provided with water quality test information, they did not use it as a data source, which showed their naïve beliefs that they tended to rely on external authorities as their source of knowledge rather than construct knowledge from their own investigation.

Justification of knowing. Kate, Emily, and Linda scored 1.8 and 2.4, 2.7 and 2.8, 3.0 and 2.9 on the *Reason* dimension of the pretest and posttest. That meant Kate held suboptimal epistemic beliefs before the PBL unit as she tended to agree with that justification of knowing comes from authorities. Meanwhile, Emily and Linda self-reported sophisticated epistemic beliefs as they believed justification of knowing comes from applying rules of inquiry, making evaluations and integrations of expert's views.

The inquiry practice in Group 2 revealed that Emily and Kate hold naïve beliefs of justification of knowing, as they did not make personal justification from reasoning and testing to develop their arguments. Linda held relatively sophisticated epistemic beliefs as she tended to make personal justification of her knowing, which was consistent with what she reported on the pretest and posttest.

In Group 2, Emily and Kate did not make personal justification by applying rules of inquiry, making evaluations and integrations of expert's views to support their claims about water quality. During the post interview, they explained what they have learned from the PBL unit about water quality in the conversation below.

Researcher: What did you find out about the water quality in Green Valley?

Emily: I found out that a lot of our stakeholders think that we do have a water quality problem. And in my opinion it's because both of the rivers meet together, and all of the pollution collects. And anywhere people live there's going to be pollution in the water and so that's why I thought that.

Kate: Anywhere people live, and like where people are there will be water pollution.

Linda: I learned kind of the specific standards that water is held to for water quality tests for like levels of phosphate, nitrate, pH, dissolved oxygen, all those things. And I think that's a good thing to know and I think that a lot of people should learn about water quality.

As shown in the conversation, what they learned from the PBL unit was not based on their investigation. Emily and Kate believed there was pollution in the river but they never used any water quality test data or their observations to justify their claims. Although some stakeholders said there was no pollution problem in Green Valley, they chose one side of opinions from the stakeholders. As Kate and Emily believed that where people are there will be water pollution, they simplified the concept of water pollution because they thought any impact of human activities to water quality count as water pollution. They did not realize the importance to analyze the water quality data to examine if there is any pollution in the river. Rather, they assumed that there was a water quality problem without considering any water quality standards. Their discourse revealed their naïve beliefs of justification knowing, as they tended to justify their knowing through authority, or on the basis of what feels right (Hofer, 2000).

During the conversation, Linda mentioned that she learned several specific water quality standards she learned from the PBL unit. In fact, unlike Emily and Kate, Linda stated that she tended to use water quality data as her evidence to support her claim. During the post interview, Linda explained to me her approach to investigating water quality in the conversation below.

> Researcher: How did you create your argument [about water quality]?
>
> Linda: Getting the information from experts and different stakeholders is good, but a really good thing you need in an argument is the evidence. Like data, when we did our own water quality tests its hard to say that's biased because that's hard facts.
>
> Researcher: So you think that's more reliable than the opinions from the stakeholders?
>
> Linda: Yeah, it's probably more reliable if you do tests and find the evidence because if you talk to people it's likely that there might be a bias in what they're saying.

Linda said that she believed that water quality data are "hard facts" that are more reliable than the opinions from the stakeholders. She acknowledged that stakeholders' opinions might be biased based on their different perspectives, which meant she did not automatically accept information from stakeholders. It was consistent with her self-reported epistemic beliefs in the *Reason* dimension that justification of knowing comes from reasoning and testing. Unfortunately, her absence from Day 6 to Day 9 made it difficult for her to be involved in the later part of the PBL unit. During the post interview, she said, “the difficulty I had [in the problem solving process] is I wasn’t here.” In summary, the inquiry activities revealed that Emily and Kate held naïve epistemic beliefs of the source of knowledge. Linda, on the contrary, hold sophisticated epistemic beliefs on the source of knowledge.

RQ2: How do students’ epistemic beliefs contribute to the construction of their problem solving processes. In Group 2, under the influenced of their suboptimal epistemic beliefs, the students tended to use their assumptions rather than solid evidence to support their claims.

Using information from stakeholders as evidence in a superficial way. As discussed earlier, Kate and Emily’s inquiry practice revealed that they held naïve beliefs of the source of knowledge as they did not construct knowledge on their own by making investigation of the water quality problem. Since Linda was absent for four days, Emily and Kate were in charge of investigating water quality most of the time. Influenced by Emily and Kate’s suboptimal beliefs, the approach they used to solve the problem was to gather information from stakeholders to support their claims without evaluating or comprehending it. During the post interview, they explained their approach to creating argument during the PBL unit to me in the conversation below.

Researcher: Can you describe your approach to creating an argument? How did you create your argument?

Emily: I just got all the information that we got, like where we went, I got all the information and put it together and realized that most of the places that we went, most of the speakers said that there was a water quality problem and they told us why so I just mixed it all together.

Researcher: What about you?

Kate: All the stakeholders said that we did have a water quality problem in Green Valley so what we did was, we put it all together, we saw who did say yes and who said no we don't and most of the people said yes we do.

Researcher: How and where did you find evidence to support your claim?

Emily: We just found all of our evidence when we went on all of our field trips. We asked a lot of the stakeholders and the presenters what they thought and we just got all of that information. We asked them because they've been in this job for a long time. They've studied in it so we trust their opinions.

Kate: Same with her too, but I also went around and asked all of the kids in the class, "What do you think?," "What do you think?" And most of them said no, but we kind of stayed with what the adults said.

Emily and Kate noted that the approach they used to create argument was to get information from stakeholders and "mix it all together" as their evidence because they "trust their opinions." The conversation indicated that they viewed knowledge as isolated pieces exist that they could obtain from external authorities and all they need to do is to "mix it all together." In addition, although Kate mentioned that some of the stakeholders said there was no water quality problem, they chose to ignore this opinion. It showed that they did not evaluate and integrate different opinions from stakeholders as they said to "mix" all the information from stakeholders. Instead, they chose information that seemed to mesh with their claim. For instance, during their presentation, Kate said the water in the mountain is very purified because one of the stakeholders said that "there is no pH" in the water. It showed the students did not understand the concept of pH, but they still used it as their evidence. As such, the discourse in these examples indicated that, guided by their naïve epistemic beliefs, they used the information from stakeholders in a superficial way as they did not fully understand and integrate information from authorities.

Using their assumptions rather than validated evidence to support their claims. Kate and Emily held naïve beliefs of the justification of knowing, as they tended to justify their knowing through authority, or on the basis of what feels right. As a result, their problem solving processes were also influenced by such beliefs on their approach to acquiring and validating evidence. On Day 7, during a field trip to the neighboring national forest, Mr. Scott posed a question "*Is the forest healthy or dying*" to all students and asked them to use evidence to support their answers. After about half an hour of observation, Emily and Kate decided that the forest is not healthy and Emily made a speech as the spokesperson to represent other students on her side. In her speech, she stated that the forest was not healthy for three reasons. First, she said she thought the forest was unhealthy because "when we look around, we found there are beetles…they are killing the trees by eating them." Second, she said there was not enough protection for wildlife because "there is camping ground like this to disturb the wildlife. And the road is close that means this area could be more polluted." Third, she said, "there are tons of dead trees lying on the ground." However, Mr. Scott noted that these three points were based on insufficient evidence and assumptions. As he said: "I heard a lot of *I think* [in Emily's argument], but *I think* does not count as your evidence." First, Mr. Scott said they did not find any beetles and larvae in the dead trees, which showed that beetles were not the cause of dead trees. Second, although there was a highway across the forest, Mr. Scott said they needed to find specific evidence that shows oils and chemicals are washed into the forest to prove that there is pollution. If animals were killed on the highway, their dead bodies would become fertilizers for the forest, which would benefit the forest eventually. Third, Mr. Scott stated that as there are far more young trees than dead trees in the forest, the forest was actually growing rather than declining. Therefore, as the argument Emily proposed was not based on validated evidence, they lost the debate. It should be noted that Emily and other students did try to search for evidence to support their claim. They went around the forest to examine the condition of the trees, they noticed that there were beetles in the forest, and they also considered the surroundings of the forest as they mentioned the nearby highway. However, the evidence they used was based on limited observations and assumptions as they did not go further to find validated evidence to support her claim. Because Emily and Kate tended to justify their knowing on the basis of what feels right, when they found "evidence" that seemed in favor of their claim, they used it to support their claim without any evaluation, integration, and validation. To sum up the approaches Kate and Emily adopted to solve the problem and construct arguments were not effective, perhaps due to the facts that their views on the nature of knowing were naïve and Linda was absent. They tended to use information from external authorities directly as their evidence and justified their knowing based on their assumptions rather than validated evidence.

RQ3b: How and why do students' epistemic beliefs changes. As stated earlier, in Group 2, Kate scored 69 and 81, Emily scored 87 and 87, and Linda scored 92 and 93 in the pretest and posttest, respectively. The results showed that Emily and Linda's self-reported epistemic beliefs stayed consistent, and Kate's scores improved from 69 to 81. Although it was not a significant improvement from pretest to posttest, she improved a few points on every dimension on the posttest. Based on my observation and the examination of video recordings, the improvement of her beliefs may due to that she was interested in the PBL unit and learned more about how scientists do research during their field trips.

At the beginning of the unit, as the students were new to the water quality problems, none of them remembered to ask questions to the stakeholders. Later, as they got more interested in the PBL unit, Emily often asked questions to the stakeholders for their opinions of water quality issues. Influenced by Emily, although Kate did not ask questions by herself to the stakeholders, she started to listen carefully to the stakeholders when they talked about water quality and made notes on her science journals. Although they used the information from the stakeholders in a superficial way, they still tried to acquire information from the stakeholders, which was better than other students in the class who did not pay attention during the field trips.

On Day 6, Emily and Kate brought a brochure of local drinking water quality report that was mailed to their house by the local public works department to the class. They said they found this brochure at their house and thought it was related to the water quality issues. Emily and Kate also asked me how to convert the physical unit used on the brochure to the unit they used during the PBL unit. Although they did not use this brochure as their evidence, it showed that they were interested in the unit.

During the post interview, the students all stated that they believed they learned more about how scientists do research during the PBL unit. Kate said, “I never knew that they actually did the water quality test. I have never noticed and learned about that.” Linda thought doing water quality “helped me learn the most. It is one thing to be taught it in the classroom, it is a completely different thing to go out and do it. By going out and doing it, it is easier to understand, it sticks better." Emily said she also learned that "they [the fish biologist] actually caught fish from the river and did tests on them" to conduct research about fish. As such, her discourse showed that conducting these hands-on activities provided opportunities for her to experience and observe how scientists do research in different fields. Reporting higher scores on posttest meant that Kate agreed more with sophisticated epistemic beliefs, which implies that she started to understand more about the nature of knowledge and knowing. Although her epistemic beliefs revealed from practices were still at suboptimal level, considering she just graduated from 6th grade, the improvement of her self-reported epistemic beliefs might form a basis for her to develop more sophisticated epistemic beliefs in the future.

Group 3

RQ1b: Epistemic beliefs revealed from scientific inquiry practice. Group 3 consisted of three girls, Haley, Sara, and Molly. Both Sara and Molly were set to enter 8th grade, and Haley was set to enter 10th grade in Fall 2014. Haley came from Mountain High school, Sara and Molly were from two other different schools. Although they had not known each other before the summer class, they seemed to get along very well and enjoyed work together during the entire PBL unit. Haley scored 95 and 95, Sara scored 93 and 92, and Linda scored 95 and 96 on the pretest and posttest, respectively (the highest possible score is 99), which indicated that their self-reported epistemic beliefs were relatively sophisticated.

Nature of knowledge. In Elder's *Epistemological Beliefs Questionnaire*, reporting high scores on *Certainty* and *Developing* dimensions mean that participants view scientific knowledge consists of complex concepts with subjectivity and evolves over time as new discoveries are made. Haley scored 2.9 and 2.8, Sara scored 2.5 and 2.8, Molly scored 2.8 and 3 on average in *Certainty* and *Developing* dimensions on the pretest and posttest, respectively. The results showed that their self-reported beliefs were relatively sophisticated as they believed knowledge consists of complex concepts that evolve over time. During the post interview, they also expressed such beliefs:

Researcher: Okay, so do you think scientific knowledge is certain and objective?

Haley: Well, nothing is certain. There's always going to be more evidence and more discoveries.

Sara: So they can counter the claim or whatever it is.

Researcher: Okay. So do you think scientific knowledge will change over time?

Sara: Yeah, it will change as new discoveries as made.

From the conversation above, it was shown that the students believed scientific knowledge is uncertain and evolving because the current scientific knowledge can be "countered" by new evidence or discoveries. In addition, during the conversation below, their discourse also revealed that they understood the subjectivity of scientific knowledge.

Researcher: So if you find two websites that offer opposite information about something, what do you do?

Haley: Look for other websites and see what they say. Like find my own information besides just the two.

Researcher: Okay. So do you think only one website is right or could both of them be right?

Haley: They could both be somewhat right because it's also about how you say it. Because the same evidence could be used for or against it in the way you put it into your argument.

Researcher: Depends on how you use it…what claim you are going to make?

Haley: Yeah.

As Haley mentioned, she believed two websites that provided opposite information could both be somewhat right based on "how you say it." According to the developmental model of epistemic beliefs, her discourse reflected a multiplism/ subjectivism point of view (Muis et al., 2012), in that she believed knowledge consists of subjective, uncertain opinions that can be equally right. That meant, she started to understand the subjectivity of knowledge and did not believe knowledge is either right or wrong and can be known with certainty. When dealing with the information from stakeholders, Haley also expressed her understanding of the subjectivity of knowledge. During the post interview, she said although a few stakeholders said water quality is not good, such opinions were "kind of relative" because "compared to other places, like California, our water quality is pretty good." It indicated that she understood that the statement of whether water quality is good or bad is relative and subjective based on different contexts and perspectives. In summary, the discourse of the students in Group 3 revealed that they acknowledge the uncertainty and subjectivity of knowledge, which was consistent with their self-reported epistemic beliefs from pretest and posttest.

Nature of knowing. Students' epistemic beliefs of the nature of knowing were discussed below under the *Source of knowledge* and *Justification of knowing* dimensions separately.*Source of knowledge.* According to their responses on the *Epistemological Beliefs Questionnaire*, Haley, Sara, and Molly scored 2.8 and 3.0, 3.0 and 3.0, 3.0, and 3.0 on the *Authority* dimension on the pretest and posttest, showing that all of them hold sophisticated beliefs about the source of knowledge. All of them self-reported that they believed individuals can construct knowledge in interaction with others rather than only acquiring knowledge resides in external authority. During their inquiry practice, they tended to use water quality tests, online information, and observation as their source of knowledge, which was consistent with their sophisticated beliefs reported on the pretest and posttest.

The students in Group 3 collected information during their field trips. For example, both Haley and Molly carefully recorded all water quality test data they collected during the field trips in a data table. Molly also drew a map of their local river on the whiteboard and marked all sites where they did water tests. All three students also made notes of the stakeholders they visited. They all created a table with three columns to record the names of the stakeholders, their occupations, and their opinions about water quality.

On Day 6, the students spent one hour to search for online information about water quality. They decided to assign Haley to search for information about pH and nitrate, Molly to search for dissolved oxygen and turbidity, Sara to search for phosphate. It is important to note that when the students in Group 3 searched for information about water quality indicators, they also tried to understand why these indicators are important. Haley told Molly and Sara, "besides looking for definitions [of indicators], we should also look for why it is important, like how it affects water quality," which showed that they were actively acquiring knowledge by conducting online search. Hence, in their journals, they made notes of water quality indicators as well as why these indicators are important to water quality. Besides the definition of phosphate, Sara also wrote down why phosphate is important to water quality—"Phosphate is necessary for the growth of plant and animals. If there is too much phosphate then weeds and algae will increase in growth and block the water ways." In addition, in Haley and Molly's journals, they also noted the name of the websites that they acquired information from, which implied that they were aware of the importance of recording the source of information. Later on Day 6, the students also searched for the state water quality standards on the Internet and listed all six water quality indicators (e.g., phosphate, nitrate, dissolved oxygen) on their journals.

The students in Group 3 also used information from the stakeholders as evidence. Unlike other students, they tended to evaluate the information from the stakeholders before they used it as their evidence. During the post interview, they expressed their attitude toward information from stakeholders:

Researcher: When we talked to the stakeholders, some of them had different opinions about water quality. So what would you do in that situation?

Sara: Well you can't use opinions as something for an essay or a report because that's not fact. And everyone is entitled to their opinion, it's not that. You can't say that the stakeholder, even if he has a giant cattle farm, you can't say that he thinks the water quality is good and just leave it at that. You have to have more evidence; you can't take an opinion because it just won't cut it at all.

Researcher: Okay, what about you two?

Haley: Well with the stakeholders if they said the water quality was good or bad, I wasn't really grateful if they did not say why they thought that. They have to have the facts to back up their claim.

Researcher: So if they're saying it's good or not, and they don't provide any evidence then it's hard to tell if it's true or not?

Sara: You also kind of have to decided who's opinions matter because the people that don't know, the people who don't work with water all the time, they don't know what the water quality is like but the people that are working with the drinking water as it comes in from the water, those people know what they're talking about.

Researcher: Yeah, so they are professionals in their field. So it's not like you are asking this question to a random person?

Haley: Yeah.

From the conversation above, it can be seen that the students were critical of information from the stakeholders. They stated that they could not use opinions as their evidence if they are not facts. They expected stakeholders to use facts to back up their claims when they were expressing their opinions of water quality. In addition, they also mentioned a need to consider the credentials of the stakeholders before they accept the information from them, because some people may not know about water quality if they do not work with water all the time. Therefore, their discourse indicated that they viewed themselves as knowers who actively acquire and evaluate knowledge from others rather than accepting knowing passively. During their presentation, they stated,

> When we went to a drinking water treatment plant they said that the only chemical that they had to put into our water was chlorine. And if they only need to put in one substance that isn't natural into our water system then that indicates that water is fine on its own, it only needs one substance in it.

Rather than stating the spring water is good only because one of the stakeholders said so, they had evaluated and comprehended the information from the stakeholders before they used it as their evidence. They trusted information from people who works with drinking water was credible because they are professionals in their field and "know what they are talking about." Therefore, they believed spring water is good quality because it was based on the evidence that "only one substance" chlorine is being added to the spring water" in the drinking water plant. To sum up, the discourse showed in these examples indicated that the students in Group 3 constructed knowledge as knower by actively acquiring and evaluating knowledge, which was consistent with their sophisticated self-reported epistemic beliefs.

Justification of knowing. Haley, Sara, and Molly scored 3.0 and 2.9, 2.9 and 2.8, 2.8 and 2.9 on the *Reason* dimension on the pretest and posttest respectively. That meant that they held sophisticated epistemic beliefs as they believed justification of knowing comes from applying rules of inquiry, reasoning, and testing. Such beliefs were evidenced in their inquiry practice as they made personal interpretations and evaluations of the data they collected as their evidence. They also comprehended and evaluated information from stakeholders before they used it as evidence.

With the information they collected during the field trips and from their online search, the students were able to justify their knowing by analyzing water quality data and interpreting the results. For example, Molly wrote in her journal, "the dissolved oxygen was below the minimum [level required the standard] when it close to the city. The air and water temperature also fluctuates a lot more when it get closer to the city." Her discourse indicated that she started to justify her knowing by comparing the water quality data against the state standards and identifying the change of data across multiple sites. Similarly, Sara also made personal justification of knowing by examining the trend of water quality data. In her journal, she wrote "the water quality is good in the mountain but it is not as good in the valley. The water turbidity increases as it comes closer to the town." Unlike Molly and Sara, Haley did not analyze water quality data by identifying trends. Instead, she calculated average readings for all the water quality indicators from the eleven tests they conducted. On Day 8, when I asked her why she was calculating average readings, she responded "I want to get a general idea of this [data] and compare it with the standards." Although comparing average readings to the standard may not be the correct way to examine water quality, this act still showed that Haley was using her own way to get a sense of the water quality data. By calculating average readings, she tried to justify her knowing by summarizing the water quality data.

RQ2: How do students' epistemic beliefs contribute to the construction of their problem solving processes. In Group 3, guided by their sophisticated epistemic beliefs, the students were able to analyze and interpret the information they have found before they used it as their evidence.

Using water quality data as their evidence. As discussed earlier, the students' inquiry practice revealed that they held sophisticated beliefs of the source of knowledge as they self-constructed knowledge by conducting their own investigations rather than automatically accepting information from external authorities. Guided by such beliefs, they analyzed and evaluated water quality data and used it as evidence to support their claims during their problem solving processes. They did not use much information from the stakeholders as their evidence as they believed opinions from stakeholders cannot be used directly as evidence. During the post interview, students described their approach to use evidence to support their claims about water quality in the conversation below.

Researcher: What kind of things do you think can be used as evidence?

Sara: For our argument the tests that we do, the turbidity, the phosphate and all that…

Researcher: Water quality tests?

Sara: Um huh. That could all be evidence.

Haley: And actual facts from the tests, not opinions.

Sara: Because it was kind of subjective, we would ask people, "Do you think we have a water quality problem?" So their answer was their opinion so there was no cold, hard fact if they just said it was not.

Researcher: So you think the water quality test is the cold, hard fact?

Sara: Yes.

Researcher: Okay so what about you?

Molly: Yeah just the real facts that aren't opinions.

Researcher: So… just opinions cannot be used as evidence?

Sara: Yeah.

Researcher: So how and where did you find the evidence to support your claim?

Sara: We did the tests and we went to multiple sites throughout Green Valley, we went up into the mountains and did it there a few times throughout the classes and then most recently this week we went down to the city.

Researcher: Right. What kind of evidence is particularly helpful to support your claim? For example, the observation that you made during the field trip, or things that you learned from guest speakers, or water quality test, what kind of information do you think is particularly useful?

Haley: I think, again, the test data. That's been most useful.

Researcher: Do you all agree with that?

Sara: Yes.

In the conversation above, the students mentioned that the information from stakeholders is "kind of subjective" because they are just opinions rather than "cold, hard facts." Therefore, they did not think opinions from stakeholders could be directly used as evidence. As they said, they tended to use water quality data as their evidence to support their claim, which was consistent with their performance in their presentation. In their final presentation, the students stated, "there is no water quality problem in Green Valley because it has good dissolved oxygen levels, good phosphorus levels, and a good average temperature for animals to survive in." In the presentation, Haley said;

> Green Valley has good dissolved oxygen levels. For an aquatic area water must have good DO number of 6.5 for plants and animals to thrive. Based on our results, Green Valley has a healthy number for dissolved oxygen…around 7 or 8,

except the site at storm water [management facility].

Sara said, "the phosphorus levels were all 0 except for the ponds at the very last one which was a 0.1 which wasn't that bad so the phosphorus levels were pretty good."

Unfortunately, in their presentation, the students did not mention water quality test data about pH and turbidity. However, in their science journals, it can be seen that they compared data from pH and turbidity test to the state standards and interpreted the results. For example, in Haley's journal she wrote "pH level is good because pH is where it is supposed to be [on the standards]," which indicated that she evaluated the pH test data by comparing it with the state standards. Similarly, by comparing water quality data with the state standards, Molly wrote, "dissolved oxygen in general is good because it is above 6.5 except at one site, the turbidity is around 10 NTUs except at two sites." Although these findings about pH and turbidity did not make into the presentation, they still analyzed and evaluated the water quality data during the PBL unit. Their discourse from presentation and their journals indicated that, guided by sophisticated beliefs of the source of knowledge, they analyzed and evaluated water quality data as a way to develop their evidence to support their claim.

Making sense of the information they acquired. The inquiry practices of Group 3 showed that they held sophisticated epistemic beliefs of justification of knowing, as they believed justification of knowing comes from applying rules of inquiry and making personal evaluations and integrations of the views of the experts. Influenced by such beliefs, the students in Group 3 tended to comprehend the information they have acquired during the PBL unit and made sense of it before accepting it. As discussed earlier, when the students searched for information about water quality, they not only searched for the definitions of the several water quality indicators, they also searched for information about why these indicators are important to understand how they affect water quality. This shows that they tried to make sense of the information they have acquired before used it as their evidence. Hence, during their final presentations, besides presenting their findings of water quality, all the students also explained why the water quality indicators they tested with are important.

First, during the presentation Haley said, “Dissolved oxygen is the amount of oxygen in the body of water. DO is measured in milligrams per liter or the number of milligrams of oxygen dissolved in a liter of water. If the dissolved oxygen levels... fall... that will most likely result in the death of some fish, vertebrae and other small organisms.” Her discourse indicated that she learned the meaning of dissolved oxygen and understood how dissolved oxygen levels impact aquatic lives. Second, followed Haley, Sara explained how phosphorus impacts water quality. She said “phosphorus is the nutrient in short supply in most freshwater areas, and even a small increase of the phosphorus can cause everything to start going crazy. It can cause plants to start to grow too much, and algae will go everywhere. And it will reduce the dissolved oxygen level so fish will die.” It can be seen that Sara understood why phosphate level is important to water quality and how dissolved oxygen level can be influenced by phosphate level in a water system. Last, Molly explained that water temperature is important because it “should be good for fish to live in it” and can also influence water quality because “if water is too hot then the dissolved oxygen goes down.” These examples showed that the students acquired information about water quality indicators from online search. More importantly, their discourse revealed that they understood the meaning of these water quality indicators and made sense of how they impact water quality in different ways. Besides comparing water quality data with the state standards to examine water quality, they also explained to the rest of class that why these water quality indicators are important to water quality.

The students also made sense of other information they acquired during the PBL unit. For example, Molly thought the water quality is good because "we found lots of bugs in the water, so it [water] is probably not contaminated" as she wrote in her journal. Although having found bugs in the water alone may not be sufficient to prove the water quality is good, this still indicates that she made sense of the information from her observation during the field trips. Guided by their sophisticated epistemic beliefs of justification of knowing, the students made personal justification of the information they acquired. As a result, although their presentation had a few flaws (they did not mention pH and turbidity), the evidence they presented during their presentation was accurate and organized with a clear logic flow.

RQ3b: How and why do students' epistemic beliefs changes. In Group 3, Haley scored 95 and 95, Sara scored 93 and 92, and Molly scored 95 and 96 in the pretest and posttest respectively. The results showed that the students' self-reported epistemic beliefs stayed consistent during the PBL unit. Similar to Group 1, the results may be subject to a "ceiling effect" since the students received high scores in both the pretest and the posttest. During the post interview, the students' reflections implied that they might further develop their epistemic beliefs during the PBL unit through their inquiry practices.

During the post interview, the students expressed their understandings of the scientific method:

Researcher: Do you think all scientists use the same methods to do research or they may use different methods?

Haley: I think it depends on what they're looking for. Like what they are searching for and trying to understand.

Sara: And everyone has different methods of approaching something because they may be in the same field but that doesn't necessarily mean they'll do it exactly the same. Like in field trips, some of them do research on fish, some of them do other kind of tests.

Haley: It's like how some people learn differently. Scientists also research things differently.

As shown in the conversation, the students understood that scientists do research in different ways. Sara's responses implied that she learned from the field trips that different scientists use different methods to research water quality. This may have helped her to understand that even in the same research field, scientists may use different approaches to do research.

In the conversation below, the students also expressed that they learned more about how scientists do research by observing and conducting scientific inquiry in real life settings.

Researcher: Okay so during this summer class, did you learn more about how scientists do research?

Haley: Yeah, because it's not just like in a textbook or movie anymore, it's in real life.

Researcher: Okay, so can you give me any examples?

Sara: Like people have to do research, they have to go out in the field and actually collect it. They have to look up sources and consult with other people. They can't just go to Wikipedia and look it up, they have to find reliable sources and if they can't do that, then they have to go look at it in the field because that's another reliable source that they can look up.

Researcher: Okay, what about you?

Molly: Um, yeah. It would be much harder to understand how you take the tests for turbidity and the dissolved oxygen in the water and all these things if you didn't go out and do it, if you just read about it or heard about it or whatever. I wouldn't learn as much.

As the students said in the conversation, they believed that learning science in real life settings helped them understand the concept of turbidity and dissolve oxygen better. They also learned that scientists collect data "in the field" or acquire information from "reliable sources" to conduct research, which showed that they understand more about how scientists collect data in different ways. Their discourse shown in the examples indicated that, by observing and conducting scientific inquiry during field trips, the students developed their understandings of the complexity of the nature of knowledge and the method of making it.

During the post interview, the students stated that they learned how to construct argument during the PBL unit. As Haley said, "in our classes we learned how to create like essays and an argument. You need a claim, you need evidence to back it up." However, in the conversation below, the students also expressed that it was challenging for them to integrate information and use it into their argument.

Researcher: Did you find any difficulties, what are these things that were particularly difficult for you to create an argument?

Haley: I think because there's a lot of different pieces of evidence I think just connecting them.

Researcher: Integrating them?

Haley: Yeah into a logical argument.

Researcher: Okay, what about you?

Molly: Yeah just figuring out how to connect everything and sorting out the good information from the bad information was hard sometimes.

Researcher: Because we went to different field trips and we learned about different things so you think it's hard to combine the things together?

Molly: Um hum.

This indicates that students were exposed to the complex processes by which (a) information is evaluated and integrated and (b) evidence is leveraged to support claims. By integrating and evaluating information from multiple sources, the students were required to make justification of the information they were presented. The students may have benefited from this process by perceiving the uncertain, subjective nature of scientific knowledge and applying inquiry and reasoning processes to justify their knowing. Hence, although the students' self-reported epistemic beliefs stayed consistent during the PBL unit, engaging in inquiry activities provided opportunities for them to further develop their epistemic beliefs in practice.

Cross Case Analysis

Although I did not aim for generalization of the findings from the three case study groups, I compared the results from the three case study groups and summarized a few themes that were merged across groups.

RQ1: What are middle and high school students' epistemic beliefs about science. To compare students' self-reported epistemic beliefs and beliefs that revealed from their inquiry practice, I presented quantitative and qualitative results in Figures 1- 3 (each discussed and shown separately).

Nature of knowledge. In Figure 1, for each group, the scale above represents students' self-reported beliefs of the nature of knowledge, each student's average score on *Certainty* and *Developing* dimensions was marked on the scale with the initial of his/her pseudonym. The axis below represents students' beliefs of the nature of knowledge revealed from practice, group's beliefs as a whole was marked on the axis to indicate the level of sophistication of it. In Figure 1, it can be seen that for Group 1 and Group 3, the students reported sophisticated beliefs related to the nature of knowledge on pretest and posttest, and such beliefs were also revealed from the results of discourse analysis. Members of Group 1 and 3 acknowledged the uncertainty and subjectivity of knowledge and expressed their understandings that knowledge evolves as technology advances. In the case of Group 2, their epistemic beliefs scores indicated that Kate reported a neutral view on knowledge is either absolute truth or a continuum that changes over time. Emily and Linda reported relatively sophisticated epistemic beliefs. However, results from discourse analysis showed that all of them failed to understand the uncertainty and subjectivity of scientific knowledge. Therefore, although they acknowledged that scientific knowledge can change over time as new discoveries are made, their beliefs revealed from practice were still at a suboptimal level.

Nature of knowing. Figure 2 shows students' epistemic beliefs related to the source of knowledge. For each group, the scale above represents students' self-reported beliefs of the source of knowledge, each student's average score on *Authority* dimension was marked on the scale with the initial of his/her pseudonym. The axis below represents students' beliefs about the source of knowledge revealed from practice, group's beliefs as a whole was marked on the axis to indicate the level of sophistication of it. As shown in Figure 2, all three students in Group 1 reported sophisticated beliefs of the source of

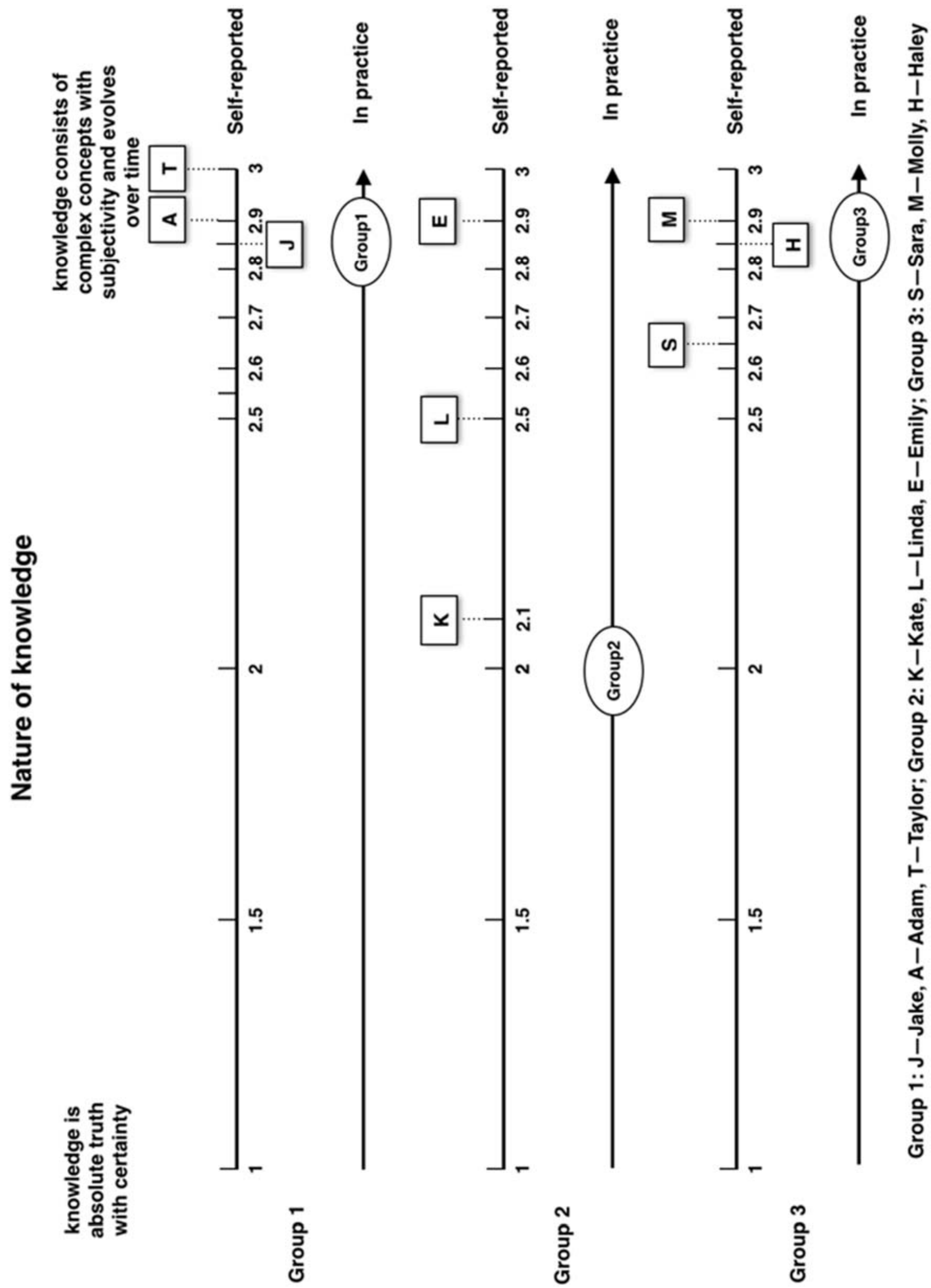

Figure 1. Students' epistemic beliefs of the nature of knowledge.

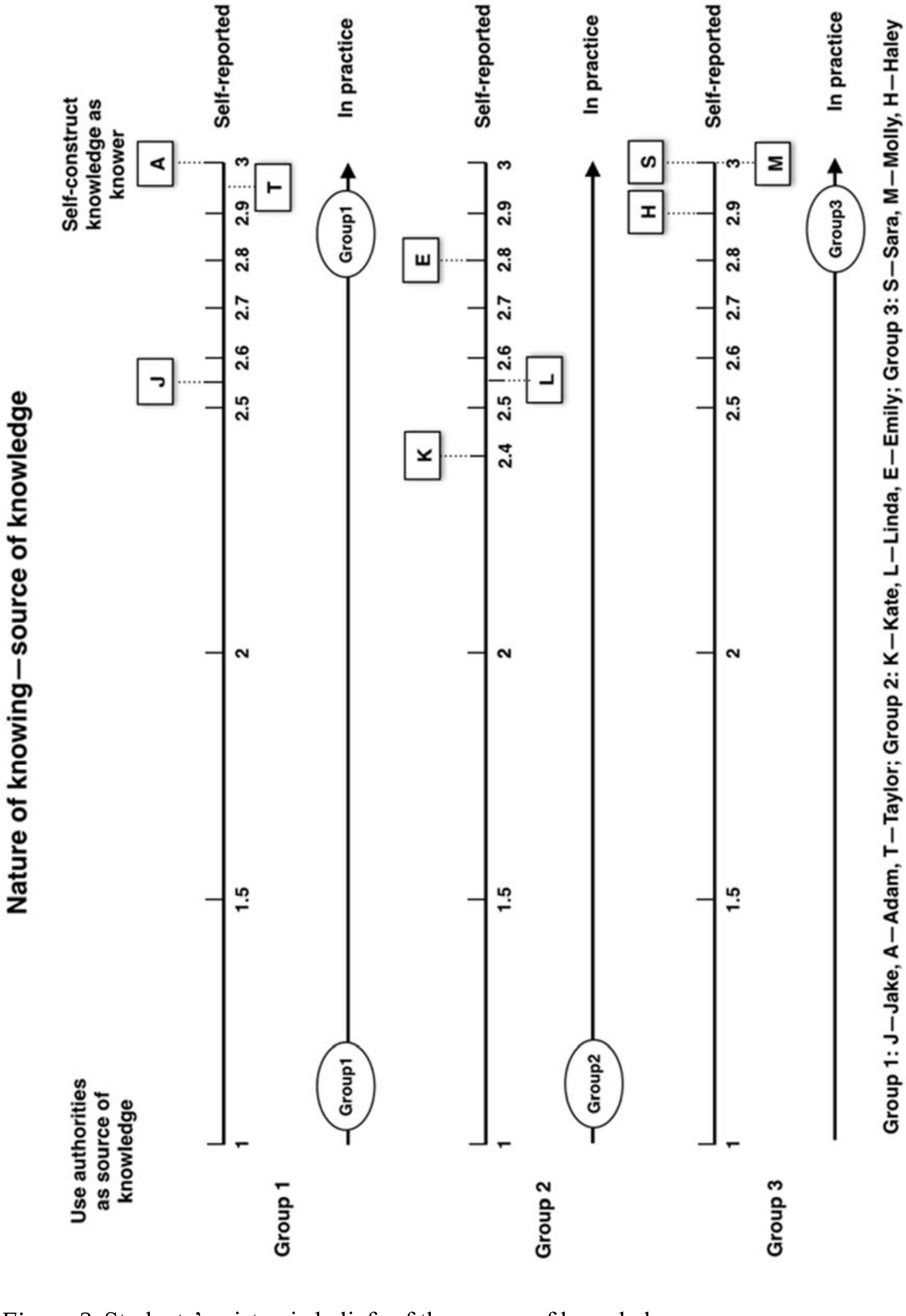

Figure 2. Students' epistemic beliefs of the source of knowledge.

knowledge, however, their inquiry practice revealed that they hold mixed beliefs of the source of knowledge. Therefore, Group 1's beliefs about the source of knowledge revealed from practice were marked on both ends of the axis. The sophisticated aspect of their beliefs of the source of knowledge was evidenced as they self-constructed knowledge by analyzing water quality data. Meanwhile, their inquiry also revealed the naïve aspect of their beliefs as they accepted knowledge directly from external authorities. In the case of Group 2, students self-reported that to some extent they agreed with knowledge comes from reasoning and applying rules of inquiry. Nevertheless, the students' inquiry practices revealed that they hold naïve epistemic beliefs of the source of knowledge as they used stakeholders as their only source of knowledge. Since they did not record any water quality test data from the field trips, they did not analyze any data to conduct their own investigations of water quality.

Members of Group 3 self-reported sophisticated beliefs of the source of knowledge, which was also revealed from their inquiry practice. They constructed knowledge by conducting investigations of water quality rather than automatically accepting information from external authorities. During the unit, they actively acquired and evaluated information from water quality tests, online search, and observation.

Figure 3 shows students' epistemic beliefs of justification of knowing. For each group, student's average score on *Reason* dimension was marked on the scale with the initial of his/her pseudonym. The axis below represents students' beliefs of justification of knowing revealed from practices. For Group 1 and 3, their group's beliefs as a whole were marked on the axis to indicate the level of sophistication of their beliefs. For Group

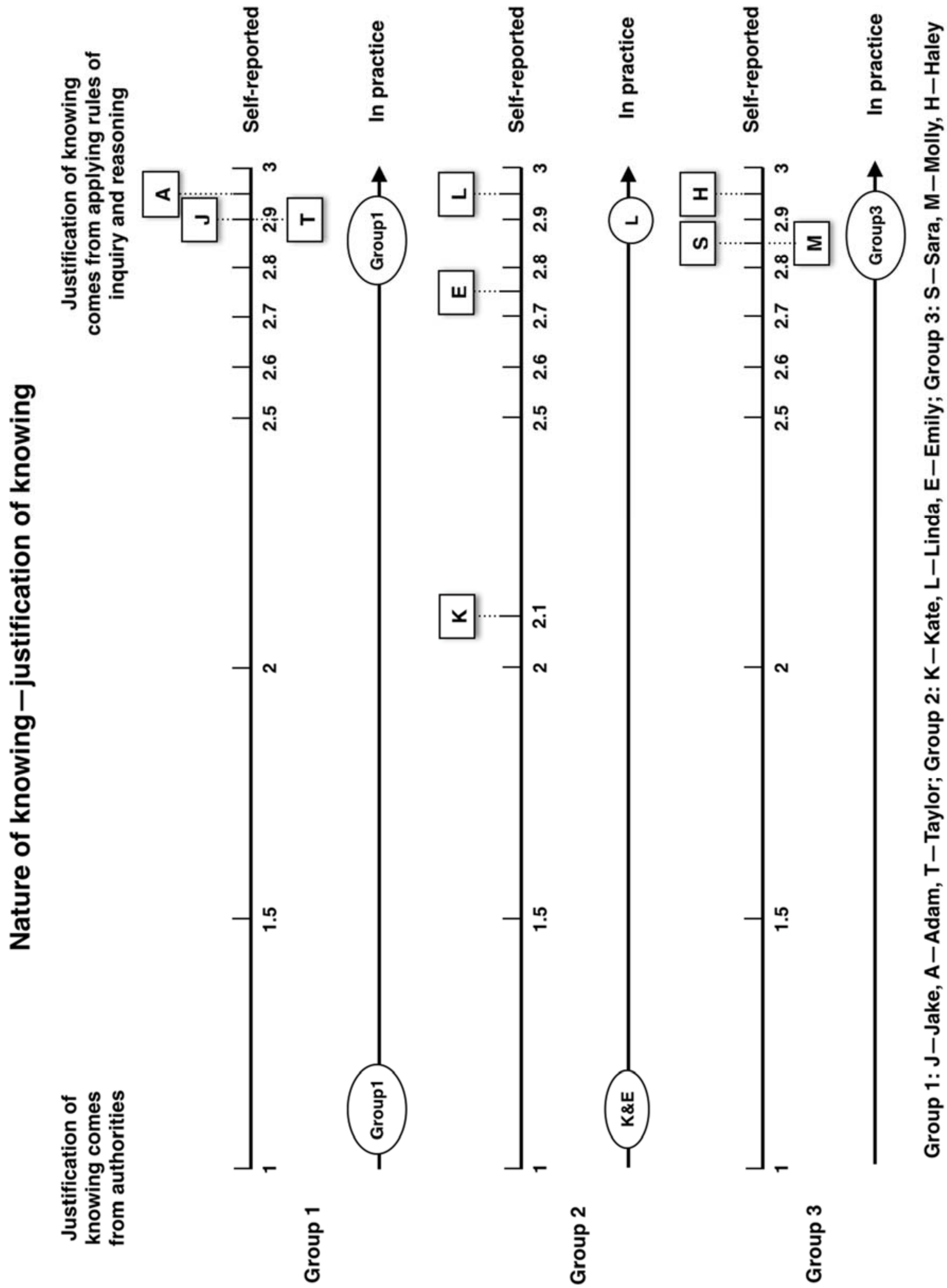

Figure 3. Students' epistemic beliefs of justification of knowing.

2, as students' beliefs revealed from practice were different, their beliefs were marked on the axis separately.

In Group 1, the students reported sophisticated beliefs of justification of knowing as they agreed with justification of knowing comes from applying rules of inquiry and reasoning. As shown in Figure 3, their inquiry practice revealed that they hold mixed beliefs of justification of knowing. To some extent they justified their knowing from reasoning and testing but at the same time, they failed to make personal justifications and integrations of expert's views.

In the case of Group 2, Kate reported suboptimal epistemic beliefs as she held a neutral view on whether justification of knowing comes from authorities or applying rules of inquiry and reasoning. Emily and Linda self-reported sophisticated epistemic beliefs of justification of knowing. Their inquiry practice revealed that Kate and Emily held naïve beliefs of justification of knowing, as they tended to justify their knowing through authority, or on the basis of what feels right. On the contrary, Linda held relatively sophisticated epistemic beliefs as she tended to make personal justification of her knowing, which was consistent with her self-reported beliefs.

Students in Group 3 all reported sophisticated beliefs of justification of knowing as they agreed that justification of knowing comes from applying rules of inquiry and reasoning. Such beliefs were also evidence in their practice. They tended to comprehend the information they have acquired during the PBL unit and made sense of it before accepting it.

The results from three case study groups indicated that some students' self-reported epistemic beliefs were inconsistent with their beliefs revealed from practice. For students who reported sophisticated beliefs, their beliefs revealed from practice sometimes were less sophisticated. For students who reported suboptimal beliefs, their beliefs revealed from practice sometimes were even less sophisticated rather than more sophisticated. That being said, it is possible for students to report sophisticated beliefs and apply such beliefs or less sophisticated beliefs in practice. But it is unlikely for students to report suboptimal beliefs and apply more sophisticated beliefs in practice. Holding sophisticated self-reported epistemic beliefs is the prerequisite for students to apply such beliefs in practice.

RQ2: How do students' epistemic beliefs contribute to the construction of their problem solving processes. I did not find direct evidence that students' beliefs of the nature of knowledge contribute to the construction of their problem solving processes. However, discourse analysis indicated that students' beliefs of the nature of knowing directly influenced the way they constructed arguments during their problem solving processes. Table 7 presents the levels of sophistication of students' beliefs of the nature of knowing and associated problem solving approaches. Because the students in Group 1 held mixed epistemic beliefs, the influences of their sophisticated and naïve aspect of epistemic beliefs are discussed separately.

Influence of naïve epistemic beliefs of the source of knowledge. Students who believed that knowledge comes from external authorities did not evaluate or try to comprehend information from stakeholders before they used it directly as their evidence. Group 2 members misunderstood information from stakeholders and used the incorrect

Table 7

Students' Epistemic Beliefs of the Nature of Knowing and Problem Solving Approaches

Group	Epistemic beliefs	Level	Problem solving approaches
1	Source of knowledge	Naïve	Accept knowledge directly from external authorities
		Sophisticated	Conduct online search and analyzed water quality data
	Justification of knowing	Naïve	Failed to address and integrate conflict views from the stakeholders and chose one side of view to support their claim
		Sophisticated	Using findings from water quality data to support their claim
2	Source of knowledge	Naïve	Did not record or analyze water quality data, misunderstood the information from stakeholders
	Justification of knowing	Naïve	Used information from external authorities directly as their evidence and justified their knowing based on their assumptions rather than validated evidence
3	Source of knowledge	Sophisticated	Analyzed and evaluated water quality data as a way to develop evidence to support their claim
	Justification of knowing	Sophisticated	Comprehended and evaluated the information from the Internet and the stakeholders before they used it as evidence

information as evidence to support their claim. Group 1 members used information about drinking water from stakeholders as their evidence, although it could not support their claim about surface water quality.

Influence of sophisticated epistemic beliefs of the source of knowledge. Students who viewed themselves as knowers who can construct knowledge in interaction with others tended to actively acquire information from multiple sources. In the case of Group 3, the students acquired knowledge from water quality data, online search, and their observations and used it as their evidence. Influenced by their sophisticated aspect of beliefs of the source of knowledge, Group 1 members also analyzed water quality data and conduct online search to acquire knowledge.

Influence of naïve epistemic beliefs of justification of knowing. Students who believed justification of knowing comes from authorities failed to evaluate and integrate information from stakeholders to support their claims. Group 2 members failed to integrate conflicting information from different stakeholders and chose one side of opinions as their evidence. Also, they used their assumptions rather than validated evidence to support their claims. Similarly, influenced by the naïve aspect of their epistemic beliefs, Group 1 members chose one side of opinions from stakeholders as their evidence.

Influence of sophisticated epistemic beliefs of justification of knowing. Students who believed justification of knowing comes from applying rules of inquiry and reasoning made sense of information they acquired before using it as evidence. In the case of Group 3, they conducted online search to understand the meanings of water quality indicators and how these indicators influence water quality in different ways. In the case of Group 1, they made sense of water quality data by comparing it against the state water quality standards, and use the findings from data as evidence to support their claim.

RQ3: How and why do students' epistemic beliefs change. The self-reported epistemic beliefs of only one student (Kate from Group 2) from the case study groups improved (scores increased from 69 to 81) during the unit. Other case study students' epistemic beliefs scores stayed consistent during the unit (gain scores from posttest to pretest equal to 0, 1 or -1). Discourse analysis indicated that conducting scientific inquiry led Kate to become interested in the unit and learn more about how scientists do research, which may have contributed to the improvement in her epistemic beliefs. Although the epistemic beliefs of the other two students in Group 2 did not become more sophisticated, they still stated that conducting scientific inquiry in real life settings helped them learn science better, and they had opportunities to observe how scientists conduct research during the field trips.

Group 2 and Group 3 members reported sophisticated epistemic beliefs on both pretest and posttest. That meant their sophisticated epistemic beliefs stayed consistent during the unit. This result may due to a "ceiling effect" since these students received high scores in both the pretest and the posttest. Nevertheless, discourse analysis indicated that these students still benefited from participating in the scientific inquiry unit as they experienced the complex processes of conducting investigations and using evidence to support claims. By experiencing scientific inquiry in the unit, Group 1 members realized that scientific inquiry is a complex process that involves using advanced equipment and strict methods to get accurate and precise results. In addition, they also started to understand that water quality is a complex concept that can be investigated from multiple perspectives. By observing and conducting scientific inquiry in real life settings, Group 3 members understood more about how scientists collect data in different ways. As students were required to evaluate information and use it to support their claims, they benefited from this process by perceiving the uncertain, subjective nature of scientific knowledge and applying inquiry and reasoning processes to justify their knowing. Therefore, for students whose self-reported epistemic beliefs stayed consistent during the unit, engaging in inquiry activities still provided opportunities for them to further develop their epistemic beliefs in practice.

CHAPTER V

DISCUSSION

Interpretation of Results

RQ1: What are Middle and High School Students' Epistemic Beliefs about Science?

Self-reported epistemic beliefs. Pretest and posttest results showed that the students' self-reported epistemic beliefs were relatively sophisticated. On a 3-point scale, the pretest and posttest means on each dimension were equal or larger than 2.5, which indicated that the majority of the students espoused sophisticated epistemic beliefs stated in the questionnaire. In that sense, the students started to understand the nature of knowledge and knowing. Most participants self-reported that they perceived scientific knowledge as complex, uncertain, highly integrated and evolving, and agreed that scientific knowing stems mostly from applying rules of inquiry, logical reasoning, and testing.

Overall comparison. To compare the results from empirical studies that used the *Epistemological Beliefs Questionnaire* (Conley, Pintrich, Vekiri, & Harrison, 2004; Elder, 1999; Ricco et al., 2009), I listed the results from these studies in Table 8. Because I used a 3-point scale rather than a 5-point scale that used in these studies, I converted the means into standardized percentage means, defined as raw mean divided by the highest score on the scale. For example, a raw score of 2.5 out of 3 would be converted to a standardized percentage mean of 83.3%, while a raw mean of 2.5 out of 5 would be converted to a standardized percentage mean of 50%. As shown in Table 8, compared to the other three

Table 8

Students' Self-Reported Epistemic Beliefs from Empirical Studies

		Nature of knowledge				Nature of knowing			
		Certainty		Developing		Authority		Reason	
Results	Grade	Raw	Stand. % mean	Raw	Stand. % mean	Raw	Stand. % mean	Raw	Stand. % mean
The present study (3-point scale)	6-8	2.54	84.7	2.69	89.7	2.61	87.0	2.60	86.7
	9-12	2.46	82.0	2.80	93.3	2.61	87.0	2.74	91.3
Elder, 1999 (5-point scale)	5	2.54	50.8	3.99	79.8	2.28	45.6	4.33	86.6
Conley et al. 2004 (5-point scale)	5	3.38	67.6	3.90	78.0	3.68	73.6	4.26	85.2
Ricco et al. 2010 (5-point scale)	6	2.64	52.8	3.72	74.4	2.35	47.0	3.91	78.2
	7	2.51	50.2	3.55	71.0	2.24	44.8	3.83	76.6
	8	2.29	45.8	3.78	75.6	2.11	42.2	3.97	79.4

Note. To eliminate the impact of different instructional methods, the results from the present study and Conley et al. 2004 study were from pretests.

studies (Conley et al., 2004; Ricco, Schuyten Pierce, & Medinilla, 2010) that used the *Epistemological Beliefs Questionnaire* among K-12 students, the participants in this study espoused more sophisticated epistemic beliefs on all four dimensions. This result is encouraging as it indicated that middle and high school students with the average age of 15 can hold sophisticated epistemic beliefs. It also should be noted that this result may also due to the fact that different scales were used in these studies. Although I converted the scores into the percentage of the highest of scores on each scale, participants may not have a consistent interpretation of the distance between a response of agreement and disagreement.

Grade difference. The results from the present study showed that there was no statistically significant difference between middle and high school students' epistemic beliefs. High school students scored slightly higher on the pretest (*ES* = 0.13) and lower on the posttest (*ES* = -0.083) than middle school students. Using the same questionnaire, the results from Ricco et al. (2010) study also provided little evidence of consistent developmental changes in middle school students' epistemic beliefs. The current literature suggests that there is little difference between middle and high school students' epistemic beliefs. Middle and high school students are often categorized as one age group that is supposed to hold similar epistemic beliefs (Greene et al., 2008). Significant differences in epistemic beliefs was only found between adolescents (5th, 8th, and 12th graders) and college students or more mature adults (Kuhn et al., 2000) or between 5th graders and 13^{th} graders (Mason, Boldrin, & Zurlo, 2006). Overall, the results provide no evidence of differences in epistemic beliefs on the basis of grade level.

Gender difference. The results showed that female students scored higher than male students on both pretest (*ES* = 0.49) and posttest (*ES* = 0.55) with medium effect sizes according to Cohen (1988). However, since the sample size was small and the mean differences (overall scores or dimension scores) were not statistically significant, one cannot say that female students hold more sophisticated beliefs than male students. In the current literature, there are inconsistent results on whether there are gender differences in epistemic beliefs (DeBacker et al., 2008; Kessels, 2013). Gender differences in epistemic beliefs have been found on the dimensions of quick learning (Neber & Schommer-Aikins, 2002), innate ability (Topçu & Yilmaz-Tüzün, 2009), certainty of knowledge (Bendixen, Schraw, & Dunkle, 1998; Hofer, 2000), and justification of knowledge (Ozkan & Tekkaya, 2011) in favor of female students and on the dimension of omniscient authority in favor of male students (Topçu & Yilmaz-Tüzün, 2009). However, other studies found no gender difference (Buehl et al., 2002; Karabenick & Moosa, 2005; Kuhn et al., 2000; Liu & Tsai, 2008). Since these studies (including this study) used different conceptual models of epistemic beliefs and were conducted with different populations (e.g., elementary students, high school students, and undergraduate students), it was difficult to make general conclusions about gender differences in epistemic beliefs.

Overall, the quantitative results indicated that (a) the current participants' self-reported epistemic beliefs were more sophisticated than those of similar participants reported in the literature, and (b) there was no significant difference in epistemic beliefs between middle and high school students. Although no significant gender difference was found, female students reported more sophisticated epistemic beliefs than male students.

Epistemic beliefs revealed from practice. Students' epistemic beliefs revealed from practice are discussed below.

Nature of knowledge. Discourse analysis indicated that most participants were able to acknowledge the uncertainty and changing nature of knowledge. They believed that knowledge evolves as technology advances and the current scientific knowledge can be "countered" by new evidence or discoveries. However, members of Group 2 struggled to understand uncertainty and subjectivity of scientific knowledge. They believed scientific knowledge is certain and objective because it was based on "data" rather than "opinions." This shows that they failed to understand that scientific data are uncertain and subjective as the methods of acquiring and analyzing data is often influenced by the subjectivity of researcher (Ratner, 2002). According to the developmental model of epistemic beliefs, these two students hold an absolutist view that knowledge is absolute, either right or wrong since it is based on observation from reality or authority (Kuhn et al., 2000). The rest of the participants acknowledged the subjectivity of knowledge. For instance, one student in Group 2 stated that opposite information could both be somewhat right based on "how you say it." According to the developmental model of epistemic beliefs, her discourse indicated that she believed knowledge consists of subjective, uncertain opinions that can be equally right, which reflects a multiplism/subjectivism point of view of knowledge (Muis et al., 2012). Compared to a study conducted among 5^{th}- through 13^{th}-grade students (Mason et al., 2006), a lower portion of participants in this study showed absolutist point of view. More importantly, the finding of Mason et al.'s study indicated that, high school science curricula that present scientific knowledge in a manner with absolute certainty will lead more students to hold absolutist view of scientific knowledge. Thus, the fact that the participants in this study expressed more sophisticated beliefs of the nature of knowledge may due to their engagement in the open-ended, inquiry-based learning unit instead of a typical school science curriculum. Additionally, two students in Group 1 were able to understand the diversity of scientific methods, which is one aspect of the "*practical epistemologies*" (Sandoval, 2005) that are essential for students to effectively engage in scientific inquiry. It may due to the fact that students observed different scientific methods used by different stakeholders during the field trips, which helped them to perceive the diversity of scientific methods.

Nature of knowing. In terms of the source of knowledge dimension, the participants in this study mainly used two approaches to acquire knowledge. First, some students relied on external authorities to acquire knowledge; specifically, their only source of knowledge was what stakeholders said. Hence, these students' inquiry activities revealed naïve epistemic beliefs of the source of knowledge, as they did not acquire knowledge by conducting their own investigations of water quality. In the literature, it is often posited that students from four years old to early college age tend to believe that knowledge comes from authorities (Greene et al., 2008; Hofer, 2000). Therefore, it is not surprising to find out that some students in this study expressed such beliefs during their inquiry activities. Since these students did not have adequate ability to construct knowledge by themselves, they tended to rely on authorities to acquire knowledge (Muis & Duffy, 2013).

Second, the results also indicated that some participants in this study were able to self-construct knowledge by conducting investigations rather than automatically accepting information from external authorities. These students actively acquired and evaluated information from water quality tests, online searches, and observations, which indicated that their epistemic beliefs revealed from practice were relatively sophisticated. In this study, since students conducted investigations on their own during field trips, they were provided with more opportunities to gather evidence and support their claims, which in turn may have helped them to construct knowledge by themselves. In addition, as these students became active constructors of knowledge, they may have started to hold one of the "practical epistemologies" that scientific knowledge is socially constructed by people rather than simply discovered out in the world (Sandoval, 2005). This result is encouraging as it demonstrated that some middle and high school students are capable of constructing knowledge on their own when they are provided with opportunities to do so.

In terms of justification of knowing, some participants in this study tended to justify their knowing through authority, or on the basis of what feels right. When asked to use evidence to support their claims, they failed to make personal justifications of the information they collected or integrate stakeholders' views with evidence they themselves collected. Such difficulty integrating information from different perspectives is widely reported in the literature. When conducting online learning, although 6th graders were able to perceive the differences in perspective between conflicting information, they failed to integrate the conflicting information to form an integrated understanding (Barzilai & Zohar, 2012). Recent studies showed that even most college students did not use scientific standards to evaluate online information although they believed that knowledge claims can be compared and evaluated based on to what degree it is supported by evidence (Mason, Boldrin, & Ariasi, 2010). Therefore, in this study the result that some students failed to evaluate and integrate conflicting information during the unit is in line with the literature since middle and high school students often may not have sufficient epistemic metacognition strategies to integrate conflicting information (Barzilai & Zohar, 2014; Strømsø & Bråten, 2009).

Nevertheless, this study also provided evidence that some students were able to make personal justification of knowledge by applying rules of inquiry and reasoning. In the case of Group 3, students evaluated the information they acquired during the unit before accepting it and they compared the water quality data against the state standards to identify potential problems. These students may learn how to use evidence to justify knowledge claims from the instruction they received during the unit. As mentioned before, during the unit the teachers and I often encouraged students to collect evidence during field trips and use evidence to support their claims. Mr. Scott also asked students to debate with each other to exercise how to justify their claims. Because Mr. Scott commented on the students' debate with explanations of how to collect evidence and how to use evidence to support their claims, some students may have learned such strategies and applied such in their inquiry activities. Such contextual, explicit, reflective instruction on the approach to justify knowledge with evidence can help students develop more sophisticated understanding of the nature of science and argumentation skills (Khishfe, 2014; Khishfe & Abd-El-Khalick, 2002; Lederman, Lederman, & Antink, 2013). By receiving explicit and reflective instruction on how to use evidence to justify knowledge, some of the students were able to make personal justification of knowledge by applying rules of inquiry and reasoning.

Comparison between quantitative and qualitative data. Results from three case study groups indicated that among the three case study groups, only Group 3's self-reported epistemic beliefs were consistent with their beliefs revealed from practice. The rest of students' self-reported epistemic beliefs were at least partially inconsistent with their beliefs revealed from practice. There are three patterns can be summarized from the comparison between self-reported epistemic beliefs and the beliefs revealed from practice. First, for students who reported sophisticated epistemic beliefs, some of them applied such beliefs in practice. In the case of Group 3, they reported sophisticated epistemic beliefs and applied such beliefs during their inquiry activities. Members of Group 3 constructed knowledge by conducting investigations of water quality rather than automatically accepting information from external authorities. They tended to comprehend the information from water quality tests, online search, and observation and made sense of it, which indicated sophisticated beliefs of justification of knowing. In the current literature, all four dimensions of epistemic beliefs have been identified in students' think-aloud protocols during their learning process (e.g., Mason, Ariasi, & Boldrin, 2011). The results of this study further demonstrated that epistemic beliefs can also be revealed in students' inquiry activities in the four dimensions. It should note that in this study the students' epistemic beliefs were mostly revealed by their actions rather than utterances except during the post interview. As the students spent most of their time outdoor, they were provided with limited opportunities for prolonged conversation during the fieldtrips. In addition, as Strømsø and Bråten (2010) noted, students' epistemic beliefs are complex in nature, which is difficult to articulate in action. In this study, the students seldom spontaneously engaged in conversation about the nature of knowledge and knowing during the unit, but they were able to express their epistemic beliefs when asked about related questions during the post interview. This situation may due to that students' epistemic thinking process is at the metacognitive level (Hofer, 2004a), which is silent unless they are promoted to verbalize their thinking processes (Mason & Boldrin, 2008; Muis & Franco, 2009). As such, although in this study the students worked together to construct their arguments during the unit as shown by their group learning activities, it was rare for them to spontaneously express their epistemic beliefs during their inquiry activities.

Second, some students self-reported sophisticated beliefs but their epistemic beliefs revealed from practice were less sophisticated. These students to some extent agreed with sophisticated statements on the nature of knowledge and knowing in the area of science, but they failed to fully apply such beliefs in practice. In the case of Group 1, their self-reported sophisticated epistemic beliefs of the nature of knowledge were also evidenced in their discourse. Nevertheless, their sophisticated self-reported epistemic beliefs of the nature of knowing were partially inconsistent with their beliefs revealed from practice. The sophisticated aspect of their beliefs of the nature of knowing was evidenced as they self-constructed knowledge by analyzing water quality data and justified their knowing from reasoning and testing. Meanwhile, their inquiry also revealed the naïve aspect of their beliefs as they accepted knowledge directly from external authorities and failed to make personal justifications and integrations of expert's views. Similarly, two students in Group 2 self-reported sophisticated beliefs of the source of knowledge, but neither of them analyzed any data to conduct their own investigations of water quality and they used stakeholders as their only source of knowledge. When presented with conflicting information, they also struggled to evaluate it from different perspectives and integrate it due to their insufficient epistemic metacognition strategies (Barzilai & Zohar, 2014; Strømsø & Bråten, 2009).

Third, for students who reported suboptimal beliefs, their beliefs revealed from practice were found to be even less sophisticated. One student in Group 2 self-reported suboptimal beliefs as she was not sure whether knowledge exists with certainty and whether justification of knowing comes from authority. During the unit, her discourse indicated that she failed to understand the uncertain and subjective nature of knowledge. Her epistemic beliefs revealed from practice were naïve as she did not record or analyze any water quality data and justified her knowing through authority or on the basis of what feels right. That means, if students do not report sophisticated epistemic beliefs, it is unlikely for them to apply such beliefs in practice because students' epistemic beliefs influence the goals they set during their learning processes (Bråten et al., 2011; Hofer, 2004b; Muis, 2007). For instance, for students who believe knowledge comes from authorities, they are more likely to view learning as simply a matter of reiterating the knowledge comes from authorities (Muis & Franco, 2009) so that it is unlikely for them to construct knowledge by themselves.

These patterns can be interpreted from several perspectives. First, the results showed that although middle and high school students may self-report sophisticated beliefs of the nature of knowledge and knowing, it was challenging for them to apply such sophisticated beliefs in practice. In the current literature, it has been well documented that middle and high school students often struggle in PBL as they lack of sufficient skills to actively acquire and evaluate information, and use evidence to support their claims (Berland & Reiser, 2009; Kuhn et al., 2000; Kyza & Edelson, 2005). These difficulties may result from insufficient cognitive ability to engage in argumentation among adolescents (Barzilai & Zohar, 2014, Kuhn & Udell, 2007). Adolescents often do not have the necessary epistemological understanding of the meaning of justification

(Kuhn et al., 2000; Mason & Boscolo, 2004). The fact that some students failed to apply their sophisticated epistemic beliefs in practice may be explained by their difficulties to conduct scientific inquiry in real life settings.

Second, from the methodology perspective, the inconsistent results from qualitative and quantitative analysis also raise the question of the reliability of self-reported measures. The validity of self-report instruments is threatened because some instruments have low internal consistency and poor factor structure of the instruments (DeBacker et al., 2008; Greene et al., 2008). Also, students may interpret the meaning of items in the self-report measures differently than researchers (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Muis et al., 2012). In this study, on pretest and posttest, students reported to what extent they agree with several statements of beliefs of the nature of knowledge and knowing in the area of science. In order to examine students' understanding of how scientists construct scientific knowledge, some items were written as statements about scientists. For example, item 31 ("Scientists always agree about what is true in science") was supposed to examine students' understanding of the uncertain, subjective nature of knowledge. However, agreeing to such beliefs does not necessarily mean that the students would apply such beliefs when engaging in scientific inquiry. For example, some students stated that scientists used more advanced and accurate methods than them to conduct scientific inquiry, but they also thought although the water quality tests methods they used were not strictly controlled, but it "will do" for their purpose. Therefore, reporting sophisticated understandings of how scientists conduct scientific inquiry does not necessary mean that the students would use the same way to conduct scientific inquiry on their own. Students may hold different beliefs of science in general and scientific practices that conducted by themselves. Therefore, only using self-reported measures of epistemic beliefs about science in general is not sufficient to understand what epistemic beliefs students would apply during scientific inquiry.

Third, the difference between students' self-reported beliefs and their beliefs revealed from practices implies that epistemic beliefs are highly influenced by contextual factors. In the current literature, researchers tended to agree that epistemic beliefs are domain-specific (Buehl et al., 2002) or at least both domain-general and domain-specific (Muis et al., 2006). In this study, students' self-reported beliefs were measured in the science domain, and their beliefs revealed from practice were examined in a specific problem-based scientific inquiry unit. The differences between these two types of beliefs may represent the differences between students' general epistemic beliefs in the science domain and their context-specific beliefs of the scientific inquiry unit. Students may hold general epistemic beliefs in the science domain, but their beliefs are also malleable (Gill et al., 2004) as they can be affected by a specific context (Gottlieb & Institute, 2007; Hammer et al., 2002). As the participants conducted scientific inquiry in real life settings, the contextual factors in these settings may influence, shape, and elicit individuals' epistemic beliefs differently than in-class learning (Hofer, 2006). As such, students' epistemic beliefs revealed from practice were under the influence of the context factors in this specific unit so that it may become inconsistent with the ones measured by the questionnaire.

Based on the comparison between these two types of epistemic beliefs, general speaking, holding sophisticated epistemic beliefs on their minds is a prerequisite for students to apply such beliefs in practice. Some students were able to apply sophisticated beliefs while others failed to do so. Students who reported suboptimal beliefs applied even less sophisticated beliefs in practice. It is not likely for students to apply sophisticated beliefs in practice if they do not hold such sophisticated self-reported epistemic beliefs. The inconsistency between these two types of epistemic beliefs may due to students' inadequate cognitive ability, the reliability issue of self-report measure, and the influence of contextual factors.

The results from this study indicated that some participants were able to report and apply sophisticated epistemic beliefs in their inquiry activities. Generally speaking, the participants in this study reported more sophisticated beliefs than the beliefs reported in the literature. Although some participants failed to apply such sophisticated beliefs in practice, it was understandable since even some college and graduate students failed to do so. More importantly, it is encouraging to find out that some participants were able to apply sophisticated epistemic beliefs in practice. They constructed knowledge by themselves and make personal justification of the information they acquired during the unit. This result indicated that, by having students conduct scientific inquiry in real life setting with explicit and reflective instructions, some middle and high school students are capable of applying sophisticated epistemic beliefs in practice.

RQ2: How do Middle and High School Students' Epistemic Beliefs Contribute to the Construction of Their Problem Solving Processes?

In this study, I examined students' epistemic beliefs in the context of scientific inquiry to explore how their epistemic beliefs contribute the ways they acquire and use knowledge to solve problems and construct arguments. Since epistemic beliefs include beliefs of the nature of knowledge and the nature of knowing, I discuss the influence of these beliefs separately in the following.

Nature of knowledge. The results from pretest and posttest showed that the students in the case study groups scored 2.7 on average on the *Certainty* and *Developing* dimensions, which indicated that they self-reported sophisticated beliefs of the nature of knowledge. The results of discourse analysis revealed that, with the exception of two students in Group 2, most students hold sophisticated beliefs of the nature of knowledge as they to some extent agreed that scientific knowledge is uncertain and evolving over time. However, I did not find evidence that students' epistemic beliefs of the nature of knowledge directly influenced their problem solving and construction of arguments during their inquiry activities. In the current literature, several researchers stated that students' epistemic beliefs, including beliefs of the nature of knowledge, have an impact on the approach students adopt during their online learning (Barzilai & Zohar, 2012; Mason et al., 2010; Mason, Pluchino, & Ariasi, 2014). For example, if students believe knowledge is simple and certain, it is unlikely for them to search for additional information to verify the credibility of the online sources (Hofer, 2004a). High school students who believe scientific knowledge as static, certain, and unchanging tend to view science learning as memorizing, testing, calculating and practicing (Hsu, Tsai, Hou, & Tsai, 2014). On the contrary, students who hold sophisticated beliefs on the nature of knowledge tend to compare and integrate contrasting information during their online searching. In this study, since students spent limited time in the classroom, most of them did not have enough time to search for additional information online. Hence, students' limited engagement in online learning may be the reason why I did not find a direct impact of their beliefs of the nature of knowledge on their online searching. Another possible reason is the methodology I used to examine students' epistemic beliefs during their inquiry activities. It should be noted that, except in the post interview, I did not find many incidents or conversation that revealed students' beliefs about the nature of knowledge during their inquiry activities. Although the students worked together to construct their arguments during the unit, it may be unnatural for them to spontaneously express their beliefs of the nature of knowledge during their inquiry activities. In the current literature, researchers often use the think-aloud methodology (e.g., Mason & Boldrin, 2008; Muis & Franco, 2009) to intentionally ask students to verbalize their epistemic beliefs in practice. However, the think-aloud methodology also has limitations as it can only reveal students' epistemic thinking processes that they are aware of (Mason et al., 2011) and interpret and alter students' thinking processes (Veenman, Hout-Wolters, & Afflerbach, 2006). Additionally, as in this study students spent most of their time outdoors, the think-aloud methodology could not be used to examine students' epistemic beliefs. Therefore, without having students to think aloud their epistemic thinking processes, they seldom spontaneously expressed their beliefs about the nature of knowledge during the unit. Hence, there is no sufficient evidence to conclude the influence of students' beliefs of the nature of knowledge on their problem solving processes. In the next section, I discuss the influence of their beliefs about the nature of knowing on their problem solving processes.

Nature of knowing. The students in the case study groups on average scored 2.8 on the *Authority* and *Reason* dimensions on the pretest and posttest, which indicated that they self-reported sophisticated beliefs of the nature of knowing. The results of discourse analysis revealed that members in Group 3 applied such sophisticated beliefs in practice. For the remaining students, they all to some extent applied naïve epistemic beliefs in practice. I discuss the influence of students' epistemic beliefs of the source of knowledge and justification of knowing on their problem solving processes separately below.

Influence of epistemic beliefs of the source of knowledge. In the current literature, several researchers (e.g., Bråten et al., 2011; Muis, 2007) posited that epistemic beliefs influence students' perceptions of the learning tasks and the goals students set during their learning processes. On the dimension of the source of knowledge, the results of this study indicated that epistemic beliefs influence students' approaches for knowledge acquisition and construction. Students who held sophisticated beliefs of the source of knowledge actively acquired information from multiple sources and construct knowledge by analyzing water quality data. In the case of Group 3, the students acquired knowledge from water quality data, online search, and their observations and used it as their evidence. Influenced by their sophisticated aspect of beliefs of the source of knowledge, Group 1 members also analyzed water quality data and conducted online search to acquire knowledge. Consistent with this result, other studies also demonstrated that students with more sophisticated epistemic beliefs perform better in knowledge acquisition. Students with more sophisticated epistemic beliefs tend to view themselves as knowers who can construct knowledge in interaction with others, therefore they engaged more and used advanced search strategies in information searching (Hsu et al., 2014; Strømsø & Bråten, 2010). For example, in open-ended online learning tasks, 8th grade students who held more sophisticated epistemic beliefs purposefully filtered information to arrive at better information searching outcomes (Tu, Shih, & Tsai, 2008). Conversely, students' beliefs that knowledge comes from authority may lead them to set up a learning goal to acquire information from authorities without carefully consideration (Bråten & Strømsø, 2005; Muis, 2007). The results from this study showed that students who believed that knowledge comes from external authorities did not evaluate or try to comprehend information from stakeholders before they used it directly as their evidence. In the case of Group 2, students misunderstood the information from stakeholders and used incorrect information as evidence to support their claim. Since members of Group 1 also held naïve beliefs of the source of knowledge, they incorrectly used information about drinking water from stakeholders as their evidence, although it could not support their claim about surface water quality. Hence, members of Group 1 and 2 used information from stakeholders as evidence without evaluation and did not construct knowledge by themselves. Thus, as seen in this study, students' epistemic beliefs of the source of knowledge directly influenced the approaches they adopt to acquire and construct knowledge. Students with more sophisticated epistemic beliefs of the source of knowledge outperformed their peers in knowledge acquisition and construction. They actively acquired and evaluate information from multiple sources and self-construct knowledge by analyzing water quality data.

Influence of epistemic beliefs of justification of knowing. Justification of knowing is the central question in the research area of epistemology (Pollock & Cruz, 1999; Williams, 2001). Sources of justification range from personal experience, authority, or what feels right to applying rules of inquiry and the evaluation and integration of multiple sources. It is expected that students' epistemic beliefs of justification of knowing are related with the way they justify their knowing during their problem solving processes. The results of discourse analysis confirmed this anticipation. In this study, students who believed justification of knowing comes from applying rules of inquiry and reasoning made sense of and evaluated information they acquired before using it as evidence. In the literature, students' beliefs about how to justify knowing are posited to have an impact on the achievement goals students set for learning (Hofer & Pintrich, 1997; Muis, 2007). The more students hold sophisticated beliefs of justification of knowing, the more they establish mastery goals in their learning processes to understand the learning content and acquire competence (Chen & Pajares, 2010; Mason, Boscolo, Tornatora, & Ronconi, 2013). In the case of Group 3, besides searching for the definitions of water quality indicators they also searched for how these indicators influence water quality in different ways. This shows that they set up a learning goal to comprehend and make sense of the information they have acquired before used it as their evidence. Hence, during their final presentations, besides presenting their findings of water quality, they also explained why these water quality indicators are important to support their claims. In addition, higher sophistication of beliefs of justification of knowing is also related with whether students use scientific evidence to evaluate information (Mason et al., 2011; Muis & Franco, 2010). Middle school students who believe knowledge claims can be justified based on evidence produced high quality arguments, counterarguments, and rebuttals than others (Mason & Scirica, 2006). Consistent with the literature, since members of Group 1 to some extent they believed justification of knowing comes from testing and reasoning, they evaluated water quality data against the state standards, and use the findings from data as evidence to support their claim. On the contrary, students who hold naïve epistemic beliefs were challenged with effectively integrating information gathered from the internet (Hsu et al., 2014) and exhibited confirmation bias, in that they tended to accept information consistent with their own views (Kuhn & Udell, 2007; Mokhtari, 2014). As seen in this study, members of Group 2 and Group 1 failed to integrate conflicting information from different stakeholders and chose one side of opinions as their evidence. Therefore, their final arguments were weakened by the fact that they did not fully address and integrate conflicting information. Thus, the results of this study showed that, students with more sophisticated beliefs of justification of knowing made sense of and evaluated information they acquired and use it to support their claims. Therefore, students with sophisticated epistemic beliefs presented more solid evidence and use it to support than their peers with naïve epistemic beliefs, which in turn strengthened their arguments in their final presentation.

In summary, the finding that students' beliefs of the nature of knowing contribute the way they constructed knowledge and justified their knowing during a PBL unit is aligned with the literature. In PBL, students are required to identify information they need to know, gather relevant information, evaluate and use evidence to support their problem solutions (Barrows, 1996; Belland et al., 2010), all of which is directly related with the approach they adopt to acquire knowledge and justify their knowing. Therefore, students' beliefs about the nature of knowing are expected to have an impact on students' learning processes in PBL. In addition, students' epistemic beliefs also influence students' learning processes in many aspects, such as self-regulated learning (Greene et al., 2010; Strømsø & Bråten, 2010), text comprehension (Ferguson & Bråten, 2013; Strømsø & Bråten, 2009), argumentation skills (Mason & Scirica, 2006; Nussbaum, Sinatra, & Poliquin, 2008), and online searching (Barzilai & Zohar, 2012; Hsu et al., 2014; Mason et al., 2011), all of which are also critical to problem solving. Hence, as evidenced in this study, students' scientific inquiry practice and problem solving approach are influenced by their epistemic beliefs of the nature of knowing.

RQ3: Do Middle and High School Students' Epistemic Beliefs Change During a PBL Unit?

The results from Wilcoxon Signed-Rank Test showed a significant increase of students' self-reported epistemic beliefs from pretest to posttest with an effect size of 0.23. Overall, the mean scores on all dimensions increased from pretest to posttest. Mean scores on the *Authority* dimension significantly increased from pretest to posttest, with an effect size of 0.31. Hence, the quantitative results indicated that in general, students' developed more sophisticated epistemic beliefs during the PBL unit. The results from discourse analysis indicated that students benefited from participating in the scientific inquiry unit as they experienced the complex process of conducting investigations and using evidence to support claims. During the unit, students learned more about how scientists do research in different ways, perceived the uncertain, subjective nature of scientific knowledge, and learned to apply rules of inquiry and reasoning to justify their knowing.

The impact of inquiry-based instruction. The improvement of students' epistemic beliefs may due to the PBL approach adopted during the unit. The current literature suggested that having students study open-ended, complex, and controversial issues may facilitate more sophisticated and adaptive epistemic beliefs (Bråten et al., 2011; Ferguson & Bråten, 2013; Greene et al., 2010; Tsai, 2004). When presented with conflicting information, students may become aware of the subjective nature of scientific knowledge and develop their understanding of justification of scientific knowledge. According to the discovery learning theory (Bruner, 1977), having students to experience cognitive conflict is critical for their intellectual development since it will lead students to progress beyond their current mode of thinking through confrontation by concrete examples. Likewise, by integrating and justifying conflicting information from different sources, students' current naïve epistemic beliefs may be challenged as they start to perceive the uncertain, subjective nature of scientific knowledge and started to apply rules of inquiry to justify their knowing (Ferguson, Bråten, Strømsø, & Anmarkrud, 2013). Just as cognitive development is at least partially driven by cognitive disequilibrium (Piaget, 1985), epistemic belief development may also be driven by cognitive disequilibrium (Kienhues et al., 2008). As students' naïve beliefs are challenged, they start to doubt and reassess their current naïve epistemic beliefs, which in turn promote them to develop more sophisticated beliefs (Bendixen & Rule, 2004). After reading multiple conflicting texts during one class session, 10th grade students' beliefs about justification of knowing became more sophisticated with an effect size of 0.24 (Ferguson & Bråten, 2013). By conducting online inquiry learning for a month, 10th-grade students also believed more strongly in the tentative and changing nature of knowledge with an effect size of 0.17 (Tsai, 2008). Similarly, after studying conflicting information on a controversial topic, undergraduate students improved their topic-specific epistemic beliefs as they believed less in a clear cut solvability of the task (Kienhues, Stadtler, & Bromme, 2011). Although the intervention only last one class session, the epistemic beliefs of students who were presented with conflicting information were higher than those who were presented with consistent information (*ES* = 0.5) after the intervention. As such, studying conflicting information from multiple stakeholders during problem solving process is one factor that fosters the development of students' epistemic beliefs in this study. Although the effect size found in this study is relatively small, the PBL unit led to the improvement of students' epistemic beliefs on all four dimensions.

The impact of socio-scientific issues. Having students addressing socio-scientific issues may be another factor that contribute to the improvement of students' epistemic beliefs. Socio-scientific issues are scientific issues that have political and social implications (Sadler & Zeidler, 2005). Addressing SSIs provide opportunities to restructure classrooms as communities of practice where students can learn science as engaged citizens to contribute to authentic problems (Sadler, 2009). Students' epistemic beliefs may have changed due to their interactions with the socio-cultural context by addressing these authentic problems (Ferguson et al., 2013; Muis et al., 2006). Through discussing complex environmental SSIs, students as young as 10 years old were shown to be able to understand the importance of SSIs and position themselves as active contributor to society (Byrne, Ideland, Malmberg, & Grace, 2014). Water quality problems involve the interests of different stakeholders within the context of students' everyday lives and in relation to society at large. Having students investigating local water pollution problems has been demonstrated to promote students' interest and participation in science learning as it connects knowledge, experience, and interests between school and community contexts (Bouillion & Gomez, 2001). In line with the literature, in this study the results of discourse analysis indicated that students increased their interests of the topic. During the unit and post interview, many students stated that they appreciate the learning experience as they learned the importance of water quality, which is "something they have never thought about before." The students also expressed interests in visiting many stakeholders, as they "get to see the things behind the scenes" to understand the social and economic aspects of water supply, water consumption, and waste water treatment. In the case of Group 2, the students brought a brochure of a local water quality report to their class as additional information, which implies that they were interested in the topic even when they were out of school. Middle and high school students' epistemic beliefs have been found to be positively related to motivation in several aspects such as self-efficacy, goal orientation, task value (Chen, 2012; Chen, Metcalf, & Tutwiler, 2014; Ricco et al., 2010). Thus, the increased students' interest in the unit may facilitate their development of episteme beliefs. In addition, as SSIs often involve disagreements among experts and unsolved problems, they provide meaningful contexts for students to perceive the complex and subjective nature of science, which may potentially promote their understandings of the nature of science (Eastwood et al., 2012; Khishfe & Lederman, 2006).

The impact of field-based learning activities. The enhancement of participants' epistemic beliefs may also be due to the field-based learning activities. During the unit, the students went on field trips each day to conduct observational, exploratory, students-centered science activity that beyond classrooms, which may promote their understanding of scientific inquiry for two reasons. First, field trips have been demonstrated to be an effective approach for children to learn and engage with science and scientific practices (NRC, 2009). Participation in outdoor activities that include hands-on exercises and field experience can lead to better understanding and empathy toward environmental issues and willingness to protect the environment (Palmberg & Kuru, 2000). Research indicated that field-based learning activities centered on environmental issues can help students to understand the scientific method and develop positive affective attitudes toward the natural environment (Carrier, Thomson, Tugurian, & Stevenson, 2014; Cheng & Monroe, 2012). Second, as students conducted scientific inquiry in real life settings, they were exposed to the complex processes of authentic scientific inquiry instead of oversimplified "school inquiry" activities. The field-based learning activities provide opportunities for students to engage in personally meaningful scientific inquiry like scientists in a less contrived environment, which help them to understand the nature and value of scientific investigation (Bell, Urhahne, Schanze, & Ploetzner, 2010; Grandy & Duschl, 2007).

Compared to classroom instruction, field-based learning showed unique benefits to help students achieve positive affective outcomes (e.g., positive interest, attitude, emotion) toward learning (Boxerman, 2013). Conducting investigations of students' locally accessible world can promote students to develop a sense of wonder that leads to curiosity and a desire for explanation, which is often missing from school science (Sharples et al., 2015). In this study, by observing and conducting authentic scientific inquiry, students were provided with opportunities to acquire and make sense of complex and conflicting scientific data, evaluate the relevance and credibility of scientific evidence in the manner of real scientists, which in turn may promote the development of their epistemic beliefs of science.

The impact of epistemic climate. The development of students' epistemic beliefs may also be due to the positive atmosphere of the PBL unit. The epistemic climate—"how the nature of knowledge and knowing is portrayed and perceived" (Muis & Duffy, 2013, p. 214) and epistemic virtues (individuals' dispositions such as intellectual carefulness, intellectual courage, and open-mindedness; Chinn, Buckland, & Samarapungavan, 2011) are also critical for students to develop sophisticated epistemic beliefs. As shown in the literature, establishing a positive epistemic climate through teaching can support students to develop epistemic beliefs and use critical thinking strategies. Individuals' epistemic virtues such as truth-seeking, open-mindedness, and analyticity are also associated with their epistemic beliefs (Valanides & Angeli, 2008). By establishing a positive epistemic climate in a semester-long graduate level course, students improved their epistemic beliefs with a large effect size of 0.87 (Muis & Duffy, 2013). In this study, Mr. Scott consistently reminded the students that scientists were "observant, careful, precise, ethical, skeptical, and open-minded" and asked them to adopt these characteristics in their learning activities. In addition, Mr. Scott and I also often guided students to adopt sophisticated beliefs and apply such beliefs in practice, such as asking them to evaluate and validate their evidence and integrate information from different stakeholders. These practices may in turn cultivate positive epistemic climate and epistemic virtues that support the development of epistemic beliefs. Although the effect size (0.23) found in this study was not as large as the one found in Muis and Duffy's study, it is promising to find a significant improvement of students' epistemic beliefs within only two weeks.

Summary

Overall, the participants' in this study self-reported more sophisticated epistemic beliefs than those of similar participants reported in the literature. Although no significant gender difference was found, female students reported more sophisticated epistemic beliefs than male students with medium effect size. The results of mixed-methods analysis indicated that holding sophisticated epistemic beliefs is a prerequisite for students to apply such beliefs in practice. For students who reported sophisticated epistemic beliefs, some of them applied such beliefs in practice while others failed to do that. For students who reported suboptimal beliefs, their beliefs revealed from practice were found to be even less sophisticated. The inconsistency between these two types of epistemic beliefs may due to students' inadequate cognitive ability, the reliability issue of self-report measure, and the influence of contextual factors.

Students' beliefs about the nature of knowing influenced the way they constructed knowledge and justified their knowing during problem solving processes. Consistent with the current literature, students' with more sophisticated epistemic beliefs of the source of knowledge and justification of knowing performed better than others, as they acquired more information from multiple sources, made sense of information they acquired, and used evidence to support their claims.

By participating in a two-week long scientific inquiry unit, students' self-reported epistemic beliefs were significantly promoted with an effect size of 0.23. Students improved their scores on all four dimensions of epistemic belief - engagement in scientific inquiry, field-based learning activities, learning content around socio-scientific issues, and positive epistemic climate - and these dimensions interacted together to contribute to the enhancement of students' epistemic beliefs.

Implications

Implications for Research of Epistemic Beliefs

The findings of this study have three implications for research of epistemic beliefs. First, the finding that students' self-reported epistemic beliefs may not be consistent with their beliefs revealed from practice raises the methodological issue of the assessment of epistemic beliefs. As mentioned earlier, in recent years researchers started to adopt new approaches such as cognitive interviews (Muis et al., 2012), think-aloud protocols (Hofer, 2004a; Mason et al., 2011), and screen-capture videos (Tu et al., 2008) to examine individuals' epistemic beliefs. The results of this study support the new directions of assessments of epistemic beliefs by demonstrating that self-reported measures by itself are not sufficient for researchers to fully examine students' epistemic beliefs. Students may report sophisticated epistemic beliefs in their responses to questionnaires but not necessarily apply such beliefs in practice. In the current literature, several assessments of epistemic beliefs were demonstrated to have low internal consistency and poor factor structure (DeBacker et al., 2008; Greene et al., 2008). Specifically, instruments of epistemic beliefs may be less effective to capture individuals' beliefs of the nature of knowing. Since individuals' beliefs of how to acquire and justify knowledge are complex and multifaceted, it is difficult to interpret it only based on a simple measurement on a Likert scale in a decontextualized manner (Hofer, 2004b). As shown in this study, most of the discrepancy between students' self-reported beliefs and their beliefs revealed from practice are in the area of the beliefs of the nature of knowing. Some students applied both sophisticated and naïve beliefs in practice, which indicates that such complex beliefs cannot be reflected by a single point on a Likert scale. It should be noted that some students' self-reported epistemic beliefs were consistent with their beliefs revealed from practice. As found in this study, if students do not report sophisticated epistemic beliefs, it is unlikely for them to apply sophisticated beliefs in practice. That means, although self-report measures lack of accuracy to fully reflect students' complex epistemic beliefs, they do provide an approximate estimate of what students have the tendency to do for learning (Muis & Franco, 2010). Overall, the results of this study recommend using multiple approaches to examine students' epistemic beliefs to increase the validity of research. Mixed-methods approach may be particularly powerful to capture the role of epistemic beliefs play in dynamic learning processes (Bråten et al., 2008; Hofer, 2006).

Second, the discrepancy between self-reported beliefs and beliefs revealed from practice also calls for more research of epistemic beliefs in practice. Theoretically speaking, the beliefs reflected by self-reported measures may be characterized as individuals' "mental states" while beliefs revealed from practice may be characterized as individuals' "mental acts" (Searle, 1983; Strømsø & Bråten, 2010). These two types of beliefs represent the two types of research objectives: beliefs that individual hold in general and beliefs that individuals apply in practice. In the current literature, more recent research is in line with the latter one as more attention is paid on the role of epistemic beliefs play in learning processes such as in online learning (Barzilai & Zohar, 2012; Hsu et al., 2014; Mason et al., 2011) and multiple text comprehension (Ferguson & Bråten, 2013; Strømsø & Bråten, 2009). Researchers tend to agree that students' epistemic beliefs should not be interpreted in a general sense without considering specific contexts (Chinn et al., 2011; Rosenberg, Hammer, & Phelan, 2006). The results of this study also suggest that, to help students better construct knowledge and justify their knowing, more research is needed to help students apply sophisticated epistemic beliefs in practice instated of only paying attention to the "pure" beliefs they hold in general.

Third, the finding that students in general developed more sophisticated epistemic beliefs during a two-week long PBL unit is promising, as it shows that middle and high students' epistemic beliefs can be promoted within a short period of time. By conducting scientific inquiry in real life setting with hands-on, field-based learning activities, some middle and high school students are capable of applying sophisticated epistemic beliefs in practice. Although this study was conducted in a field-based summer class rather than a typical K-12 classroom setting, it provides an example of promoting students' epistemic beliefs by engaging them in scientific inquiry. By observing and conducting authentic scientific inquiry, students were provided with opportunities to acquire and construct scientific data, evaluate scientific evidence in the manner of real scientists, which in turn may promote their beliefs of the nature of science and the method of making it. In the current literature, although several studies were designed to promote students' epistemic beliefs by having them address open-ended, complex, and controversial issues (e.g., Ferguson & Bråten, 2013; Kienhues et al., 2011; Tsai, 2008), few of them involve observational, exploratory science activity that beyond classrooms. Hence, more research is needed to have students conduct more hands-on, field-based learning activities to enhance their epistemic beliefs in the domain of science. Additionally, consistent with the results of Muis and Duffy's study (2013), this study also suggests that establishing a positive epistemic climate may help students to develop more sophisticated epistemic beliefs. Individuals' dispositions such as intellectual carefulness, truth-seeking, and intellectual courage are related with their epistemic beliefs (Chinn et al., 2011; Valanides & Angeli, 2008). Future research is needed to further explore how to cultivate an epistemic climate that value such dispositions to promote the development of students' epistemic beliefs (Gu & Belland, 2015).

Implications for Supporting Students in Scientific Inquiry

The results of this study also provide several implications for supporting students as they engage in scientific inquiry. First, this study provides detailed evidence of the impact of students' epistemic beliefs on their inquiry activities during a PBL unit. Specifically, students' epistemic beliefs influence their approaches to acquiring and constructing knowledge and creating evidence-based arguments. During scientific inquiry, students' epistemic beliefs influence the processes and strategies they adopt to search for and evaluate information (Barzilai & Zohar, 2012; Mason et al., 2009). In this study, students who hold sophisticated epistemic beliefs tended to actively acquire information from multiple sources and construct knowledge by analyzing scientific data. In addition, students' epistemic beliefs also have an impact on their construction of arguments. Engaging in argumentation is critical for students to conduct scientific inquiry as they need to evaluate evidence, interpret results, and make conclusions (Bricker & Bell, 2008; Ford, 2012; Osborne, Erduran, & Simon, 2004). Research indicated that the criteria students adopt to judge knowledge claims and make reasoning during scientific inquiry are also influenced by their perceptions and epistemological understanding of science (Abi-El-Mona & Abd-El-Khalick, 2011; Hogan, 2002). The results of this study showed that students with more sophisticated epistemic beliefs tended to make sense of and evaluate the information they acquired before using it as evidence. Therefore, these students performed better than their peers with naïve epistemic beliefs as they presented more solid evidence and use it to support their claims. As such, to help students successfully engage in scientific inquiry, more effort is needed to promote students' epistemic beliefs and explore the role of epistemic beliefs play in students' scientific inquiry activities.

Second, the results of this study suggest that educators incorporate hands-on activities and socio-scientific issues (SSIs; Sadler & Zeidler, 2005) in science curriculum to engage students in scientific inquiry. During the unit and post interviews, many students expressed that they enjoyed and appreciated the hands-on activities and field trip experiences offered in the unit. By conducting scientific inquiry in real life settings, students learned the importance of water quality, which is “something they never thought about before.” Students also learned the processes to conduct scientific experiments by testing water quality and analyzing the data they collected, which in turn enabled them to reflect on their inquiry practices and compare such with authentic scientific inquiry practices. Also, as students visited many stakeholders during the unit, they learned how water quality impacts various stakeholders differently so that they perceived the social value of scientific knowledge and saw how scientific issues are related to their lives. Hence, to help students develop adequate skills and understandings of scientific inquiry, hands-on activities and SSIs should be incorporated into science curriculum. By addressing SSIs with a focus on scientific content knowledge, students may perceive the importance of the learning tasks and increased their interests in science (Dawson & Venville, 2008; Dolan, Nichols, & Zeidler, 2009). To reform current science curriculum, educators should incorporate more emerging real-world problems in the curriculum through inquiry-based learning approach, which will promote students’ interest and disposition with science learning (Crippen & Archambault, 2012).

Third, as shown in this study, although some students self-reported relatively sophisticated epistemic beliefs, they still struggled with applying such beliefs in practice.

This may be because middle and high school students often do not have adequate metacognitive abilities to spontaneously monitor their thinking processes (Hofer, 2004a; Mason & Boldrin, 2008). Thus, it is crucial for educators to provide timely support to students to help them successfully engage in scientific inquiry. In this study, as students spent most of time outdoors, it was difficult for Mr. Scott and myself to monitor students' learning progress and provide sufficient support to them in a timely manner. Indeed, although timely one-to-one support is often required in PBL (Belland, 2012; Hmelo-Silver et al., 2007), teachers struggle to provide such support to all students in their classes in typical K-12 classroom settings. Hence, providing computer-based scaffolding is one way to supplement teachers to provide such support to students (Puntambekar & Hubscher, 2005; Quintana et al., 2004). When students conduct scientific inquiry in PBL, computer-based scaffolding can (1) help students to identify what they need to know, (2) guide students through essential steps, (3) assist students to manage and monitor learning and problem solving processes, and (4) provide learning strategies to solve problems (Kim & Hannafin, 2011). In addition, computer-based scaffolds may also help students develop epistemological understandings of scientific inquiry. By providing prompts to set investigation goals, construct explanation, and link evidence to causal claims, computer-based scaffolding helps students (a) understand what counts as explanations and evidence (Sandoval & Reiser, 2004) and (b) use validated evidence to justify their knowledge claims (Belland, Gu, Armbrust, & Cook, 2015). Therefore, the use of computer-based scaffolding is a promising strategy to help students monitor their learning processes, set epistemic criteria, evaluate their evidence, which frames the inquiry process in epistemically important ways (Sandoval & Reiser, 2004).

Limitations and Suggestions for Future Research

Limitations

Lack of a control group. In order to rigorously examine the impact of conducting scientific inquiry on students' epistemic beliefs, it would be more effective to adopt an experimental design with a control group. As the purpose of the summer class was to provide outdoor learning opportunities to any students who were interested, it was not feasible to include a control group in this study. Without a control group, the validity of the quantitative result is in question due to possible history, maturation, and testing effects (Cook & Campbell, 1979). Therefore, the improvement of students' self-reported epistemic beliefs showed in this study cannot be fully interpreted as the impact of engagement in scientific inquiry.

Small sample size. Because only 24 students enrolled in this summer class, the sample size of the study is relatively small. Three students dropped out of the summer class three days before the unit ended, which made the sample size even smaller for quantitative analysis. As a result, it would have been inappropriate to use several statistical analyses such as repeated measures ANOVA to examine the impact of other factors (such as students' academic achievement level, gender, and socioeconomic status level) on change in students' self-reported epistemic beliefs. Hence, I was unable to further explore the impact of conducting scientific inquiry on students' epistemic beliefs among student subgroups.

Data collection. In this field-based learning summer class, students spent most of the time outdoors to explore the natural environment and conduct scientific inquiry. As they often scattered during field trips, it was difficult for me to video record all of their inquiry activities by myself during the field trips. As a result, it is likely that I missed essential conversations between students during their outdoor activities, which may be the reason why I did not find much evidence in the videos that captures the change of students' epistemic beliefs.

Limited in-class time. Originally, Mr. Scott and I planned to schedule one hour each day for students to organize their field notes, analyze water quality test data, and conduct online searching. However, as field-based learning was the major purpose of this study, Mr. Scott and Mr. Davis decided to reduce the amount of time for in-class activities. Later in the unit, Mr. Scott spent about 15 minutes at the beginning of each day to help students analyze data by demonstrating how to make graphs and tables to present the results. Besides getting instructions from Mr. Scott to analyze data, the students only spent about two and half hours in class to analyze water quality data and develop their arguments on their own during the PBL unit. This may have potentially impeded their inquiry processes, as they did not have sufficient time to work as groups in their classroom to analyze data and search for additional information online.

Suggestions for Future Research

Integrate similar PBL unit in K-12 science curricula. The result of this study shows that students developed more sophisticated epistemic beliefs by engaging in a problem-based scientific inquiry unit. As this study was conducted in a field-based summer class, the instructional design of the PBL unit involves many hands-on activities and field trips, which is different than typical K-12 science curriculum. Consistent with current science education reforms to incorporate more inquiry activities in K-12 school (NRC, 2012), more research is needed to design such problem-based, scientific inquiry unit that is suitable to implement in formal K-12 settings. Specifically, future studies should implement a similar unit in formal K-12 settings to examine if students' epistemic beliefs can be promoted by engaging in scientific inquiry.

Large sample size with a control group. Since this study was conducted with a small sample size, it would be important to see if similar results can be achieved with a large sample. By adding a control group in the experimental design, the impact of engagement in scientific inquiry on students' self-reported epistemic beliefs could be compared between the experimental and control groups. In addition, with a larger sample size, a future study can examine the interaction between the engagement in scientific inquiry and other factors (such as students' academic achievement level, gender, and SES level), which will inform researchers about the change of students' epistemic beliefs among student subgroups. In future studies, one-way ANOVA could be used to examine the difference in gain scores between experimental and control groups. Based on an effect size of 0.23, power of .8, and an alpha level of .05, as with the current study, a sample size of 150 is suggested when using one-way ANOVA. Additionally, for future studies that involve participants from multiple classrooms, a nested ANOVA could be conducted to detect any potential nested effect. In that case, a nested ANOVA analysis may require an even larger sample size.

Use of computer-based scaffolds. As discussed earlier, it is necessary to use computer-based scaffolds to supplement teachers' support to help students overcome their difficulties during scientific inquiry. Moreover, computer-based scaffolds can also be designed to examine students' learning processes at a fine-grained level by using trace logs data or screen capture tools, which can enable researchers to better measure students' epistemic beliefs revealed from practice (Greene et al., 2010). For future study, researchers may provide computer-based scaffolds to students during a similar unit to see if students' epistemic beliefs can be promoted to a greater extent. In addition, as the use of computer-based scaffolds offers better tools to examine students' epistemic beliefs, future study can also further explore how and why students' epistemic beliefs change during scientific inquiry.

Conclusion

Current science education reform calls for a shift from the traditional approach that focus on content knowledge and process skill to a goal of engaging students in scientific inquiry to acquire adequate skills and understandings of science (NRC, 2012, National Science Teachers Association [NSTA], 2011; Next Generation Science Standards [NGSS], 2013). Students' understanding of science is reflected in their epistemic beliefs—beliefs of the nature of knowledge and knowing (Bråten et al., 2011; Hofer & Pintrich, 1997). In the current literature, since few studies examined middle and high school students' epistemic beliefs based on their performance during scientific inquiry, it is not clear how students' epistemic beliefs and their inquiry activities are related. Therefore, it remains unclear how students' epistemic beliefs influence the way students acquire and integrate information and use evidence to construct arguments during scientific inquiry. In addition, as most of the studies examine students' epistemic beliefs within a fairly short period of time (e.g., one class period), it is difficult to capture if there is any change of students' epistemic beliefs (Ferguson & Bråten, 2013; Knight & Mattick, 2006). As a result, in the current literature, it is also not clear how and why students' epistemic beliefs change over time.

To fill the gap in the current literature, this study adopted a mixed-methods approach to: (1) examine students' self-reported epistemic beliefs and their epistemic beliefs revealed from inquiry practices, (2) explore how their epistemic beliefs influence their inquiry practice, and (3) discover how their epistemic beliefs change during a problem-based, scientific inquiry unit. This study contributes a more fine-grained analysis of students' epistemic beliefs in the context of scientific inquiry for research purposes. The results of this study indicated that students' self-reported epistemic beliefs were not be consistent with their beliefs revealed from practices. Although some students self-reported sophisticated epistemic beliefs, they still struggled applying such beliefs in practices. Students' beliefs about the nature of knowing directly influenced the approach they adopted to construct knowledge and justify their knowing during scientific inquiry. Students who hold sophisticated epistemic beliefs of the nature of knowing tended to actively acquire information from multiple sources and make sense of the information they acquired before using it as evidence. Through engagement in the PBL unit, students in general significantly increased their self-reported epistemic beliefs from pretest to posttest with an effect size of 0.23. Students benefited from participating in the unit as they experienced the complex processes of conducting investigations, integrating conflicting information from multiple sources, and using evidence to support claims. Conducting scientific inquiry in real life settings and establishing a positive epistemic climate may help students to develop more sophisticated epistemic beliefs.

REFERENCES

Abi-El-Mona, I., & Abd-El-Khalick, F. (2011). Perceptions of the nature and "goodness" of argument among college students, science teachers, and scientists. *International Journal of Science Education*, *33*(4), 573-605. Retrieved from http://doi.org/10.1080/09500691003677889

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching & Learning*, *1996*, 3-12. Retrieved from http://doi.org/10.1002/tl.37219966804

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition & Instruction*, *30*(1), 39-85. Retrieved from http://doi.org/10.1080/07370008.2011.636495

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist*, *49*(1), 13-35. Retrieved from http://doi.org/10.1080/00461520.2013.863265

Baxter Magolda, B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Baxter Magolda, B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist*, *39*(1), 31-42. Retrieved from http://doi.org/10.1207/s15326985ep3901_4

Belland, B. R. (2009). Portraits of middle school students constructing evidence-based arguments during problem-based learning: the impact of computer-based scaffolds. *Educational Technology Research & Development*, *58*, 285-309. Retrieved from http://doi.org/10.1007/s11423-009-9139-4

Belland, B. R. (2012). Habitus, scaffolding, and problem-based learning: Why teachers' experiences as students matter. In S. B. Fee & B. R. Belland (Eds.), *The role of criticism in understanding problem solving: Honoring the work of John C. Belland* (pp. 87-100). New York, NY: Springer. Retrieved from http://doi.org/10.1007/978-1-4614-3540-2_7

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2008). A scaffolding framework to support the construction of evidence-based arguments among middle school students. *Educational Technology Research & Development*, *56*, 401-422. Retrieved from http://doi.org/10.1007/s11423-007-9074-1

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2010). Problem-based learning and argumentation: Testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science*, *39*, 667-694. Retrieved from http://doi.org/10.1007/s11251-010-9148-z

Belland, B. R., Gu, J., Armbrust, S., & Cook, B. (2015). Scaffolding argumentation about water quality: A mixed-method study in a rural middle school. *Educational Technology Research & Development*, *63,* 1-29. Retrieved from http://doi.org/10.1007/s11423-015-9373-x

Belland, B. R., Gu, J., Kim, N., Turner, J., & Weiss, M. (2015, April). *The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science*. Paper presented at the 2015 American Educational Research Association Annual Meeting, Chicago, IL.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education*, *32*, 349-377. Retrieved from http://doi.org/10.1080/ 09500690802582241

Bendixen, L. D., & Rule, D. C. (2004). An integrative approach to personal epistemology: A guiding model. *Educational Psychologist*, *39*(1), 69-80. Retrieved from http://doi.org/10.1207/s15326985ep3901_7

Bendixen, L. D., Schraw, G., & Dunkle, M. E. (1998). Epistemic beliefs and moral reasoning. *The Journal of Psychology*, *132*, 187-200. Retrieved from http://doi.org/10.1080/00223989809599158

Berger, P., & Luckmann, T. (1991). *The social construction of reality: A treatise in the sociology of knowledge*. London: Penguin Books.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26-55. Retrieved from http://doi.org/10.1002/sce.20286

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: Real world problems and school-community partnerships as contextual scaffolds. *Journal of Research in Science Teaching*, *38*, 878-898. Retrieved from http://doi.org/10.1002/tea.1037

Boxerman, J. Z. (2013). *Echoes from the field: An ethnographic investigation of outdoor science field trips* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3563696)

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J. F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist*, *46*(1), 48-70. Retrieved from http://doi.org/10.1080/ 00461520.2011.538647

Bråten, I., & Strømsø, H. I. (2005). The relationship between epistemological beliefs, implicit theories of intelligence, and self-regulated learning among Norwegian postsecondary students. *British Journal of Educational Psychology*, *75*, 539-565. Retrieved from http://doi.org/10.1348/000709905X25067

Bråten, I., Strømsø, H. I., & Samuelstuen, M. S. (2008). Are sophisticated students always better? The role of topic-specific personal epistemology in the understanding of multiple expository texts. *Contemporary Educational Psychology*, *33*, 814-840. Retrieved from http://doi.org/10.1016/j.cedpsych. 2008.02.001

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*, 473-498. Retrieved from http://doi.org/10. 1002/sce.20278

Bruner, J. S. (1977). *The process of education* (Revised edition). Cambridge, MA: Harvard University Press.

Buehl, M. M., & Alexander, P. A. (2001). Beliefs about academic knowledge. *Educational Psychology Review*, *13*, 385-418. Retrieved from http://doi.org/10.1023/A:1011917914756

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology*, *27*, 415-449. Retrieved from http://doi.org/10.1006/ceps.2001.1103

Burr, V. (2003). *Social constructionism*. New York. NY: Routledge.

Byrne, J., Ideland, M., Malmberg, C., & Grace, M. (2014). Climate change and everyday life: Repertoires children use to negotiate a socio-scientific issue. *International Journal of Science Education*, *36*, 1491-1509. Retrieved from http://doi.org/ 10.1080/09500693.2014.891159

Cano, F. (2005). Epistemological beliefs and approaches to learning: Their change through secondary school and their influence on academic performance. *British Journal of Educational Psychology*, *75*, 203-221. Retrieved from http://doi.org/ 10.1348/000709904X22683

Capps, D. K., & Crawford, B. A. (2012). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education*, *24*, 497-526. Retrieved from http://doi.org/10.1007/s10972-012-9314-z

Carrier, S. J., Thomson, M. M., Tugurian, L. P., & Stevenson, K. T. (2014). Elementary science education in classrooms and outdoors: Stakeholder views, gender, ethnicity, and testing. *International Journal of Science Education*, *36*, 2195-2220. Retrieved from http://doi.org/10.1080/09500693.2014.917342

Chen, J. A. (2012). Implicit theories, epistemic beliefs, and science motivation: A person-centered approach. *Learning & Individual Differences*, *22*, 724-735. Retrieved from http://doi.org/10.1016/j.lindif.2012.07.013

Chen, J. A., Metcalf, S. J., & Tutwiler, M. S. (2014). Motivation and beliefs about the nature of scientific knowledge within an immersive virtual ecosystems environment. *Contemporary Educational Psychology*, *39*(2), 112-123. Retrieved from http://doi.org/10.1016/j.cedpsych.2014.02.004

Chen, J. A., & Pajares, F. (2010). Implicit theories of ability of Grade 6 science students: Relation to epistemological beliefs and academic motivation and achievement in science. *Contemporary Educational Psychology*, *35*(1), 75-87. Retrieved from http://doi.org/10.1016/j.cedpsych.2009.10.003

Cheng, J. C.-H., & Monroe, M. C. (2012). Connection to nature children's affective attitude toward nature. *Environment & Behavior*, *44*(1), 31-49. Retrieved from http://doi.org/10.1177/0013916510385082

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist*, *46*(3), 141-167. Retrieved from http://doi.org/10.1080/00461520.2011.587722

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175-218. Retrieved from http://doi.org/10.1002/sce.10001

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Cohen, B. H. (2007). *Explaining psychological statistics* (3rd ed.). Hoboken, NJ: Wiley.

Conley, A. M., Pintrich, P. R., Vekiri, I., & Harrison, D. (2004). Changes in epistemological beliefs in elementary science students. *Contemporary Educational Psychology*, *29*(2), 186-204. Retrieved from http://doi.org/10.1016/j.cedpsych.2004.01.004

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design & analysis issues for field settings*. Boston, MA: Houghton Mifflin.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed method approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2012). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage.

Crippen, K. J., & Archambault, L. (2012). Scaffolded inquiry-based instruction with technology: A signature pedagogy for STEM education. *Computers in the Schools*, *29*(1-2), 157-173. Retrieved from http://doi.org/10.1080/ 07380569.2012.658733

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Thousand Oaks, CA: Sage.

Dawson, V. M., & Venville, G. (2008). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education*, *40*(2), 133-148. Retrieved from http://doi.org/10.1007/ s11165-008-9104-y

DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *The Journal of Experimental Education*, *76*, 281-312. Retrieved from http://doi.org/10.3200/JEXE.76.3.281-314

Dolan, T. J., Nichols, B. H., & Zeidler, D. L. (2009). Using socioscientific issues in primary classrooms. *Journal of Elementary Science Education*, *21*(3), 1-12. Retrieved from http://doi.org/10.1007/BF03174719

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education*, *34*, 2289-2315. Retrieved from http://doi.org/10.1080/09500693.2012.667582

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*, 554-567. Retrieved from http://doi.org/10.1002/sce.1023

Elder, A. D. (1999). *An exploration of fifth-grade students' epistemological beliefs in science and an investigation of their relation to science learning* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. AAT 9929819).

Elder-Vass, D. (2012). *The reality of social construction*. New York, NY: Cambridge University Press.

Ericsson, K. A., & Simon H. (1984). *Protocol analysis: Verbal reports as data. Cambridge*, MA: MIT Press.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. Retrieved from http://doi.org/10.3758/BF03193146

Feagin, J. R., Orum, A. M., & Sjoberg, G. (Eds.). (1991). *A case for the case study*. Chapel Hill, NC: UNC Press Books.

Ferguson, L. E., & Bråten, I. (2013). Student profiles of knowledge and epistemic beliefs: Changes and relations to multiple-text comprehension. *Learning & Instruction*, *25*, 49-61. Retrieved from http://doi.org/10.1016/j.learninstruc.2012.11.003

Ferguson, L. E., Bråten, I., Strømsø, H. I., & Anmarkrud, Ø. (2013). Epistemic beliefs and comprehension in the context of reading multiple documents: Examining the role of conflict. *International Journal of Educational Research*, *62*, 100-114. Retrieved from http://doi.org/10.1016/j.ijer.2013.07.001

Flick, U. (2007). *Designing qualitative research*. Los Angeles, CA: Sage.

Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition & Instruction*, *30*, 207-245. Retrieved from http://doi.org/10.1080/07370008.2012.689383

Gee, J. P. (1999). *An introduction to discourse analysis: Theory & method*. New York, NY: Routledge.

Gee, J. P. (2011). *An introduction to discourse analysis: Theory and method* (3rd ed.). New York, NY: Routledge.

Gijbels, D., Dochy, F., Bossche, P. V. den, & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research*, *75*(1), 27-61. Retrieved from http://doi.org/10.3102/00346543075001027

Gill, M. G., Ashton, P. T., & Algina, J. (2004). Changing preservice teachers' epistemological beliefs about teaching and learning in mathematics: An intervention study. *Contemporary Educational Psychology*, *29*(2), 164–185. http://doi.org/10.1016/j.cedpsych.2004.01.003

Gottlieb, E., & Institute, M. L. (2007). Learning how to believe: Epistemic development in cultural context. *Journal of the Learning Sciences*, *16*(1), 5-35. Retrieved from http://doi.org/10.1080/10508400709336941

Grandy, R., & Duschl, R. A. (2007). Reconsidering the character and role of inquiry in school science: Analysis of a conference. *Science & Education*, *16*(2), 141-166. Retrieved from http://doi.org/10.1007/s11191-005-2865-z

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist*, *43*(3), 142-160. Retrieved from http://doi.org/10.1080/00461520802178458

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist*, *45*, 245-257. Retrieved from http://doi.org/10.1080/00461520.2010.515932

Gu, J., & Belland, B. R. (2015). Preparing students with 21st century skills: Integrating scientific knowledge, skills, and epistemic beliefs in middle school science curricula. In X. Ge, D. Ifenthaler, & J. M. Spector (Eds.), *Emerging technologies for STEAM education* (pp. 39-60). Switzerland: Springer International Publishing. Retrieved from http://link.springer.com/chapter/10.1007/978-3-319-02573-5_3

Hammer, D., Elby, A., Hofer, B. K., & Pintrich, P. R. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich, (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169-190). Mahwah, NJ: Erlbaum.

Hammersley, M., & Atkinson, P. (2010). *Ethnography: Principles in practice*. New York, NY: Routledge.

Hibberd, F. J. (2005). *Unfolding social constructionism*. New York, NY: Springer.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235-266. Retrieved from http://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99-107. Retrieved from http://doi.org/10.1080/00461520701263368

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*(4), 378-405. Retrieved from http://doi.org/10.1006/ceps.1999.1026

Hofer, B. K. (2004a). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist*, *39*(1), 43-55. Retrieved from http://doi.org/10.1207/s15326985ep3901_5

Hofer, B. K. (2004b). Introduction: Paradigmatic approaches to personal epistemology. *Educational Psychologist*, *39*(1), 1-3. Retrieved from http://doi.org/10.1207/s15326985ep3901_1

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*(1-2), 85-95. Retrieved from http://doi.org/10.1016/j.ijer.2006.08.006

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88-140. Retrieved from http://doi.org/10.1006/ceps.1999.1026

Hogan, K. (2002). A sociocultural analysis of school and community settings as sites for developing environmental practitioners. *Environmental Education Research*, *8*, 413-437. Retrieved from http://doi.org/10.1080/1350462022000026818

Hsu, C. Y., Tsai, M. J., Hou, H. T., & Tsai, C. C. (2014). Epistemic beliefs, online search strategies, and behavioral patterns while exploring socioscientific issues. *Journal of Science Education & Technology*, *23*, 471-480. Retrieved from http://doi.org/10.1007/s10956-013-9477-1

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14-26. Retrieved from http://doi.org/10.3102/0013189X033007014

Jonassen, D. (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. *Educational Technology Research & Development*, *45*(1), 65-94. Retrieved from http://doi.org/10.1007/BF02299613

Jonassen, D. (2011). Supporting problem solving in PBL. *Interdisciplinary Journal of Problem-Based Learning*, *5*(2). Retrieved from http://doi.org/10.7771/1541-5015.1256

Jørgensen, M., & Phillips, L. (2002). *Discourse analysis as theory and method*. Thousand Oaks, CA: Sage.

Karabenick, S. A., & Moosa, S. (2005). Culture and personal epistemology: U.S. and Middle Eastern students' beliefs about scientific knowledge and knowing. *Social Psychology of Education*, *8*, 375-393. Retrieved from http://doi.org/10.1007/s11218-005-1826-3

Kessels, U. (2013). How epistemological beliefs relate to values and gender orientation. *Learning & Individual Differences*, *23*, 256-261. Retrieved from http://doi.org/10.1016/j.lindif.2012.10.008

Khishfe, R. (2014). Explicit nature of science and argumentation instruction in the context of socioscientific issues: An effect on student learning and transfer. *International Journal of Science Education*, *36*, 974-1016. Retrieved from http://doi.org/10.1080/09500693.2013.832004

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, *39*, 551-578. Retrieved from http://doi.org/10.1002/tea.10036

Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching*, *43*, 395-418. Retrieved from http://doi.org/10.1002/tea.20137

Kienhues, D., Bromme, R., & Stahl, E. (2008). Changing epistemological beliefs: The unexpected impact of a short-term intervention. *British Journal of Educational Psychology*, *78,* 545-565. Retrieved from http://doi.org/10.1348/000709907X268589

Kienhues, D., Stadtler, M., & Bromme, R. (2011). Dealing with conflicting or consistent medical information on the web: When expert information breeds laypersons' doubts about experts. *Learning & Instruction*, *21*(2), 193-204. Retrieved from http://doi.org/10.1016/j.learninstruc.2010.02.004

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers & Education*, *56*, 403-417. Retrieved from http://doi.org/10.1016/j.compedu.2010.08.024

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.

King, P. M., & Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions through adulthood. *Educational Psychologist*, *39*(1), 5-18. Retrieved from http://doi.org/10.1207/s15326985ep3901_2

Kitchener, R. F. (2002). Folk epistemology: An introduction. *New Ideas in Psychology*, *20*(2), 89-105.

Kitchner, K. S. (1983). Cognition, metacognition, and epistemic cognition. *Human Development*, *26*(4), 222-232. Retrieved from http://doi.org/10.1159/000272885

Knight, L. V., & Mattick, K. (2006). "When I first came here, I thought medicine was black and white": Making sense of medical students' ways of knowing. *Social Science & Medicine*, *63*, 1084-1096. Retrieved from http://doi.org/10.1016/j.socscimed.2006.01.017

Kuhn, D. (1991). *The skills of argument*. New York, NY: Cambridge University Press.

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development*, *15*, 309-328. Retrieved from http://doi.org/10.1016/S0885-2014(00)00030-7

Kuhn, D., & Udell, W. (2007). Coordinating own and other perspectives in argument. *Thinking & Reasoning*, *13*(2), 90-104. Retrieved from http://doi.org/10.1080/13546780600625447

Kyza, E. A., & Edelson, D. C. (2005). Scaffolding middle school students' coordination of theory and evidence. *Educational Research and Evaluation*, *11*, 545-560. Retrieved from http://doi.org/10.1080/13803610500254857

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*, 497-521. Retrieved from http://doi.org/10.1002/tea.10034

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science & Technology*, *1*(3). Retrieved from http://doi.org/10.18404/ijemst.19784

Liu, S.-Y., & Tsai, C.-C. (2008). Differences in the scientific epistemological views of undergraduate students. *International Journal of Science Education*, *30*, 1055-1073. Retrieved from http://doi.org/10.1080/09500690701338901

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*(1), 57-68. Retrieved from http://doi.org/10.1207/s15326985ep3901_6

Mason, L., Ariasi, N., & Boldrin, A. (2011). Epistemic beliefs in action: Spontaneous reflections about knowledge and knowing during online information searching and their influence on learning. *Learning & Instruction*, *21*(1), 137-151. Retrieved from http://doi.org/10.1016/j.learninstruc.2010.01.001

Mason, L., & Boldrin, A. (2008). Epistemic metacognition in the context of information searching on the Web. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 377-404). New York, NY: Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4020-6596-5_18

Mason, L., Boldrin, A., & Ariasi, N. (2009). Epistemic metacognition in context: Evaluating and learning online information. *Metacognition & Learning*, *5*(1), 67-90. Retrieved from http://doi.org/10.1007/s11409-009-9048-2

Mason, L., Boldrin, A., & Ariasi, N. (2010). Searching the web to learn about a controversial topic: Are students epistemically active? *Instructional Science*, *38*, 607-633. Retrieved from http://doi.org/10.1007/s11251-008-9089-y

Mason, L., Boldrin, A., & Zurlo, G. (2006). Epistemological understanding in different judgment domains: Relationships with gender, grade level, and curriculum. *International Journal of Educational Research*, *45*(1-2), 43-56. Retrieved from http://doi.org/10.1016/j.ijer.2006.08.003

Mason, L., & Boscolo, P. (2004). Role of epistemological understanding and interest in interpreting a controversy and in topic-specific belief change. *Contemporary Educational Psychology*, *29*(2), 103-128. Retrieved from http://doi.org/ 10.1016/j.cedpsych.2004.01.001

Mason, L., Boscolo, P., Tornatora, M. C., & Ronconi, L. (2013). Besides knowledge: a cross-sectional study on the relations between epistemic beliefs, achievement goals, self-beliefs, and achievement in science. *Instructional Science*, *41*(1), 49-79. Retrieved from http://doi.org/10.1007/s11251-012-9210-0

Mason, L., Pluchino, P., & Ariasi, N. (2014). Reading information about a scientific phenomenon on webpages varying for reliability: An eye-movement analysis. *Educational Technology Research & Development*, *62*, 663-685. Retrieved from http://doi.org/10.1007/s11423-014-9356-3

Mason, L., & Scirica, F. (2006). Prediction of students' argumentation skills about controversial topics by epistemological understanding. *Learning & Instruction*, *16*, 492-509. Retrieved from http://doi.org/10.1016/j.learninstruc.2006.09.007

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage.

Mokhtari, H. (2014). A quantitative survey on the influence of students' epistemic beliefs on their general information seeking behavior. *The Journal of Academic Librarianship*, *40*, 259-263. Retrieved from http://doi.org/10.1016/j.acalib. 2014.04.001

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist*, *42*(3), 173-190. Retrieved from http://doi.org/10.1080/ 00461520701416306

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, *18*(1), 3-54. Retrieved from http://doi.org/10.1007/s10648-006-9003-6

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology*, *105*, 213-225. Retrieved from http://doi.org/10.1037/a0029690

Muis.K., Duffy.M., Trevors.M., Foy, M. J., Ranellucci, J., Gierus, B., & Wang, X. (2012, April). *What were they thinking? Using cognitive interviewing to examine the nature and validity of self-reported epistemic beliefs*. Paper presented at the 2012 Meeting of the American Educational Research Association, Vancouver, Canada.

Muis, K. R., & Franco, G. M. (2009). Epistemic beliefs: Setting the standards for self-regulated learning. *Contemporary Educational Psychology*, *34*, 306-318. Retrieved from http://doi.org/10.1016/j.cedpsych.2009.06.005

Muis, K. R., & Franco, G. M. (2010). Epistemic profiles and metacognition: Support for the consistency hypothesis. *Metacognition & Learning*, *5*(1), 27-45. Retrieved from http://doi.org/10.1007/s11409-009-9041-9

Muis, K. R., Kendeou, P., & Franco, G. M. (2011). Consistent results with the consistency hypothesis? The effects of epistemic beliefs on metacognitive processing. *Metacognition & Learning*, *6*(1), 45-63. Retrieved from http://doi.org/10.1007/s11409-010-9066-0

Muis, K. R., Winne, P. H., & Jamieson-Noel, D. (2007). Using a multitrait-multimethod analysis to examine conceptual similarities of three self-regulated learning inventories. *The British Journal of Educational Psychology, 77,* 177-195. Retrieved from http://doi.org/10.1348/000709905X90876.

Murphy, P. K., Edwards, M. N., Buehl, M. M., & Zeruth, J. A. (2007). Using the domain-specific beliefs questionnaire with adolescents enrolled in high-poverty, high-minority schools: Examining psychometric properties. *The Journal of Experimental Education*, *76*(1), 3-25.

National Research Council. (1996). National science education standards. Washington DC: National Academy Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academy Press.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog/12190/learning-science-in-informal-environments-people-places-and-pursuits

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

National Science Teachers Association. (2011). *NSTA position statement: Quality science education and 21st-century skills*. Retrieved from http://www.nsta.org/about/positions/21stcentury.aspx

Next Generation Science Standards. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Neber, H., & Schommer-Aikins, M. (2002). Self-regulated science learning with highly gifted students: The role of cognitive, motivational, epistemological, and environmental variables. *High Ability Studies*, *13*(1), 59-74. Retrieved from http://doi.org/10.1080/13598130220132316

Nussbaum, E. M., Sinatra, G. M., & Poliquin, A. (2008). Role of epistemic beliefs and scientific argumentation in science learning. *International Journal of Science Education*, *30*, 1977-1999. Retrieved from http://doi.org/10.1080/09500690701545919

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*, 994-1020. Retrieved from http://doi.org/10.1002/tea.20035

Ozkan, S., & Tekkaya, C. (2011). How do epistemological beliefs differ by gender and socio-economic status? *Hacettepe University Journal of Education*, *41*, 339-348.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2013). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration & Policy in Mental Health & Mental Health Services Research*, *42*, 533-544. Retrieved from http://doi.org/10.1007/s10488-013-0528-y

Palmberg, I. E., & Kuru, J. (2000). Outdoor activities as a basis for environmental responsibility. *The Journal of Environmental Education*, *31*(4), 32-36. Retrieved from http://doi.org/10.1080/00958960009598649

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage.

Perry, W. G. (1970). *Patterns of development in thought and values of students in a liberal arts college: A Validation of a scheme*. Retrieved from http://files.eric.ed.gov/fulltext/ED024315.pdf

Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York, NY: Holt, Rinehart and Winston.

Piaget, J. (1985). *The equilibration of cognitive structures*. Chicago, IL: University of Chicago Press.

Pollock, J., & Cruz, J. (1999). *Contemporary theories of knowledge* (2nd ed.). Lanham, MD: Rowman & Littlefield.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, *40*(1), 1-12. Retrieved from http://doi.org/10.1207/s15326985ep4001_1

Qian, G., & Alvermann, D. (1995). Role of epistemological beliefs and learned helplessness in secondary school students' learning science concepts from text. *Journal of Educational Psychology*, *87*(2), 282-292. Retrieved from http://dx.doi.org/10.1037/0022-0663.87.2.282

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., … Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences*, *13*, 337-386. Retrieved from http://doi.org/10.1207/s15327809jls1303_4

Ratner, C. (2002). Subjectivity and objectivity in qualitative methodology. *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, *3*(3). Retrieved from http://www.qualitative-research.net/index.php/fqs/article/view/829

Ricco, R., Schuyten Pierce, S., & Medinilla, C. (2009). Epistemic beliefs and achievement motivation in early adolescence. *The Journal of Early Adolescence*, *30*, 305-340. Retrieved from http://doi.org/10.1177/0272431609333299

Ricco, R., Schuyten Pierce, S., & Medinilla, C. (2010). Epistemic beliefs and achievement motivation in early adolescence. *The Journal of Early Adolescence*, *30*, 305-340. Retrieved from http://doi.org/10.1177/0272431609333299

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle. *Journal of the Learning Sciences*, *15*, 261-292. Retrieved from http://doi.org/10.1207/s15327809jls1502_4

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42. Retrieved from http://doi.org/10.1080/03057260802681839

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1), 112-138. Retrieved from http://doi.org/10.1002/tea.20042

Saldaña, J. (2013). *The coding manual for qualitative researchers* (2nd ed.). Los Angeles, CA: Sage.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*, 634-656. Retrieved from http://doi.org/10.1002/sce.20065

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*, 345-372. Retrieved from http://doi.org/10.1002/sce.10130

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*, 498-504. Retrieved from http://dx.doi.org/10.1037/0022-0663.82.3.498

Schommer, M. (1993a). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education*, *34*, 355-370. Retrieved from http://doi.org/10.1007/BF00991849

Schommer, M. (1993b). Epistemological development and academic performance among secondary students. *Journal of Educational Psychology*, *85*, 406-411. Retrieved from http://dx.doi.org/10.1037/0022-0663.85.3.406

Schommer-Aikins, M. (2004). Explaining the epistemological belief system: Introducing the embedded systemic model and coordinated research approach. *Educational Psychologist*, *39*(1), 19-29. Retrieved from http://doi.org/10.1207/s15326985ep3901_3

Searle, J. R. (1983). *Intentionality: An essay in the philosophy of mind*. Cambridge, MA: Cambridge University Press.

Sharples, M., Scanlon, E., Ainsworth, S., Anastopoulou, S., Collins, T., Crook, C., … O'Malley, C. (2015). Personal inquiry: Orchestrating science investigations within and beyond the classroom. *Journal of the Learning Sciences*, *24*, 308-341. Retrieved from http://doi.org/10.1080/10508406.2014.944642

Strømsø, H. I., & Bråten, I. (2009). Beliefs about knowledge and knowing and multiple-text comprehension among upper secondary students. *Educational Psychology*, *29*, 425-445. Retrieved from http://doi.org/10.1080/01443410903046864

Strømsø, H. I., & Bråten, I. (2010). The role of personal epistemology in the self-regulation of internet-based learning. *Metacognition & Learning*, *5*(1), 91-111. Retrieved from http://doi.org/10.1007/s11409-009-9043-7

Topçu, M. S., & Yilmaz-Tüzün, Ö. (2009). Elementary students' metacognition and epistemological beliefs considering science achievement, gender and socioeconomic status. *Elementary Education Online*, *8*, 676-693.

Tsai, C. C. (2004). Beyond cognitive and metacognitive tools: The use of the Internet as an "epistemological" tool for instruction. *British Journal of Educational Technology*, *35*, 525-536. Retrieved from http://doi.org/ 10.1111/j.0007-1013.2004.00411.x

Tsai, C. C. (2008). The use of Internet-based instruction for the development of epistemological beliefs: A case study in Taiwan. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 273-285). New York, NY: Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4020-6596-5_13

Tu, Y. W., Shih, M., & Tsai, C. C. (2008). Eighth graders' web searching strategies and outcomes: The role of task types, web experiences and epistemological beliefs. *Computers & Education*, *51*, 1142-1153. Retrieved from http://doi.org/10.1016/j.compedu.2007.11.003

Valanides, N., & Angeli, C. (2008). An exploratory study about the role of epistemological beliefs and dispositions on learners' thinking about an ill-defined issue in solo and duo problem-solving contexts. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 197-218). New York, NY: Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4020-6596-5_9

Veenman, M. V. J., Hout-Wolters, B. H. A. M. V., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition & Learning*, *1*(1), 3-14. Retrieved from http://doi.org/10.1007/s11409-006-6893-0

Williams, M. (2001). *Problems of knowledge: A critical introduction to epistemology*. Oxford, UK: Oxford University Press.

Winne, P. H., Jamieson-Noel, D., & Muis, K. (2002). Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In P. R. Pintrich & M. L. Maehr (Eds.), *Advances in motivation and achievement: New directions in measures and methods* (Vol. 12, pp. 121-155). Greenwich, CT: JAI.

Wooffitt, R. (2005). *Conversation analysis and discourse analysis a comparative and critical introduction*. Thousand Oaks, CA: Sage.

Wu, H.-K., & Wu, C.-L. (2010). Exploring the development of fifth graders' practical epistemologies and explanation skills in inquiry-based learning classrooms. *Research in Science Education*, *41*, 319-340. Retrieved from http://doi.org/ 10.1007/s11165-010-9167-4

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

APPENDICES

Appendix A

Epistemological Beliefs Questionnaire

Epistemological Beliefs Questionnaire

(Elder, 1999, p.139-140)

CERTAINTY: Knowledge is Certain

2) All questions in science have one right answer. R

4) The most important part of doing science is coming up with the right answer. R

7) Scientists pretty much know everything about science; there is not much more to know. R

8) Scientific knowledge is always true. R

9) If scientists try hard enough, they can find the answer to any question. R

22) Once scientists have a result from an experiment, that is the only answer. R

31) Scientists always agree about what is true in science. R

32) Scientists never say “maybe” because they know what is true. R

DEVELOPING: Knowledge is Less Certain/Changeable/Developing

11) The ideas in science books sometimes change.

12) Ideas in science sometimes change.

13) There are some questions that even scientists cannot answer.

1) Some ideas in science today are different than what scientists used to think.

24) New discoveries can change what scientists think is true.

26) Sometimes scientists change their minds about what is true in science.

AUTHORITY: Knowledge Comes from Authority

15) In science, you have to believe what the science books say about stuff. R

17) Whatever the teacher says in science class is true. R

18) If you read something in a science book, you can be sure it’s true. R

19) Sometimes you just have to believe what the teacher says in science, even if you don't understand it. R

27) Ideas in science can come from your own questions and experiments.

28) Only scientists know for sure what is true in science. R

33) Ideas in science always come from teachers or scientists. R

23) Everybody has to believe what scientists say. R

14) Good ideas in science can come from anybody, not just from scientists.

3) Ideas about science experiments come from being curious and thinking about how things work.

REASON: Knowledge is Derived from Reasoning/Thinking/Testing

5) In science, there can be more than one way for scientists to test their ideas.

6) One important part of science is doing experiments to come up with new ideas about how things work.

20) Part of doing science is asking questions about other people's ideas or answers.

21) Experiments are used to test different ideas.

25) Good answers are based on evidence from many different experiments.

16) A good way to know if something is true is to do an experiment.

29) It is good to have an idea before you start an experiment.

30) A good way to get ideas in science is to wonder why things happen.

10) It is good to try experiments more than once to make sure of your findings.

Note: R indicates that the item is reverse scored.

Appendix B

Post Interview Protocol

Background Information

First off, please tell me your names and your stakeholder.

Could you tell me your opinion about this project? What did you find out about the water quality of the river? What did you learn from this project? Why?

Examining Prompting Videos

We will watch some episodes from the project, then I will ask you to describe what you were doing.

(Play prompting videos to students)

In the episode we just watched, could you tell me what you were doing?

Why you were doing _______?

How did you decide to do _______?

Did you have any problem or difficulties when you were_______?

Remaining Questions

1. Can you describe your approach to solving the problem?
2. How did you find evidence?
3. What kind of websites did you use to find evidence? Why?
4. Did you encounter any difficulties when you were searching for information?
5. Did you find some websites you think are particularly helpful? Why?
6. What is a good website? Why?
7. If you find two websites that provide opposite information about something, what do you do? Why? Is only one site right or could both be somewhat right? Why?
8. How did you use the information you found online?
9. How do you prove your point? Why?
10. Can you describe your approach to writing the report?
11. How did you choose the information to write in your report?

Appendix C

Coding Scheme

- Epistemic beliefs
    - Justification of knowing
    - Simplicity, certainty of knowledge
        - Knowledge is simple and certain
        - Knowledge is uncertain and evolving
    - Source of knowledge
        - External authorities
        - Personal justification
    - Understanding of science
        - About scientific method
        - About scientific knowledge
- Evaluate information
    - Accepting information without questioning
    - Comparing water test data to standards
    - Consider conflicting information
    - Consider credibility
    - Consider source of information
    - Consider stakeholder perspective
    - Consider validly of water tests
    - Interaction
        - Ask peers for help
        - Ask the teacher or researchers for help
        - Teacher initiated discussion
        - Discussion with peers
- Gather information
    - From teacher
    - From stakeholders
    - From Observation
    - From Online search
    - From Other sources

  - From Water test
  - Interaction
    - Ask peers for help
    - Ask the teacher or researchers for help
    - Teacher initiated discussion
    - Discussion with peers
- Reflections about approach to create arguments
  - About argument
  - About claim
  - About evidence
- Students' interest
  - About science
  - About field trips
  - About in-class activities

Appendix D

Parent Permission/Student Assent

Epistemic Beliefs of Middle School Students in a Problem-based, Scientific Inquiry Unit

Introduction/ Purpose Professor Brian Belland and his doctoral student Jiangyue Gu in the Department of Instructional Technology and Learning Sciences at Utah State University are conducting a research study to understand how middle and high school students think of science and how their understanding of science influence their practice during a scientific inquiry project. Your child has been asked to participant because he/she registered in the summer program *Cache Classroom*. We invite your child to participant a two-week long science project to investigate water quality of their local river.

Procedures If you allow your child to participate in this research study, he/she

1. will complete a survey (takes about 15 minutes) at the beginning and the end of the project.
2. will participate in a three-week long science project in their science class to investigate the water quality of their local river and provide solutions to improve water quality. Your child will go to a one-day field trip to collect water quality information. Your child maybe be videotaped during the entire project.
3. may be asked to participant in one interview to give feedback of this project, explain his/her way to do investigation and develop problem solutions, and explain their understandings of science. The interview will last about 30 minutes and will be videotaped.

Risks No study is without risks. The researchers believe that this study poses no greater risk than your child would encounter in everyday life. There is a slight chance of loss of confidentiality, but we will do our best to protect your child's confidentiality by taking steps to prevent that as described below.

Benefits Your child's understanding of science and his/her ability to do scientific inquiry may be improved. The investigator may better understand how middle and high school students think of science and how to support students develop advanced view of science. Hence, the results of this study may in turn benefit other middle and high school students and science teachers.

Voluntary nature of participation and right to withdraw without consequence
Participation in research is entirely voluntary. You may refuse to allow your child to participate or withdraw his/her participation at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator and his research assistant will have access to the data. The data will be kept in a locked file cabinet in a locked room or on a password-protected computer. To protect your child's privacy, the researcher will assign an ID code to your child and replace his/her name. All personal information will be removed from survey results and interview transcripts at the end of data collection. Personal, identifiable information will be kept for at most two years following data analysis, after which it will be destroyed. The video and/or audio (with face blurred out) maybe played in presentations at professional meetings, unless you opt out of allowing the researchers to play the video and audio at professional conferences. The researchers will not use your child's name or any of his/her identifiable characteristics in any oral or written publication.

IRB Approval Statement The Institutional Review Board for the protection of human participants at USU has approved this research study. If you have any pertinent questions or concerns about your rights as a parent or your child's as a participant, or if your child has a research-related injury, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu. If you have a concern or complaint about the research and you would like to contact someone other than the research team, you may contact the IRB Administrator to obtain information or to offer input.

Copy of Permission Form You have been given two copies of this Parent Permission form. Please sign both copies, including your child's assent (agreement) and signature, return one to school with your child and retain one copy for your files.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

Signature of PI Signature of Student Researcher

______________________________	______________________________
Brian Belland, Principal Investigator	Jiangyue Gu, Student Researcher
435-797-2535	435-881-9785
brian.belland@usu.edu	iiangyue.gu@aggiemail.usu.edu

❑ Video and audio of my child (with the face blurred) may not be played at professional conferences

Signature of Parent/Guardian By signing below, I agree to allow my child to participate.

______________________________	____________________	________
Parent or Guardian's signature	Relationship to student	Date

Child/Youth Assent: I understand that my parent(s)/guardian is/are aware of this research study and that permission has been given for me to participate. I understand that it is up to me to participate even if my parents say yes. If I do not want to be in this study, I do not have to and no one will be upset if I don't want to participate or if I change my mind later and want to stop. I can ask any questions that I have about this study now or later. By signing below, I agree to participate.

______________________________	________________________	________
Student's Signature	Name (Please Print)	Date

Appendix E

Permission Letter

PERMISSION LETTER

Date: January 6, 2016
Name: Dr. Anastasia Elder
Address: Counseling & Educational Psychology
508 Allen Hall, Box 9727
Mississippi State, MS 39762

Dear Dr. Elder:

I am in the process of preparing my dissertation in the Instructional Technology and Learning Sciences department at Utah State University. I hope to complete my degree program in Instructional Technology and Learning Sciences.

I am requesting your permission to include the attached material as shown. I will include acknowledgments and appropriate citations to your work as shown and copyright and reprint rights information in a special appendix. The bibliographic citation will appear at the end of the manuscript as shown. Please advise me of any changes you require.

Please indicate your approval of this request by signing in the space provided, attaching any other form or instruction necessary to confirm permission. If you charge a reprint fee for use of your material, please indicate that as well. If you have any questions, please call me at the number below.

I hope you will be able to reply immediately. If you are not the copyright holder, please forward my request to the appropriate person or institution. Thank you for you cooperation.

Jiangyue Gu
(435-881-9785)

I hereby give permission to Jiangyue Gu to reprint the following material in her dissertation.

Appendix C (Epistemological Beliefs Questionnaire Items for Study Two), p.139-140 in Elder, A. D. (1999) An exploration of fifth-grade students' epistemological beliefs in science and an investigation of their relation to science learning. UMI ProQuest Digital Dissertation No. AAT 9929819.

Fee: -0-
Signed: ____________

CURRICULUM VITAE

JIANGYUE (GRACE) GU

Department of Instructional Technology and Learning Sciences
Emma Eccles Jones College of Education & Human Services
Utah State University
Mobile: +1 (435)-881-9785, Email: jiangyue.gu@aggiemail.usu.edu

EDUCATION

- Ph.D. in Instructional Technology and Learning Sciences Sep. 2010 - Present
  Department of Instructional Technology and Learning Sciences,
  Utah State University, Logan, Utah
- M.S. in Higher Education Sep. 2007 - Jul. 2010
  Higher Education Research Institute, Xi'an Jiao Tong University, China
- B.S. in Material Science and Engineering Sep. 2003 - Jul. 2007
  College of Material Science and Engineering, Xi'an Jiao Tong University, China

RESEARCH EXPERIENCE

- Research Assistant Aug. 2011 - Present
  Department of Instructional Technology and Learning Sciences, USU
  Project "Supporting middle school students' construction of evidence-based arguments" funded by National Science Foundation. Principal Investigator: Dr. Brian Belland
- Research Assistant Aug. 2015 - Present
  School of Teacher Education and Leadership, USU
  Project "STEM Teaching Integrating Textiles and Computing Holistically (STITCH)" funded by National Science Foundation. Principal Investigator: Dr. Colby Tofel-Grehl
- Research Assistant Aug. 2014 – Nov. 2015
  STE2M (Science, Technology, Engineering, Education, Mathematics) Center, USU
- Research Assistant Aug. 2013 - Sep. 2014
  Department of Instructional Technology and Learning Sciences, USU
  Joint-project "Kids DIY Media" with the Faculty of Information, University of Toronto, funded by the Social Sciences and Humanities Research Council (SSHRC) of Canada.

TEACHING EXPERIENCE

- Teaching Assistant, INST 7000 Pro Seminar I, Dr. Belland's section, Fall 2013, USU
- Teaching Assistant, General Psychology, Spring 2008, XJTU
- Teaching Assistant, Introduction to Psychology, Fall 2008, XJTU

PUBLICATIONS

Referred Journals

Belland, B. R., **Gu, J**., Armbrust, S., & Cook, B. (2015). Scaffolding argumentation about water quality: A mixed method study in a rural middle school. *Educational Technology Research and Development, 63*(3), 325-353. Available online: http://dx.doi.org/10.1007/s11423-015-9373-x [ISI-indexed journal; 2013 5-year Impact Factor: 1.52

Belland, B. R., Burdo, R., & **Gu, J**. (2015). A blended professional development program to help a teacher learn to provide one-to-one scaffolding. *Journal of Science Teacher Education 26*(3), 263-289, Available online: http://dx.doi.org/10.1007/s10972-015-9419-2 [Scopus-indexed journal; 2013 Scimago Journal Rank: 1.128]

Book Chapters

Gu, J., & Belland, B. R. (2015). Preparing students with 21st century skills: Integrating scientific knowledge, skills, and epistemic beliefs in middle school science curricula. In X. Ge, D. Ifenthaler, & J. M. Spector (Eds.), *Full STEAM ahead: Emerging technologies for STEAM education.* (pp.39-60). Cham, Switzerland: Springer International Publishing.

Conference Proceedings

Belland, B. R., **Gu, J**., Armbrust, S., & Cook, B. (2013). Using generic and context-specific scaffolding to support authentic science inquiry. In D. G. Sampson, J. M. Spector, D. Ifenthaler, & P. Isais (Eds.), *Proceedings of the IADIS international conference on cognition and exploratory learning in the digital age* (CELDA 2013)(pp. 185-192). Fort Worth, TX, USA: IADIS.

Gu, J., & Belland, B. R. (2012). A scaffolding framework to promote the transfer of argumentation ability. *Proceedings of selected research and development presentations at the 2012 annual convention of the Association for Educational Communications and Technology* (vol. 2, pp. 273-279). Louisville, KY, USA: AECT.

Belland, B. R., **Gu, J**., & Burdo, R. (2012). Computer-based scaffolding's role in developing middle school students' ability to argue about socioscientific issues. *Proceedings of selected research and development presentations at the 2012 annual convention of the Association for Educational Communications and Technology* (vol. 1, pp. 88-94). Louisville, KY, USA: AECT.

Manuscripts Under Review

Belland, B. R., **Gu, J**., Kim, N., & Turner, D. J. (Under review). An ethnomethodological perspective on how middle school students addressed a water quality problem. Manuscript submitted for publication to *Educational Technology Research and Development*.

Belland, B. R., **Gu, J**., Kim, N., Turner, J., & Weiss, M. (Under review). The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science. Manuscript submitted for publication to *The Elementary School Journal*.

Tofel-Grehl, C., Fields, D. A., **Gu, J**., Sun, C., & Maahs-Fladung, C. (Under review). Sewing Electronics in Science Class: Improving Student Interest in Science. Manuscript submitted for publication to *Research in Science Education*.

Feldon, D., Chao, J., Franco, J., **Gu, J**., & Maahs-Fladung. (Under review). The effects of cognitive load reduction on students motivation in an undergraduate biology course. Manuscript submitted for publication to *Journal of Educational Psychology*.

Refereed Conference Presentations

Gu, J., Tofel-Grehl, C., Fields, D. A., Sun, C., & Maahs-Fladung, C. A. (Accepted). Sewing electronics in class: Improving middle school students' science learning. Paper accepted for presentation at the 2016 American Education Research Association Annual Meeting, Washington, DC, USA.

Belland, B. R., **Gu, J**., Weiss, D. Mark., & Kim, N. An examination of credit recovery students' use of computer-based scaffolding in a problem-based, scientific inquiry unit. (Accepted). Paper accepted for presentation at the 2016 American Education Research Association Annual Meeting, Washington, DC.

Gu, J., Belland, B. R., Weiss, M., & Kim, N. (2015, April). Middle school students' science interest and epistemic beliefs in a technology enhanced, problem-based, scientific inquiry unit. Paper presented at the 2015 American Educational Research Association Annual Meeting, Chicago, Illinois.

Belland, B. R., **Gu, J**., Kim, N., Turner, J., & Weiss, M. (2015, April). The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science. Paper presented at the 2015 American Educational Research Association Annual Meeting, Chicago, Illinois.

Gu, J., & Belland, B. R. (2015, April). Prompting adolescents' epistemic beliefs in a field-based science Program: An exploratory, mixed methods study. Paper presented at the 2015 NARST Annual International Conference, Chicago, Illinois.

Belland, B. R., **Gu, J**., Thayne, J., Armbrust, S., & Cook, B. (2014, April). How middle school students investigated water quality, evaluated evidence, and constructed arguments: An ethnomethodological study. Paper accepted for presentation at the 2014 American Educational Research Association Annual Meeting, Philadelphia, PA.

Belland, B. R., **Gu, J**., Armbrust, S., & Cook, B. (2013, October) Using generic and context-specific scaffolding to support authentic science inquiry. Paper presented at Cognition and Exploratory Learning in the Digital Age (CELDA), Fort Worth, TX.

Gu, J., & Belland, B. R. (2013, April). The role of epistemic beliefs in argumentation and science inquiry: A conceptual framework. Poster presented at the 2013 American Educational Research Association Annual Meeting, San Francisco, CA.

Belland, B. R., **Gu, J**., Armbrust, S., & Cook, B. (2013, April). Scaffolding middle school students' arguments about water quality: A mixed method study. Paper presented at the 2013 American Educational Research Association Annual Meeting, San Francisco, CA.

Gu, J., & Belland, B. R. (2012, November). A scaffolding framework to promote the transfer of argumentation ability. Paper presented at the 2012 Association for Educational Communications and Technology International Convention, Louisville, KY.

Brush, T., Glazewski, K., Belland, B. R., **Gu, J**., Burdo, R. A., Ottenbreit-Leftwich, A., & Leary, H. (2012, November). Problem-based Learning and Teacher Education. Paper presented at the 2012 Association for Educational Communications and Technology International Convention, Louisville, KY.

Belland, B. R., **Gu, J**., & Burdo, R. (2012, November). Computer-based scaffolding's role in developing middle school student's ability to argue about socioscientific issues. Paper presented at the 2012 Association for Educational Communications and Technology International Convention, Louisville, KY.

Belland, B. R., Burdo, R., & **Gu, J**. (2012, April). Supporting teacher professional development in PBL via distance learning technologies. Paper presented at the 2012 American Educational Research Association Annual Meeting, Vancouver, Canada.

Manuscripts in Progress

Gu, J., Belland, B.R. Epistemic beliefs of middle and high school students in a problem-based, scientific inquiry unit: An exploratory, mixed methods study.

Gu, J., Belland, B. R., Weiss, M., & Piland, J. Middle school students science interest and epistemic aims in a technology-enhanced, problem-based, scientific inquiry unit.

Belland, B. R., **Gu, J**., Weiss, D. Mark., & Kim, N. An examination of credit recovery students use of computer-based scaffolding in a problem-based, scientific inquiry unit.

PROFESSIONAL SERVICES AND ACTIVITIES

Memberships

- Member of AERA since 2011; Member of AECT since 2012; Member of NARST since 2015

Review

- Conference Reviewer: AECT 2013, AERA 2015
- Book Chapter Reviewer: Full STEAM Ahead-Emerging Technologies for STEAM. Springer.

Conference Session Chair

- AERA 2012, Session: Instructional Design Research: Current and Emerging Trends

Member of Faculty Search Committee

- Department of ITLS, USU, 2014-2015

Vice President

- Instructional Technology Student Association (ITSA), USU, 2011-2012

SCHOLARSHIPS AND AWARDS

- Outstanding Graduate Researcher, Dept. ITLS, Utah State University, 2014-2015
- ITLS Academic Excellence Scholarship, Dept. ITLS, Utah State University, Fall, 2014-2015.
- ITLS Academic Excellence Scholarship, Dept. ITLS, USU, Spring, 2013-2014.
- ITLS Academic Excellence Scholarship, Dept. ITLS, USU, Fall, 2013-2014.

- Outstanding Graduate Research Assistant, Dept. ITLS, USU, 2012-2013.
- Presidential Fellowship, USU, 2010-2011.
- Excellent Graduate Student Award, XJTU, 2008-2009.
- First-class Graduate Student Scholarship, XJTU, 2009-2010.
- Second-class Graduate Student Scholarship, XJTU, 2008-2009.
- Second-class Graduate Student Scholarship, XJTU, 2007-2008.