AN ABSTRACT OF THE DISSERTATION OF

Micki Marie Halsey Randall for the degree of Doctor of Philosophy in Science Education presented on July 5, 2016.

Title: Developing NGSS Scientific Practices Through Inquiry In An Outdoor Learning Environment

Abstract approved: ____

Larry Flick

The National Research Council has aggregated research evidence on the pedagogy of science teaching and learning (NRC, 2012), culminating in the *Next Generation Science Standards* (NGSS). These standards support emphasis on eight scientific practices as an important component for teaching science as inquiry to K-12 students. This latest framework for curriculum and instruction poses the question of the role of science practices in student content understanding as well as understanding the nature of science inquiry. Improved understanding of students' knowledge construction while engaged in an outdoor learning environment (OLE) can help improve theory about students' knowledge-building work that imply ways to structure better contexts for learning involving scientific practices. The present investigation provides descriptive evidence of students' epistemological moves as they engaged in a six-month inquiry investigation in an OLE on the school campus designed to embed scientific practices as described in the NGSS. Berland et al. (2015) *Epistemologies in Practice* (EIP) provided the conceptual framework for examining student knowledge construction. The data consisted of written artifacts and recorded discourse events that were used to provide evidence of student thinking as it related to scientific sense-making in a school context. The analysis parsed the data as to whether students' thinking was meaningful within four "epistemological considerations" in building knowledge: Nature, Generality, Justification, and Audience. Evidence suggests student thinking progresses over time from a classroom goal orientation to inclusive of scientific sense-making. Students constructed knowledge in a

variety of science and non-science topics, as well as demonstrating personal and social skills. This study suggests that there may be a productive hierarchy or progression in the epistemological considerations that students use in building knowledge.

Developing NGSS Scientific Practices Through Inquiry In An Outdoor Learning Environment

by
Micki Marie Halsey Randall

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented July 5, 2016
Commencement June 2017

Doctor of Philosophy dissertation of Micki Marie Halsey Randall presented on July 5, 2016

APPROVED:

Major Professor, representing Science Education

Dean of the College of Education

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Micki Marie Halsey Randall, Author

ACKNOWLEDGEMENTS

I express sincere appreciation to my advisor, Dr. Larry Flick, for opening the door to this great pursuit and mentoring me at each step. His insights, questions, and guidance have led me beyond my expectations. Our first interaction set the stage, seven years ago, for an unparalleled opportunity of growth and learning. I am immensely grateful for your dedication, support, and encouragement. Thank you.

I would also like to thank my committee members. Dr. Kathryn Ciechanowski and Dr. SueAnn Bottoms, thank you for engaging my mind as we learned of cultural and linguistic diversity. May every child find a classroom open for their minds and bodies to learn and grow. Dr. Jennifer Bachman, thank you for inspiring me with legends of your ream-of-paper-length dissertation, for your advice on reflexivity, and for your gentle suggestions and encouragement through this dissertation. Dr. Misty Lambert, thank you for believing in me. Your kind words and honest responses let me know you were in my corner – and I needed that.

To my cohort at OSU, and all those in the classes surrounding us, thank you. We made it through together because we all had strengths and a willingness to support one another. Your patience in class as I learned what felt like a new language speaks to the character and devotion to learning of each one of you. And to my students, thank you for allowing me into your thoughts. You inspire me.

Finally, thank you to my friends and family. Jenni and Stephanie, your support – watching my kids, reading my papers, listening to my fears – without a doubt enabled me to get this far. I am forever indebted to you. Rieve, Denavae, and Taevin – my amazing children – thank you for helping me survive these four years by having fun without me and loving me anyway. And Rhett, the love of my life, thank you for supporting me and not giving up on me through all of this. As many times as I wanted to throw in the towel, you were there to remind me why I was doing this and how important it was to finish. I am so thankful you had the patience and energy to be the better half of our partnership. Thank you for enjoying time with the kids all those weekends without me. I love you.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

DEDICATION

This work and all of the work leading to this point are dedicated to my father, Laurence Moore Halsey. He encouraged me to pursue a Ph.D. and passed away just days before my first class. Without his encouragement replaying in my mind during many moments of challenge and frustration, I may have given up. Thank you, Dad, for all that you gave me and all that I am.

Chapter 1: Introduction

The Next Generation Science Standards (NGSS) released in 2013 continue to be adopted and implemented across the United States. There are three dimensions in each performance expectation – or standard – within NGSS. Cross-cutting concepts, disciplinary core ideas, and scientific practices make up the three dimensions of science learning (NGSS Lead States, 2013). These three dimensions work together as students engage with science in the classroom. As such, scientific practices (SPs) do not stand alone and should not be taught in isolation from cross-cutting concepts or disciplinary core ideas. The science curriculum must include SPs along with disciplinary content. As SPs are implemented, we need a better understanding of how SPs help students build knowledge in an inquiry context.

As much research has suggested, engagement with the content of the science curriculum in real-world situations increases learning about the subject (Braund & Reiss, 2004; Kenney, Militana, & Donohue, 2003; Lieberman & Hoody, 1998; Weilbacher, 2009). The outdoors provides such a context for students to engage in science learning. An outdoor learning environment (OLE) provides the right place for this engagement and enactment of inquiry through scientific practices. The OLE on campus contextualizes science learning of content and scientific practices in a familiar environment encouraging deeper connections to the learning for the students in this study.

Students engaged in field-based science inquiry participate in scientific practices. In field-based science inquiry, students design and run their own investigations to answer self-selected questions about phenomena in the outdoor environment. Through this process, students learn science content and scientific practices by performing investigations and using the tools necessary to do so. Students learn science by doing science in ways that are meaningful to them and their community.

Children experience science in the outdoors beginning in infancy. They see, smell, touch, hear and taste the natural world around them. In schools, outdoor experiences began to include science specific content during the early 20th century in a movement called Nature Study (for more on Nature Study, see Bailey, 1909; Comstock, 1918; Hodge, 1902; Jackman, 1891). Though Nature Study itself disappeared from most classrooms after World War I, many schools continue to utilize the outdoors as places for learning, including school gardens, outdoor laboratories, and field trip experiences. These opportunities to engage in science outside the classroom often encourage students from all backgrounds toward science learning (NGSS Lead States, 2013; National Research Council (NRC), 2012).

The Next Generation Science Standards (NGSS) authors acknowledge the benefits of outdoor learning and encourage educators to utilize these experiences in order to provide science for all students (NGSS Lead States, 2013). Scientific practices, one of the defining dimensions of NGSS, can occur easily through outdoor learning experiences. The context of science learning opportunities influences the outcome (Duschl, 2008; Giamellaro, 2014) and outdoor experiences provide learning opportunities requiring active engagement of the learner thereby increasing the potential for increased knowledge construction through work that has meaning in their lives. These opportunities include inquiry investigations in an outdoor learning environment to provide access for students to engage in scientific practices and knowledge construction. Using the *Epistemologies in Practice* (EIP) framework developed by Berland et al. (2015), my research will examine students' thinking as they engage in scientific practices through inquiry in the outdoor learning environment.

Learning through active engagement can be observed and measured through changes in academic performance and demonstrated skills. Increased motivation and engagement enhance learning opportunities and curriculum using the context of outdoor learning often increases interest, motivation, and engagement (Department for Education and Skills (DfES), 2006; Lieberman & Hoody, 1998; Malone, 2008; Office for Standards in Education (Ofsted), 2008; Weilbacher, 2009). The term *outdoor learning* in this paper applies to activities on campus, outside of the building, and within the science curriculum. These activities are distinct from off-campus outdoor school in terms of frequency and duration. The specific activities for this study center on a six-month, student-driven, science inquiry investigation with data collection sites and weekly visits to the on-campus, outdoor learning environment (OLE).

In the current study, students engage in an inquiry investigation. Science inquiry in school occurs along a continuum from full to partial inquiry (Biological Science Curriculum Study (BSCS), 2009). In the science classroom, inquiry can range from student choice of procedures given a set of materials and a prescribed question to answer, to student choice of question, material use, procedure, and evaluation of data collected (BSCS, 2009; Herron, 1971; Windschitl, Ryken, Tudor, Koehler, & Dvornich, 2007) The amount of learner self-direction and the amount of direction from the teacher create variation in the type of inquiry afforded by a classroom investigation (BSCS, 2009; Bell, Smetana, & Binns, 2005; Magnusson, Krajcik and Borko, 1999). Scientific inquiry is a process, not a set of specified steps. As such, implementation of scientific inquiry in the classroom takes many forms, including field-based (Windschitl et al., 2007), explanation-driven (Sandoval & Reiser, 2003), model-based (Windschitl, Thompson, & Braaten, 2008), and project-based science (Marx, Blumenfeld, Krajcik, & Soloway, 1997). However, all scientific investigations include collection of evidence in a systematic way, and communication of the results of the investigation (Windschitl et al., 2007). It is often teacher discretion, comfort level, and perceived availability of time that determine the type of inquiry (full or partial) provided to students. Inquiry activities take much more time than traditional, classroom laboratory exercise. Implementation of scientific inquiry in the classroom has drawn concern as many teachers do not provide appropriate inquiry opportunities, though they believe in its value in the classroom (Capps & Crawford, 2013; DiBiase & McDonald, 2015; Lebak, 2015). In this research study, students engage in full inquiry – student-driven investigations – for the better part of six months. The components of the inquiry investigation include in-classroom writing and reflection activities, as well as collection of data outside. The instructional design is described in detail in chapter 3.

The inquiry investigations in this study require students to pursue their own choice of investigation in an outdoor learning environment (OLE). They design each aspect of the inquiry work, from question to presentation and reflection, with the teacher acting as a facilitating guide in the process. The inquiry investigation takes place in the outdoor learning environment, with students collecting data in the OLE each week for approximately 20 weeks. Restrictions to topic choice and requirements regarding written and oral products exist and will be discussed later. However, students design and implement self-determined procedures and data collection methods, as well as analyses and conclusions.

Throughout the inquiry investigation, students have opportunities to actively engage in the scientific practices as described in the Next Generation Science Standards (NGSS). Classroom standards as outlined in NGSS have been adopted across multiple states, including the state where this research is occurring. As such, the use of the standards and practices in the classroom align with those in NGSS specifically. This affords an opportunity for teachers and researchers to recognize the suitability of a similar curriculum in their classrooms. The term 'practice' reflects both skills and knowledge necessary for learning and doing science (NRC, 2012). Student thinking while engaged in these practices is a significant part of this research. For this reason, the practices examined in this study are specifically those described in NGSS. For this study, I use the following descriptors for practices drawn from Appendix F of NGSS:

SP1. Asking questions (for science) and defining problems (for engineering)
SP2. Developing and using models
SP3. Planning and carrying out investigations
SP4. Analyzing and interpreting data
SP5. Using mathematics and computational thinking
SP6. Constructing explanations (for science) and designing solutions (for engineering)
SP7. Engaging in argument from evidence
SP8. Obtaining, evaluating, and communicating information

Figure 1

Scientific Practices of NGSS

According to Osborne (2014), "The primary purpose of engaging in practice is to develop students' knowledge and understanding required by that practice, how that practice contributes to how we know what we know, and how that practice helps to build reliable knowledge" (p. 189). This engagement improves the quality of learning for the students. The practices identified in the NGSS utilize skills and knowledge, and expect development of both. Inquiry investigations, such as the research in this study, provide the opportunity for students to experience those practices while working outside the classroom.

One of the interests of this study is to examine how students understand the practices developed in their outdoor learning experiences. To accomplish this goal, I used Berland et al. (2015) *Epistemologies in Practice* (EIP) framework to guide this study. Examining the discourse between students, and the written reflections of students provided evidence of students' epistemic considerations as they engage in their inquiry investigations in the OLE. For example, analysis of a written reflection might reveal a student engaging with the learning opportunity out of concern for grades. This type of engagement would be evident in a reflection such as "I am concerned my group won't get a good grade." The student's tacit epistemology would be *I learn by getting good grades*. On the other hand, a written reflection might offer an epistemic consideration suggestive of personal motivation for learning. An example of this might read, "I don't understand why . . . happens." In addition to written artifacts, discourse between students while engaging in the inquiry investigations will offer insight into students' epistemic considerations. For example, student conversations during data collection might offer insight into their thinking as they work through conflict or sense-making of the data collected. On one hand, a student might say, "The pH probe says 7.2. Just write it down and let's go to the next spot." And his partner might respond, "Wait, 7.2 doesn't make sense to me. The pH was 5.5 last week and nothing was added to the pond other than rain. I don't think it could have changed that much. Let's check it again." This conversation would suggest the first student approaches the learning event with a goal of doing the work (collecting a number) <u>to get done</u>. The other student approaches the learning event with a goal of <u>understanding the data</u> collected through immediate analysis. The sense-making taking place in this scenario is in-line with scientific sense-making and suggests an EIP reflective of meaningful use.

Epistemologies in Practice Framework

Epistemologies are the ideas people hold about the nature of knowledge and knowing (Sandoval, 2014). Epistemologies can be tacit and context sensitive, and serve as resources for students (Louca, Elby, Hammer, & Kagey, 2004). These latent resources are productive for students learning when they are activated, which is context dependent (Hammer & Elby, 2003). In the example of the last paragraph, the first student treats the OLE as a traditional school context where students often see learning and knowledge as completing tasks. The second student sees the OLE as a different context that affords different opportunities for a different kind of learning. Understanding students' epistemologies *in practice* can benefit teachers and curriculum developers. By interpreting EIP, that is by structuring an environment for scientific work and interpreting student behaviors as expressions of an epistemological framework, researchers can build theory of student knowledge building. Improved understanding of student work can also help us understand how to structure better contexts for learning.

Developed by Berland et al. (2015), the EIP framework involves examining student behaviors and knowledge building work, especially in consideration of their identified reasons for what, how, and why they are doing tasks designed to promote science learning. The term "consideration" refers to thoughts or motives taken into account when judging or deciding something. Within this framework, Berland et al. identify four epistemic considerations. They are described as questions to represent the range of ideas and context-dependence of the ideas for students. These four considerations are:

- What kind of answer should our knowledge product provide? (Nature)
- How does our knowledge product relate to other scientific phenomena and ideas? (Generality)
- How do we justify the ideas in our knowledge products? (Justification)
- Who will use our knowledge products and how? (Audience)

(Berland et al., 2015, p. 9)

These epistemic considerations reflect students' epistemological positions with regard to knowledge products. They were chosen for inclusion in this framework because they are useful to scientists and students in their knowledge building work. These epistemological positions (or considerations) may be used across a range of learning situations but for the purposes of this study, and consistent with Berland et al., they will be used to examine how students treat knowledge products in a science learning environment. Each of the considerations is explained below.

The **Nature consideration** examines students' beliefs about what counts in terms of a knowledge product. According to Ford and Forman (2006), building knowledge by distinguishing what knowledge "counts" from what does not is a central aim of practice. In this paper, the term "knowledge product" is used as Berland et al. (2015) used the term in their EIP framework. It is "the shared knowledge that students construct, evaluate, and revise . . . a 'knowledge product' could be an explanation, a model, an argument, or a research question and could be represented physically, pictorially, verbally, or with computational tools" (p. 8). Students may consider a knowledge product to be a "right answer" as determined by the teacher, or they may consider a knowledge product to be one that is explained by the evidence collected. Examination of this consideration also includes any rationale provided by the students for their knowledge product choice.

Students may consider how their knowledge product relates to other ideas or phenomena in science. This is part of the **Generality consideration**. Examination of this consideration involves identifying how students view the relationship of their knowledge product from a specific instance to usable in other contexts. In other words, do they connect the learning from the activity beyond the immediate task? Students are rarely asked to generalize during inquiry tasks (Chinn & Malhotra, 2002). However, this epistemic consideration suggests meaningful use of the learning experience when students either use their knowledge product as an instance of a general rule, or use general rules or accepted ideas to create their knowledge product during the inquiry investigation. In the inquiry investigations of this study, a student might say, "The use of compost socks could be effective on a larger stream, such as the Willamette River, because we saw improved water quality in our small stream." A statement like this would indicate application of the knowledge product from the immediate instance to a more general use.

The **Justification consideration** asks how students justify their ideas based on some criteria. At a classroom performance level, students indicate, explicitly or implicitly, a sense of doing an experiment simply to replicate what has already been done and is already known. Discourse at this level might include a student stating, "The momentum of the cars stayed the same after the collision, just like we read in the book." At a level indicative of scientific sense-making a student might state, "The turbidity data was inconsistent, but *we* noticed this was due to the depth of the water, not the compost sock." This statement indicates the students' more meaningful use of the knowledge product – the data alone was not sufficient for justification of their conclusions, nor was the knowledge product a replication of what was already known.

Finally, students consider who will view their knowledge product, making up the last consideration: **Audience** (Berland et al., 2015). At a classroom performance level, the audience is the teacher. Students with considerations at this level make statements such as, "I hope I get a good grade" or "I hope she [the teacher] likes our project." At the other end of the range for this consideration, students indicate a consideration of audience beyond the teacher. This can include awareness of an external audience, or a view of the audience as a resource and collaborator. An example of a statement indicative of meaningful use for this consideration might be "We care about our project because we want people to know there are other ways to farm and garden." The student expects an external audience for her project, and that the external audience will find value in her results. These four considerations can overlap. For example, the latter statement also indicates the student's consideration of the Generality of her project.

Examination of students' discourse and artifacts allowed me to evaluate students' epistemological understandings within these four considerations. Identifying how students approach scientific knowledge construction is important because students' abilities to learn from participation in scientific investigations depends in part on their epistemological stance with respect to scientific practices and the products they produce. Table 1 suggests the range of students' epistemologies from classroom performance to goals consistent with scientific sense-making within each epistemic consideration. Within this framework, I examined the outdoor learning experience with respect to identification of goals within the scientific sense-making column, those indicative of meaningful use.

Table 1

Range of Students' Epistemic Considerations

Epistemic Consideration	Classroom Performance	Scientific Sense-Making Goals (Meaningful Use)
Nature	Describe or show	Explain how or why
Generality	Specific case only	Knowledge products are generalized, OR Use other general ideas to create knowledge product
Justification	Task completed without need for interpretation (i.e. information is enough)	Requires interpretation and synthesis by the student
Audience	Teacher	External audience, or Audience as collaborator

The four epistemological considerations are useful in determining in what ways students find meaning in scientific practices and the resulting knowledge products. In order for the students to have meaningful use of the practice, they must see the knowledge product as useful in the classroom community as well as the scientific community (Berland et al, 2015; NRC, 2012). As a *science student*, meaningfulness of the activity encompasses both the classroom and science. The epistemic considerations were chosen for this study because they are valuable for learning science but they are valid for a wide range of knowledge products. In other words, for a task to be considered meaningful to a science student specifically, it must hold meaning in both the "science" and the "student" identity of the person holding the meaning. An activity becomes meaningful when the student sees it as offering something to be gained, both within science and within the classroom (Michaels, Shouse, & Schweingruber, 2008). Teachers and classrooms can and do provide contexts for meaningful learning as do OLE contexts. Even though students are outdoors and the affordances are different, they are still working within a structured school environment. The science learning targeted in the OLE must make sense as part of the school environment.

An examination of students' practical epistemological ideas through observations of artifacts and student to student discourse helped me uncover implicit and explicit epistemologies, as well as how and why students chose to engage scientific practices through inquiry in the manner in which they participated. Implicit epistemologies are identified as "reflected in epistemic decisions people make during the construction and evaluation of scientific knowledge" (Sandoval, 2005, p. 648). These epistemologies serve as clues about how students determine knowledge use in learning science (Russ, 2014). The artifacts students produced, as well as their conversations provided evidence of these implicit epistemologies. In this study, I used the EIP framework to interpret data on students' approach and engagement in science inquiry in the outdoor learning environment. The research questions guiding this study are:

1. In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?
2. What kinds of knowledge are students constructing as they engage in the OLE?
3. What was learned by using the EIP framework to investigate this OLE experience?

Chapter 2: Literature Review

To help our children further society, we need to prepare them to answer questions that have not yet been asked. It is foolish to only expect students to leave the classroom knowing what has already been known. Instead, they need to leave with the tools to be able to ask and then seek answers to those unknown questions. According to Garrison (1995), the goal of education should be to push society forward, not to graduate students that can only reproduce what is already known. Dewey proposed students become involved in the activities of life and through those activities the learning would develop. "Developing the ability to understand and engage in [science] requires direct experience and continued practice with the processes of inquiry" (National Research Council (NRC), 2000). This is not to say students should go out into the world on their own without any guidance or assistance from the teacher, as spontaneous learning from nature is not always happening (Brody, 2005). It is to suggest teachers should provide opportunities for students to learn though active engagement in real-world situations (Duffy & Cunningham, 1996). Learning is happening over time, through multiple personal experiences and construction of meaning (Tal & Dierking, 2014). Learning by doing provides the skills students will potentially need to be able to advance society. Schwartz & Martin (2004) found allowing students opportunities to invent and generate solutions prepares them for future learning. Students in the current study generated solutions to answer their own research questions in an OLE on campus, engaging in science learning through scientific practices outdoors.

Defining outdoor learning

Students are the primary stakeholders in their experiences (Tan & Barton, 2008) and, consequently, determine the depth of their own learning (Dhanapal & Lim, 2013), particularly evidenced when they have the opportunity to choose, discover and construct their own understandings (Morag & Tal, 2012). However, students generally do not readily discover content entirely on their own (Brody, 2005; Giamellaro, 2014). In his study of primary contextualization of science during outdoor experiences, Giamellaro (2014) found students develop more robust understandings of science content when they can connect that content to a context, specifically an outdoor environment. In his study, Giamellaro tracked 67 students in four programs focused on learning ecology concepts during outdoor immersion experiences. These programs offered authentic contexts – outdoors – in which to learn targeted science content. This contextualization gives concepts meaning by connecting them to a time and place for the student, without which the concepts remain an abstraction. Giamellaro also observed a sense of ownership of observations by the students; this led to an increase in the perception of the science content as meaningful, accessible, and trustworthy. Similarly, Barker (2005) evidenced in his research that providing learning opportunities in a novel environment, outside doing field-work rather than in a classroom, alters the process of learning and increases the motivation of the learner. Outdoor experiences provide the context for science content to be realized and constructed into knowledge. The inquiry investigations in this research study will evidence content learning and development of scientific practices in an outdoor context.

Outdoor learning is "learning that accrues or is derived from activities undertaken in outdoor locations beyond the school classroom" (Rickinson et al., 2004, p. 9). In his work to develop a framework of learning through outdoor experiences, Brody (2005) examined variables that influence this learning. After developing and modifying his framework to include the aspect of time, he studied one person's learning experience in the outdoors. His case study demonstrated meaningful learning occurs over time through direct experience, and this learning is context dependent, or connected to the environment in which it occurs. Morag & Tal (2012) also worked to construct a framework for learning, though they focused on assessment of field trips. Through observations, and interviews, they concluded outdoor learning opportunities allow students to apply theoretical knowledge to real-life situations through direct experiences. The context of the outdoors in the current study presented in this paper, provided an opportunity for meaningful learning for the students as they engaged in direct experiences over time in the outdoors.

Outdoor learning experiences provide opportunities for students to engage with science outside of the classroom and lead to gains for participating students in academics, motivation, interest, behavior, and community involvement. The Next Generation Science Standards (NGSS) promote these gains and expect students from all backgrounds to find success in science, a demonstrated attribute of outdoor learning. Evidence from research of outdoor learning suggests students benefit from these experiences in multiple ways. Children engaged in appropriate, organized, outdoor learning experiences can improve in their academic achievements, physical activity, behavior, social interactions, and motivation (Department for Education and Skills (DfES), 2006; Lieberman & Hoody, 1998; Malone, 2008; Office for Standards in Education (Ofsted), 2008; Weilbacher, 2009). According to "A review of research on outdoor learning" conducted between 1993 and 2003 Rickinson and his colleagues (2004) found:

> "Substantial evidence exists to indicate that field work, properly conceived, adequately planned, well taught and effectively followed up, offers learners opportunities to develop their knowledge and skills in ways that add value to their everyday experiences in the classroom" (p. 5).

A follow up to this review found similar evidence of the benefits of outdoor learning experiences in the years after the 2004 report (Malone, 2008). Children engaged in learning outside the classroom have increased achievement scores, as well as improvement in physical experiences, social interaction, and emotional well-being.

Engagement with the content of the science curriculum in real-world situations increases learning about the subject (Braund & Riess, 2004; Kenney, et al., 2003; Lieberman & Hoody, 1998; Weilbacher, 2009). In his argument for environmental literacy in K12 education, Weilbacher (2009) included a brief review of environmental education research and found the benefits of exposure to nature include increases in test scores and enhancement of cognitive abilities, in addition to behavioral and social improvements. In 1998, Lieberman & Hoody examined the use of the environment as an integrating context in K-12 schools. After 40 site visits and interviews with over 400 students and 250 teachers and administrators, they concluded outdoor learning increased the ability of the students to think critically, solve problems, and think strategically. They also found students "develop a clearer and deeper understanding of the importance of scientific knowledge and processes" (p. 6). Another finding from Lieberman & Hoody was the capability of students to transfer from the outdoors to the classroom. Kenney et al. (2003) also found students' capabilities to transfer learning from outdoors to indoors when they examined implementation of a specific environmental education program. They used pre and post-tests, observations, and focus group discussions to uncover improvement in students' skills, attitudes, and knowledge resulting from the teachers' use of the school's outdoor environment.

In a mixed methods, comparison study, Fagerstam and Blom (2013) found students taught in an outdoor environment appreciated the authentic learning experience. Compared to the students taught indoors, those taught outdoors developed a deeper understanding of the course content. The outdoor environment provided a context for authentic learning students appreciated. In this comparison study, the indoor class used a teacher-centered approach, while the outdoor class was participatory and contextual with students engaged in meaningful learning relevant to their daily lives. The current study provides students opportunities to engage in learning in the context of an outdoor learning environment (OLE). This context and students' choice of topics of interest provide opportunities for meaningful learning about science relevant to their daily lives. Braund & Reiss (2004) also speak to the advantage of providing students activities in which to learn about things in which they are genuinely interested. Framing curricular activities in this way provides opportunities for authentic learning.

The nature of outdoor learning experiences themselves afford opportunities for students to create long-term memories in field work (Carrier, Thomson, Tugurian, & Stevenson, 2014; DfES, 2006; Rickinson, et al., 2004). In a comparison study of two schools, one with an emphasis of outdoor learning in the curriculum and the other without, Carrier et al. (2014) found students in the school with outdoor learning in the curriculum significantly increased their science knowledge and environmental attitudes. The researchers suggest outdoor learning experiences generate lasting memories for the learners. To encourage today's students toward similar meaningful and lasting connection with the content, students need to transfer the learning done in the outdoor setting to the classroom and to the community at large (Lieberman & Hoody, 1998; Waite, 2011; Waite, 2007). Making connections between the science and their lives improves learning of the content (Lieberman & Hoody, 1998). Learning outside the classroom allows for knowledge transfer from outside to inside the classroom and vice-versa (DfES, 2006). Students engaged in learning in the environment are more capable of transferring their scientific knowledge to tasks in the classroom (Lieberman & Hoody, 1998), leading to improved academic achievement.

In addition to improved academic achievement, outdoor learning experiences lead to increased interest and motivation for and engagement in learning (DfES, 2006; Kenney et al., 2003; Lieberman & Hoody, 1998; Ofsted, 2008; Rickinson et al., 2004; Waite, 2011), and increased use and development of higher order learning and thinking skills (DfES, 2006; Kenney et al., 2003; Rickinson et al., 2004; Weilbacher, 2009). Students participating in these experiences have been shown to change their attitudes about science and increase the value given to learning science (Braund & Reiss, 2004). The benefits are most apparent when schools embed the curriculum with long-term outdoor experiences and closely link those experiences to the classroom (Ofsted, 2008). In their review of outdoor education infused with personal experience, Rios and Brewer (2014) found learning outdoors provides meaningful experiences to facilitate learning, particularly in respect to background knowledge. Infusing opportunities for direct outdoor experiences into an existing curriculum increases student achievement in science. Dhanapal & Lim (2013) conducted a comparison study of students taught indoors and those with opportunities to learn outdoors as well. They found indoor and outdoor lessons that complement each other improve academic performance. The inquiry investigations in the OLE provide such opportunities to the students in this research study. This curriculum component embeds the outdoor experience with the classroom content and allows students time to participate in the outdoors in a meaningful way while learning.

Inquiry

Inquiry refers to both practices of scientists and those of students as they seek to construct knowledge and understand the natural world. Magnusson, et al. (1999) examined the development of pedagogical content knowledge for science teaching and constructed a representation of the orientations of science teaching on a continuum from process (students learn and use thinking process to acquire science knowledge) to guided inquiry (teachers and students work together to develop and enact investigations of science). Inquiry develops along this continuum and teachers lead activities in the classroom at various points on the continuum throughout the school year. Bell, Smetana, and Binns (2005) proposed four levels of inquiry – confirmation, structured, guided, and open – based on the amount of teacher direction versus student decision making. Their research provided guidance to teachers to assist them in moving inquiry activities from confirmation inquiry toward open inquiry. Hermann and Miranda (2010) used this guidance and created a template for open inquiry specifically for Earth and Space Science classrooms. Inquiry activities properly enacted provide students opportunities to engage in science in more meaningful ways, engaging students in the activities and practices of scientists and the scientific community.

The 2009 Biology Teachers Handbook offers a list of essential features of an inquiry-based learning experience, as well as a table of ways these features can be enacted in order to determine if an inquiry experience is full or partial. Both the features and the table are based on the 2000 National Research Council's report. Magnusson, et al. (1999) suggest a continuum of teacher practices while Bell et al. (2005) provide another continuum for developing from confirmation to open inquiry. All of this variation, and many others, demonstrates the flexibility and ambiguity of the term and use of inquiry in the classroom. As Lehrer, Schauble, and Lucas (2008) argue, students prefer inquiry over science kits, but a recipe-like approach to inquiry is "a distortion of scientific practice" (p. 515). The main intent of science enactment in any inquiry-type activity is to allow students ownership of their learning. "From an epistemological perspective, inquiry is simply the process of doing science… An understanding of the epistemological frame of inquiry will help students do it better" (Sandoval, 2005, p. 636-637). Examining the epistemic considerations of students as they engage in scientific practices through their inquiry investigation in the OLE provides information useful in structuring curriculum and learning opportunities to engage students further in science learning.

Despite its longstanding inclusion in science education and reform, use of inquiry in the classroom has drawn concern. Capps & Crawford (2013) examined use of inquiry among self-selected teachers. By analyzing videos and submitted lesson plans, they found teachers were not teaching inquiry in the way it is proposed by science education reformists. Even teachers that thought they were teaching in an inquiry manner generally were not able to produce lessons that fit in the criteria of inquiry. There is a disconnect between how teachers view inquiry and their actual practice. Though enactment in the classroom does not support the intended approach to inquiry, Capps and Crawford agree inquiry-based teaching is important. Inclusion and enactment of inquiry in the science curriculum allows students to work as practicing scientists which helps them develop deeper levels of understanding of science and critical thinking skills. Teacher beliefs about inquiry are often inconsistent with practice (Capps & Crawford, 2013; DiBiase & McDonald, 2015; Lebak, 2015). DiBiase and McDonald (2015) also found teachers believed in the benefits of inquiry, particularly guided inquiry, for student learning, however, many teachers were not enacting inquiry in their classrooms. In a Likert-type survey completed by 275 secondary science teachers, teachers expressed concerns about their ability to teach inquiry. In addition to feeling unprepared to teach inquiry lessons, teachers reported concerns about time in the year's schedule and time necessary to develop the inquiry units. They also expressed concerns about student behaviors during group work time. Teachers could not foresee giving up the time needed to prepare students for the state assessments and saw these assessments as inhibitive of the use of inquiry. The current study required time to design and implement and engaged students in the scientific practices through inquiry. As the teacher in the current study, I continually increased my understanding of inquiry and NGSS over the course of the development of this curricular component.

Teachers participating in professional development (PD) to increase their understanding and inclusion of inquiry in the classroom increase their confidence. Yager and Akcay (2010) compared classes taught by 12 teachers, half of which enacted inquiry-based learning from a PD experience. Assessment of over 700 students suggested inquiry-based learning increased students' application skills, creativity, attitude toward science, and process skills more than traditional learning. Students in the inquiry group were as successful on the post-assessment of content knowledge as students in the traditional classrooms. Yager and Akcay concluded inquiry can be a highly effective teaching method, however, they acknowledged science education does not provide a formal or standardized approach to conducting science inquiry. There is not an argument for creating such an approach, but an acknowledgment that the ambiguity of enactment of inquiry in the classroom leads to different outcomes for students.

An assessment of the effects of inquiry teaching on student performance on the 2006 Programme for International Student Assessment (PISA) was conducted by Jiang and McComas (2015). Recognizing the level of inquiry experienced by students varies, Jiang and McComas developed a four level system for classifying the degree of inquiry experience by the students. They measured student performance on three outcomes: science achievement, interest in science, and support of scientific inquiry. Based on the 2006 PISA data, they found the level of inquiry teaching experienced by the students had statistically significant impacts on the three outcomes. For the outcome of student achievement, the greatest scores were evident in students experiencing inquiry at level 2, activities and drawing conclusions, while scores for science attitudes increased as the inquiry level increased to include designing investigations (level 3) and asking questions (level 4). Among their conclusions, Jiang and McComas noted not all inquiry teaching is the same.

All inquiry teaching is not the same because there is not a commonly accepted understanding of inquiry and its use in the science classroom. Osborne (2014) noted this problem with inquiry and demonstrated the link between the intended use of inquiry in the classroom and the scientific practices described by NGSS. The benefit of the transition to scientific practices is an increase in clarity of the goals of student experiences. The clarity of the scientific practices and their expectations in the classroom increase the potential for teachers to enact curriculum representative of the goals of NGSS. The practices do not exclude or compete with inquiry, in fact they can be linked together in curricular approaches. The current study explicitly addresses each of the scientific practices within the inquiry investigations conducted by the students. This link between inquiry and scientific practices provides an opportunity to decrease ambiguity and focus instruction and activities toward scientific practices.

Model-based inquiry is one such approach to science education that connects scientific practices with inquiry. Windschitl, Thompson, and Braaten (2008) reported on a series of five studies with degree-holding graduates in a pre-service teaching program. They found these students held misconceptions of science based on the scientific method (TSM) approach of their early years in school. These misconceptions about how science knowledge develops persisted through their college years and would likely continue into the next classroom taught by these soon-to-be teachers. The concern with TSM was the lack of content inclusion and understanding, and the focus on procedure and skill development exclusively. Windschitl et al. found these concerns could occur with inquiry lessons as well, when the intent of the lesson lacked content or the need for scientific reasoning. They proposed Model-Based Inquiry (MBI) as a teaching strategy to support student work in developing explanations and scientific reasoning about the natural world. Use and design of models is one of the scientific practices described in NGSS.

NGSS encourages and expects students to become proficient in the practices of science in addition to content performance outcomes. These include observing, asking questions, using models, collecting data, constructing explanations and designing solutions, etc. (NGSS Lead States, 2013), all of which can be directly tied into an outdoor experience and allow students to engage in these practices in an authentic context.

Students engaged in scientific practices apply science in meaningful ways (NGSS Lead States, 2013). When students engage in authentic practice, particularly in science outside, they find the concepts learned in the classroom to be real and believable, not suspect out of a textbook (Waite, 2011). Duschl (2008) argues for student learning and engagement in the space between idea generation and conclusion justification. His review of research on science education supports his argument for an integration, or harmonizing, of conceptual, epistemic, and social learning goals. Context and content matter in learning science. The school classroom environment does not often provide a sense of the connection between the practices of science. The current study suggests inclusion of an OLE allows students to make those connections and to explore that space between thinking of ideas and drawing conclusions – the *doing* of science is essential to learning science.

Outdoor learning provides authentic, real-world contexts for science content learning. In this research study, students, like scientists and engineers, uncover problems in their communities and work toward a solution to those problems. They design and test these solutions, collect data, and then analyze that data to develop a greater understanding of the problem and their proposed solutions. When time allows, students may have a chance to revise their solutions based on the data and analysis, as they see necessary. Throughout all of this, students are engaging in real, authentic science outside, and learning science content while engaging in scientific practices.

The scientific practices (SP) referred to in this study are those described in NGSS. Having adopted NGSS, California, Washington, and Oregon Departments of Education expect science education to be a component of each grade level beginning with kindergarten. As such, students entering 8th grade are expected to have some experience with SP from their earlier classes. The eight identified practices remain consistent through each grade level, however, the depth of experience in each one progresses as a child advances in grades. This progression has been identified in the NGSS literature and provides a basis for identifying expected capabilities of students as they enter and then leave middle school (see Appendix D).

The first SP is "asking questions and defining problems." At the middle school level, students are expected to ask scientific questions requiring empirical evidence to answer. Hypotheses at this level should be based on scientific principles, intentionally from earlier years' experiences. Students at this level should understand the distinction between scientific questions and other questions, particularly that the answers to scientific questions require empirical evidence for justification and support.

The second SP is "developing and using models." At the lower grades, students develop simple models to represent a tool or proposed object. Once in the middle grades, the expectations of students' use of models increases to include using the developed model "to generate data to test ideas about phenomena in natural or designed systems, including those representing input and outputs and those at unobservable scales" (NGSS Lead States, Appendices, p. 53). In addition to designing and producing models, students should be able to design investigations. The scientific practice of "planning and carrying out investigations" expects middle school students to design investigations in order to gather data for evidence of claims made. Field investigations are also considered in NGSS and understood to provide opportunity for appropriate investigation designs. In the case of field observations, investigation planning should acknowledge not all conditions are under the control of the student and may influence the outcome. However, field investigations should be planned to collect data about natural phenomena under a variety of conditions in order to attempt to make sense of the phenomena even with conditions of the environment outside the control of the student and investigation.

After planning and carrying out their investigations, students analyze and interpret data, the fourth SP. This practice incorporates in this research study with the fifth SP, "using mathematics and computational thinking." Creating graphs from data tables contributes to students' understanding of this practice. As they use computers to digitize their data into spreadsheets and graphs, students begin to visualize the patterns and trends evidenced in the data collected. These representations assist in the conclusions drawn which is part of the next SP, "constructing explanations and designing solutions." Part of the expectation for this practice at the middle grades level is to "apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion" (NGSS Lead States, Appendices, p. 61).

Rounding out the scientific practices are "Engaging in argument from evidence" and "Obtaining, evaluating, and communicating information." Both of these practices include oral and written presentations of data and information from research. Students engage in these practices throughout the OLE inquiry investigations. Their participation in these practices is highlighted in the final presentations and written investigation reports. In both of these artifacts, students address the science content associated with their inquiry investigations while engaging in the practices.

Content and practice intertwine in NGSS and should intertwine in the science curriculum (NGSS Lead States, 2013; Osborne, 2014). Engagement in the practices improves the quality of student learning and helps make the content meaningful by engaging the learner in the act of doing science, rather than memorizing pieces of information handed down. According to Osborne (2014), "The primary purpose of engaging in practice is to develop students' knowledge and understanding required by that practice, how that practice contributes to how we know what we know, and how that practice helps to build reliable knowledge" (p. 189). Students develop their understanding of the practices of science while engaging in a learning activity involving science content outside.

Natural settings found in the outdoors provide opportunities for students to engage in the practices. Science comes alive when students experience phenomena, animals, and artifacts in natural settings (Braund & Reiss, 2004). Outdoor learning experiences provide an authentic context for students to interact with plants and animals in the natural world and foster a deeper understanding of nature. Inquiry in these authentic contexts can provide students with data that students find meaningful and relevant (Barker, 2005), an attribute expected in the research study presented in this paper.

Taking students outside, in their community, to engage in a science activity, increases their connection to the subject, to the environment, and to their community. NGSS recognizes learning in the outdoor setting as valuable, especially for traditionally underserved populations. These opportunities encourage and recognize funds of knowledge different students bring with them to the school setting (NGSS Lead States, 2013). By utilizing this knowledge, and learning skills to apply science knowledge to local problems, students contribute to their communities and create connections with the content that serve to increase learning and understanding. When these projects connect students to their local environments, students demonstrate increased engagement and abilities in language arts and math because they make real-world connections through pursuit of their interests (Lieberman & Hoody, 1998). The students in the current study pursued their own interests through their engagement in the inquiry investigations in the OLE on campus.

Engaging students in science experiences within their communities aligns with the goals of NGSS. "Science learning builds on tasks and activities that occur in the social contexts of day-to-day living, whether or not the schools choose to recognize this" (NGSS Lead States, 2013, p. 32). Schools that recognize this and include school grounds or community projects in the science curriculum see changes in their students. Students demonstrate increased confidence, pride in community, motivation to learn, and a greater sense of belonging and responsibility (Rickinson et al*.,* 2004). The inquiry choices made in this research study are often borne from personal interests of the students. Building on interest and identity (rather than factual knowledge exclusively) in science education benefits all groups of students, particularly those who generally feel disconnected from science when it disregards personal inclinations (NRC, 2012). Interest, experience and enthusiasm are critical to the domain of science (NGSS Lead States, 2013). Science education needs to attend to the interests and motivation of students from all backgrounds in order to increase interest in science and engineering as future career paths (NRC, 2012). Increasing interest in the subject, potentially through the increase of opportunities of choice in learning provided by outdoor experiences, leads to greater learning (Waite, 2011). Exploration of the kinds of knowledge students construct during their inquiry investigations suggests to teachers and researchers the interests of students around their science learning. In addition to exploring their choice in topic and subsequent knowledge construction, the research examines student thinking as they engage in the inquiry investigations in the OLE.

Epistemologies in Practice

Student thinking can be inferred through examination of discourse and artifacts. Using the four epistemic considerations in the EIP framework, characterizations of student thinking and sense-making become evident. Understanding how students approach knowledge construction while engaged in an inquiry activity will help teachers and students construct learning opportunities. According to Sandoval (2005), inquiry investigations can improve learning as students construct their own knowledge of science. It is unclear, though, whether students recognize their ability to do this.

Examination of the practical epistemologies of students suggests how well their understanding about knowledge construction align with the epistemology of science – the nature of scientific knowledge, how it develops, and criteria for evaluating scientific claims. As suggested by Sandoval (2005; 2014), this current research study used an authentic science experience to examine the epistemological ideas of students through analysis of discourse and written artifacts. Uncovering their thinking while engaging in the OLE investigations provided evidence of their perceptions of the meaningfulness of their experiences with the scientific practices and with the context of an OLE.

One of the considerations of this framework involves understanding what students perceive as "what counts" in terms of knowledge products. Ford and Forman (2006) argue an aim of a practice is to determine what counts as knowledge in order to build knowledge claims. Students need to participate in the discourse of deciding what knowledge claims to hold as truths and what to discredit. Louca et al. (2004) argued determining what "counts" depends on context and is an epistemological issue. The epistemologies of students are tacit and context dependent. As such, teachers can provide opportunities for students to develop their epistemic resources. Students need to attain these abilities to decipher for themselves "what counts" because they will be faced with these types of decisions throughout life. Analyzing how students make these decisions enables teachers and researchers to develop methods for students to access epistemic resources when faced with decisions about scientific knowledge claims. The research in this study examined how students engaged in those decisions by looking for evidence of students explaining how and why a knowledge claim counted or was to be presented, rather than showing or describing the data or learning in a matter of fact manner.

How students approach a learning activity can change with the activity and with time. The epistemological views of science may not be stable for an individual student, and are likely to develop over time (Sandoval, 2005). These views can also be considered epistemic resources for students to draw on as needed. Epistemologies need to be productive and perceived as productive by the learner (Russ, 2014). In order to help students develop their epistemologies and recognize their use as resources in context, researchers need to examine students constructing knowledge (Sandoval, 2012).

Epistemologies are not always explicit, nor are those that are professed the epistemologies enacted (Berland et al., 2015; Louca et al., 2004; Sandoval, 2012). To better understand how students engage in knowledge construction, particularly through the use of epistemic resources, researchers need to collect data at multiple levels. In this current study, data includes written artifacts over a 20-week span, and multiple discourse recordings within inquiry groups and between groups and adults.

Chapter 3: Methods

To understand the epistemic considerations students employ as they engage in scientific practices, this research evaluated discourse among students and artifacts produced through the inquiry investigation. Analysis of the discourse and artifacts evidenced how meaningful the outdoor inquiry investigations were for students' knowledge construction. Using qualitative research methods, the analysis examined each of the artifacts and transcripts of discourse occurrences. This research study is not a justification of a specific curriculum; this is a study to examine epistemic considerations of students as they engaged in scientific inquiry through the use of specific scientific practices set in an outdoor learning environment (OLE). Data collection began when students began their inquiry investigations and continued until the final artifact was presented, approximately six months later. The study participants are described below, as is the OLE inquiry investigation, and the data collection methods.

Study Participants

The participants in this study were students at a private school with grades 6-12, in an urban environment. Each student was enrolled in 8th grade science (Earth Science). The use of inquiry investigations in the OLE began in the Winter of 2012. Each subsequent class performed inquiry investigations in the OLE and these investigations are now incorporated into the Earth Science curriculum. Students in the 2015-16 class participated in observations, reflections, presentations, and reports for data analysis. This was a sample of convenience as I, the researcher, taught at the school being researched, and had regular and in-depth access to these participants.

The student population in this research has important characteristics for gaining knowledge about the affordances of outdoor environments for achieving the goals of NGSS. Student demographics in this school include 35% Latino/a, and 35% on tuition assistance programs. 95% of the high school graduates from this school attend college, and the majority of the remaining students enlist in the military. Because of the small size of the school, many students have the opportunity, and are encouraged, to participate in extra-curricular activities.

I established the OLE with a group of students five years ago. Since that time, each class has participated in the year-long inquiry investigations described in this research. This part of the curriculum has become an expectation of each 8^{th} grade class. As a result, the students entering the class this year have some understanding of the expectation of the OLE inquiry investigation before they enter 8^{th} grade. Because of the opportunities and affordances of this population, and based on past experiences with students at this school, it was my expectation all students enrolled in this course would participate in and complete the artifacts for the inquiry investigations in the OLE. This level of participation provides a research opportunity inclusive of all students. My comfort with the curriculum of the inquiry investigation also affords an opportunity to examine student epistemologies using an established curriculum for this course. In other words, the research does not intend to justify the inquiry investigations themselves, but instead examine the interactions and artifacts of the students engaged in the learning opportunity with which I was very familiar.

Instructional Design

Inquiry investigations take place in the OLE on campus. The students in the 8^{th} grade class of 2012 and I established this area on campus as an OLE by restoring the seasonal stream system and installing a native plant garden. Subsequent classes added to, and cared for, the OLE throughout their year in 8^{th} grade. During the inquiry investigations, students collected data from the OLE each week.

The inquiry investigation is designed to encompass the eight scientific practices described in the NGSS, and listed in chapter 1 of this paper, while engaging in science content. Disciplinary core ideas (DCI) and crosscutting concepts (CCC) present in each of the investigations vary depending on the chosen scientific question of investigation. The scientific practices provide a focal point for this research because the practices are experienced within each investigation while the content, DCI, and CCC may vary. Though the analysis of this research describes evidence of the practices, each inquiry investigation encompasses all three dimensions of the NGSS. The development of these practices occurs during a full inquiry investigation.

Inquiry investigation curriculum begins with an introduction to the students. The first week of school, the students received a course syllabus. The syllabus included the following paragraph related to the inquiry investigation:

> You will engage in inquiry investigations to develop your skills in scientific practices. We will also spend time in our outdoor learning environment (OLE) and incorporate care for and learning from our stream system and native plant garden on campus into our studies.

Reviewing the syllabus with the students, I began the first introduction to the inquiry investigation. As the school year continued, brief mentions of the upcoming investigations took place periodically. About four weeks into the school year, I provided a brief overview of the project, from the generation of questions to the final presentation and report. Students from previous classes spoke with this class to share their experiences in the OLE inquiry investigations of the past. This brief dialogue included suggestions from the older students of things to do and not do. Current students asked questions of the older students, too. Current students also had access to binders left from the previous classes with their research and final lab reports inside. Though these resources were available to the students, and former students and I brought attention to them, it was uncommon for current students to spend much time looking through these binders.

In preparation of the first scientific practice, asking questions and defining problems, students walked to the garden to make general observations and wrote potential research ideas and locations. During this initial trip to the OLE, I guided the students through the area and pointed out past projects. Remnants of some projects from prior years remain in the OLE. For example, a group created a natural filter system in the stream bed by adding layers of sand, silt, and native plants to an area of the stream bed with the intention of this section trapping the water longer allowing for it to filter through the materials and into the ground, essentially creating a bioswale. Recognizing they could not sample the outcome water, the group built a model of this bioswale to use for data collection. The bioswale and the neighboring model remain in the OLE. I referred to both of these and explained the inquiry investigation the group designed that led to the bioswale and model. As the students moved through the garden area and heard about these projects, they wrote notes of ideas and asked questions.

Back in the classroom, I provided guidelines for the question to be investigated. The "Inquiry Investigation Report Guidelines" I prepared (see Appendix A) described the criteria as:

> Develop a question to guide your investigation. The entire lab experience will be designed to find answers to this question. When brainstorming ideas for a question, consider the following criteria: data gathered has to be measurable, the procedure must be ethical (no harm to animals or environment), the experiment needs to be doable within our garden and swale area, and the experiment must relate to Earth Science concepts.

I explained these criteria to the students, provided examples of previous appropriate questions, examples of inappropriate questions with explanations of why they did not fit the criteria, and answered student questions about the criteria. I also elicited responses from students about what Earth science concepts include. This generated a list on the board of concepts appropriate to include in the investigations and further discussion clarifying this criterion for the students. Many students initially wanted to investigate concepts of life science, such as presence of different organisms in the garden or stream. I used this time to explain how many branches of science can be studied in the same investigation, and provided examples of how to ask a question that encompasses a life science concept while focusing on an Earth Science standard. For example, a group wanted to examine how fish survive in an outdoor pond. Following discussion of this and related topics, the group shifted their focus to water quality in different pond systems resulting from the inclusion or exclusion of fish. This final topic encompassed their interest in having fish and allowed them the opportunity to engage in data collection related to the Earth Science topic of water quality.

For homework, students located a current news article with an Earth Science connection. The next day, the class brainstormed investigation questions using the articles found. For example, in 2014, a student came across an article on a diesel truck spill and the clean-up efforts. Another student, interested in diesel, suggested setting up a model of the ground and soil layers and pouring diesel on top to see how it travels through the layers. This inquiry investigation connected a local issue, diesel spill clean-up, to an environmental concern, how deep does the oil penetrate, leading to an opportunity for the students to learn science content related to soil, permeability, organisms in the soil, and human impacts on the environment. To develop a list of potential research ideas, I asked students to share their news articles aloud while I wrote those topics on the board. In addition to the news articles, I encouraged students to share ideas of topics from their visit to the OLE the day before. From this large list, I asked students to think about feasibility of researching the topics in the OLE. Feasibility issues addressed included weather concerns, location, money, and interest levels. This pared down the list to topics appropriate for the inquiry investigations. Once a list of potential research ideas developed with my guidance, students formed groups. These groups were self-selected and the students were encouraged to choose groups based on interest in a similar question, rather than friendships.

Once groups and topics were determined, a roundtable sharing of inquiry ideas occurred. For the roundtable, I established procedures in order to promote the best use of time and respect. Students spoke one at a time, with group members being permitted to "pass" if someone in the group had already spoken. Any questions asked by classmates outside of the group were for clarification or suggestions (such as "have you considered . . . ?") and not to ridicule or criticize. This provided an opportunity for different groups to hear about the ideas of others, as well as an opportunity for me to offer feedback about the plausibility and things to think about for each investigation. Students were encouraged to consider the connection between their proposed investigations and a current event, or a means of making this research valuable. After the roundtable discussions, individuals were given the opportunity to change groups in order to better suit their interests, however, no students chose to switch groups.

The questions developed from this process became the inquiry for the groups. This year's inquiry investigations included:

- How do DIY and store-bought worm bins compare in terms of quality and quantity of worm juice?

- Is our rain "acid rain?"
- What type of irrigation system works best for watering Douglas Fir seedlings?
- How does the color black affect the heat output of solar heaters? What other factors contribute to the temperature?
- Does the depth of water in a geothermal heating system make a difference in the output?
- How do different types of leaves placed on planting beds in the fall impact the pH levels and moisture of the soil from placement time through Spring planting time?
- Which roofing material is the better insulator?
- How well do green roofs insulate?
- Do worms in the soil increase the soil temperature and/or the growth of plants?
- How does the material in a compost sock affect the water quality?
- Does the temperature of the stream differ on the banks from the middle, and, if so, how could that impact fish?
- Which method is better for growing plants and ensuring water quality: aquaponics or hydroponics?
- How much erosion occurs on our stream bank in the course of six months?
- What materials work best to filter rain water in order to improve the quality of the water?

The last question was investigated by multiple groups using a variety of filtering materials including: charcoal, plants, gravel, sand, combinations of materials, and soil. Crosscutting concepts and disciplinary core ideas are identifiable in the inquiry investigations, as are connected NGSS performance expectations. For example, inquiries of filter systems, green roof, and compost socks from this year, as well as diesel spill and bioswales from previous years, demonstrate the NGSS performance expectation MS-ESS3-3: "Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment." This performance expectation includes the CCC of cause and effect, and the DCI of human impacts on Earth systems.

Before beginning research into their topics, I provided students with guidelines for writing the inquiry investigation final report (see Appendix A). This guideline paper provided information about each section of the report and was referenced throughout the six-month investigation. I explained to the class that these guidelines are specific for this investigation in this class, and do not represent a universal set of instructions for conducting science. Instead, these guidelines are a method for communicating through writing the work being done in this investigation. When different components of the investigation report were due, I returned to this guideline to explain expectations for that section.

The first step in writing required for this project was the background information. This portion of the investigation connects to the 8th scientific practice, obtaining, evaluating, and communicating information. To begin this process, students completed a seven-minute free-write about their chosen topics. The purpose of the free-write was to prepare students to think about the topics they chose in a safe, non-committal format. The free-writes were not graded for length, format, grammar, or accuracy. They offered a chance for students to write down their thoughts in the moment about their topics. These free-writes included what was known, as well as questions the students had about the topics. Upon entering the computer lab, the following prompt was on the board:

> For seven minutes, type everything that comes to your mind about your inquiry investigation – what you know, what you worry about, your group, ideas for the project, etc. Do not stop typing, even if you repeat yourself. Keep it on topic, and type!

This was the first of many free-write journal entries, all of which served as data for me as the researcher.

The background information report integrated science and language arts curriculum. I worked with the Language Arts teacher to assist students in their research and writing. Both of us provided time in class, scaffolding activities (i.e. outlines, review of research, peer review of ideas), and feedback for the students. The students submitted their reports to both teachers, and each of us provided feedback specific to our content area. The final lab report, which I analyzed as an artifact at the conclusion of the inquiry investigations in the spring, included a compilation of this background research and a second round of background research discussed later.

Using background information as a guide, groups decided on and wrote hypotheses. I guided them through ways of writing hypotheses by asking students to share what they knew about a hypothesis. This included what it is used for, why it is part of the process, its connection to the conclusion of the investigation, and then formats they had previously used for writing hypotheses. I allowed students to use a format they were comfortable with (for example, if-then statements), however, required them to state what they expected the data to evidence and why. If members of a group did not all agree on a single hypothesis, group members were permitted to write their own hypotheses as long as they could be tested in the same investigation with the same procedure. The written hypothesis indicated what the students thought would happen and why (based on background research) they believed that it would.

The class took another trip to the OLE to prepare for determining a procedure. This trip allowed students to identify a location for the investigation, look at the logistics as they envisioned the investigation taking place, and provided a chance to write down ideas and sketch the space. While in the OLE, I visited with each group to listen to their proposed set-up and offer suggestions as needed. For example, some students did not consider the shade of a tree through the course of the day. Having had multiple years of experience in the OLE, this is something I informed students about if that information was pertinent to their investigations. Using this information, students worked in the classroom with their groups to write a procedure. I referred the students to the "Guidelines" document given out earlier in this investigation for expectations of the written procedure. I reminded the class to make sure the data collected would work to support, or not support, the hypotheses written. Some groups struggled to identify exactly what they wanted to test, prompting more guidance from me. For example, a group interested in comparing water filtration systems wanted to determine which filter would produce drinkable water. I engaged in a conversation with them about what makes water "drinkable" and referred them back to their background information reports to help them remember what they had uncovered then. In this case and in others, the students and I worked to isolate what data would be collected within reason. Unfortunately, we did not have the means to send water samples to labs for analysis. However, we did have

Vernier probes to test water of certain characteristics of water quality, such as pH level, dissolved oxygen, temperature, and nitrates. Students identified any supplies needed, including data collection equipment. I worked with the students to obtain the supplies and equipment. If students had the means to purchase further testing equipment, that was permitted. However, this year's group did not purchase further equipment or send samples out for analysis. This portion of the investigation links to the second and third scientific practices in NGSS, developing models and planning investigations. This year's investigations included models developed by 13 of 17 groups, including models of water filtration systems, compost socks, roofs, and solar heaters. I provided and explained general guidelines for writing a procedure. Students completed a rough draft for peer review and I assessed a final draft.

On the day of set-up, groups came prepared to begin their investigations. All supplies were ready, procedures finalized and followed, and cameras available for pictures. I assisted with set-up as needed, and interacted with groups as they set-up. Some groups needed more guidance than others, and I assisted as necessary. Once the investigations were set-up, students collected their first round of data. This process required two days of class time, as some groups' set-ups were more extensive than a single class period could afford.

Students collected data on a weekly basis throughout the remainder of the school year. Students followed their written procedures for data collection and noted any modifications. Carrying out the investigation and collecting data are part of the third scientific practice in NGSS. Students wrote their data in water-resistant logbooks, and included observations as well as numerical information. I encouraged students to use pictures and video in their data collecting, as well as to be consistent in their methods. On seven occasions, students carried audio recorders into the OLE to record conversations within their groups as they collected data. These conversations were used by me, as the researcher, for analysis, and were accessible to the students for their own use during the inquiry investigation. I encouraged students to use the recording device as a means of data collection in itself and provided opportunities for groups to listen to their recordings as they began to make sense of their investigations.

After each data collection class period, the class returned to the classroom, stored the equipment properly, and changed shoes. The class period concluded with a five-minute free-write in a designated notebook capturing the day's experience in the OLE. These free-writes, like the one at the beginning of the investigation, were not assessed for grammar, spelling, etc. Instead, this was an opportunity for students to write about their experience of the day, including concerns, new ideas, information about data, etc. I expected silence during this time and encouraged students to continue writing for the full five minutes, even if they had to repeat something already noted. A few times during the investigation, I posted prompts for the free-write journals. These prompts were explained to the students and were suggestions, not requirements for the entry that day. For example, after data collection of week 10 (January 6, 2016), I wrote this prompt on the board:

> In your response today, please explain why you do what you do in the OLE.
> Inform me.

The free-write entries served as a source of data for my research. Each year, the number of weeks of data collection varied, with the present class collecting data for 20 weeks.

The fourth scientific practice is analyzing and interpreting data. This practice began with the weekly free-write reflections and conversations within groups. Analysis continued and was formalized after 10 weeks of data collection when students created digital data tables and graphs. I guided this process and provided an example with the expected criteria (title, axes labels, units, etc.). I referred the students back to the report guidelines and this section about data and analysis:

> Gather data in the field using materials specific to your investigation.
> Photographs are useful for gathering data when used appropriately (same spot, time, focus, etc). Organize your data in a table or chart and create graphs to illustrate the information. Remember to include titles, labels, and units, as well as color when helpful.
>
> After you have gathered and organized data, write an analysis. In this section, use words to describe the data shown. This is not a conclusion, but a chance to explain the data in words rather than charts and tables.

I recognized from past experience that students struggle with the analysis of data. For that reason, I explained how to write an analysis and used an example from a previous inquiry investigation for the students to see. The inquiry groups worked together to complete the tables and graphs, however, each individual wrote an analysis of the data. Students also examined the data to identify trends or patterns and note any curiosities noticed. This aspect of the investigation affords students an opportunity to engage in mathematical and computational thinking, the fifth scientific practice. On the second day of data analysis in the computer lab, the students completed a five-minute free write from the following prompt:

> Please begin class with a 5 minute free-write about your OLE project.
> What are you learning?
> How are you using the data? What does it mean?
> What are you excited about?
> Do you have any frustrations? Explain.
> Where do you think this project is heading?
> What do you need to do to be successful?

The tables, graphs, and analysis were teacher-reviewed, edited, and assessed in final draft form.

After the initial data and analysis, students revisited the background information. This component connects to the eighth practice, obtaining, evaluating, and communicating information. Though this component was addressed in the first round of background information, revisiting and applying this practice again suggests the reoccurrence and need for continuation of the practices. Science is not meant to be a “one and done” field of study. I provided a handout explaining the process for researching and writing the second background information report (see Appendix B). I discussed this handout with the students and emphasized this report acts as an addition to, not a replacement of, the first background information report. Students began by reading their original background information reports and then brainstormed with their groups current questions not already answered in that report. These questions developed since the beginning of the investigation, as the students immersed themselves in the procedure and then the data analysis. Following a similar format to the original report, students researched and wrote a second background information section complementary to the first report.

At the end of the data collection period, students reviewed their data and wrote a conclusion for their investigation. I referenced the "Guidelines" provided at the beginning of the investigations, and explained the following section:

> Write a page or two about your results. Be sure to state whether your hypothesis was supported or not. Remember not to use the term proven; a single experiment cannot prove or disprove anything. Refer back to your background information. This section ties the entire lab together. Discuss the implications of your findings, as well as the limits of your investigation. If I wanted to learn the results of someone's experiment and did not want to read the whole thing, this is the section I would turn to. Therefore, it needs to be thorough and to the point. Also, state any possible sources of error in your lab. Provide suggestions for what should be the next steps for this investigation and propose what the next group of students investigating this question should do.

In the conclusion, they stated whether their hypotheses were supported or not, and used the data as evidence to support their claims. Additionally, students referred to the background information in their explanation of the outcomes, indicated what learning occurred for them through this investigation, identified sources of error and what they would do differently if they were to do this investigation again. Students also discussed in this section the next steps or further investigations they are interested in based on their experiences with this project. Constructing explanations is the sixth scientific practice. This portion of the written report underwent peer review and was assessed in final draft form.

As a culminating event, students prepared and presented their projects to an audience. Students chose to use PowerPoint or Prezi to present their work, and included pictures and videos of their original work. Families were invited to attend this event, as were other teachers and administrators; four parents and two teachers sat in the audience for a portion of the morning of presentations. Four adults served on a panel to hear and respond to the presentations. Questions asked by panel members often uncover more learning than the digital presentation demonstrates. This component of the inquiry investigation connects to the seventh and eighth practices, engaging in argument from evidence, and communicating information. The students were assessed based on individual contributions to the presentation, as well as responses to questions from panel members. Groups prepared brochures to be handed out to the panel for this event.

After the panel presentations, students wrote a final reflection on the overall experience (see Appendix C). This was the last portion of the lab report, which was completed and turned in at the end of the experience. The final lab report included a compilation of the first and second background information reports, as well as final drafts of each other written section (hypothesis, procedure, data and analysis, conclusion, reflection). The reflection was not peer-reviewed and was only shared with me. As the researcher, I analyzed the final lab report as an artifact of the learning experience.

The entire field-based science inquiry developed from the students. When they first walked into the field, they began to explore the area and developed a list of questions to be investigated. My role as the teacher was not in supplying the questions, but rather in helping the students to frame their investigations in such a way that would lead toward successful data collection and knowledge building. I did not supply students with direction or answers, but offered support and guidance throughout the entire investigation. In order to facilitate this learning experience, at times I needed to supply terminology, or ask specific, directed questions to encourage the students to seek those answers. This was a student-directed, teacher-facilitated learning experience that followed from many weeks of preparation focused on developing student understanding of an experience with scientific practices.

The structure of the inquiry investigation explicitly included student participation in scientific practices, as well as data sources for the research over the course of approximately six months. The free-write journals began before the investigations were set-up in the OLE, and continued weekly for the remainder of the investigation. These journal entries provided multiple opportunities for reflection by the students, an opportunity for integration of the outdoor experience into the classroom setting, as well as data sources for the research spanning the entire investigation. The free-write journals and the audio recordings of discourse provided sources of data for the students as they analyzed their investigations, as well as for this research.

Subjectivity of the Researcher

In qualitative research, it is important to recognize how the researcher might influence the study, its participants, and the outcomes (Maxwell, 2013). The values and beliefs of the researcher can impact how the study plays out and the analysis. As a qualitative researcher, it is important that I examine my own beliefs and values and recognize how those might affect the research I am conducting. This section addresses my possible biases and attempts to inform the reader of how I reduced the potential negative consequences of those biases.

Though I am not writing this dissertation to defend my curriculum, I recognize I have an interest in portraying this curriculum as a successful example of inquiry in an outdoor environment. As the teacher that led the development of the outdoor learning environment (OLE), I enjoy taking the students to this area throughout the year. My enthusiasm for the OLE and the inquiry investigations conducted in the OLE, past and present, likely influences my students' perception of the experience. These influences may or may not be replicated by other teachers in similar environments. My long-term involvement with the students, as their teacher, reduces the validity threat of a perceived researcher as an outsider (Maxwell, 2013). The students know me and know me as their teacher, reducing the likelihood of changes in their approach to thinking as a result of my presence as a researcher.

I have taken students to the OLE for inquiry investigations for five years now. Each year, I adapt the curriculum to some extent in an attempt to improve the outcome for the current students. These adaptations stem from things I learned from previous classes, or from professional development experiences, or from reading about science education. I do not follow an established curriculum from an outside source.

I believe, as the authors of NGSS have penned, the performance expectations in NGSS do not constitute a curriculum. I also know students can conduct inquiry investigations on science topics that do not align with a performance expectation. These investigations still allow participation in the scientific practices and do reflect science content, though it is content outside of the scope of that presented in NGSS. Because I address all of the mandated performance expectations (PE) within my classroom content, I do not specifically encourage or require students to address a PE within their inquiry investigations. I do require, though, that the question developed by the students relate to Earth Science and be appropriate for a science inquiry. This expectation is provided to the students in writing on the “Guidelines” form, and is explained in class before topic selection begins. Students are also encouraged to consider their families, nuclear and extended, as they develop their questions. I want students to think about how an industry or hobby their families are involved with might generate a question to work through for this investigation. This is an opportunity for students to engage in dialogue with family members, or at least to think about how science connects to their families outside of the classroom and textbook.

As the teacher of the students in this research, I have a desire to see each one of them succeed. I recognize I influenced some of the choices in inquiry topic selection, particularly with groups struggling to find a topic on their own. As such, I have a vested interest in their projects becoming successful. I also recognize some of the inquiry investigations interested me more than others. Though I could have been tempted to report on the inquiry investigations I found most interesting, a threat to validity according to Maxwell (2013), I chose groups to analyze based on standardized test scores. Each group chosen has a student with a high, middle, or low score on the reading, writing, or science standardized tests completed in October, 2015. I chose this criterion for group selection in order to reduce researcher bias. The choice of which groups to analyze occurred in January, much after their inquiry investigation topics had been chosen and the investigations running. During the time of topic selection, investigation set-up, and the first 10 weeks of data collection, I did not know which groups would be used for analysis, reducing the risk of bias influencing topic choice, set-up, and data collection strategies.

I walk around the OLE while they are collecting data and check in on the groups. I try to be excited about each group’s report, but I am likely portraying varying degrees of excitement. I know some groups are not where I want them to be, and I know I may guide them more than other groups. However, I am also aware of my interactions with them as their teacher ALL THE TIME. I know I do not want to give them answers, so I do not. I also know I want them to find information they need to make sense of the data they are collecting. Sometimes, I offer questions that I think might help guide them toward sense-making.

In my first year of teaching, I served on a panel at the county level to discuss strategies for implementing inquiry in the science classroom. Since then, I have continued to improve my use of inquiry and increase the opportunities my students have for conducting inquiry during my classes. My history and belief in inquiry certainly influenced my choices of curriculum. As a researcher and proponent of appropriate inquiry, I recognize my bias leans toward demonstrating the positive attributes of inquiry.

I believe inquiry happens in a variety of ways. In this research inquiry refers to student-driven science investigations. Though some activities considered as inquiry prescribe certain components and offer student choice of other components (such as giving the students a question and list of materials, and allowing them to choose an approach to gathering data toward an answer to the question), the inquiry in this investigation is further along the continuum toward student-centered. Specifically, the inquiry in this research begins with student chosen science questions, followed by student driven background research leading to hypotheses. Students design their procedures, determine how to collect data and with what equipment, collect, graph, and analyze the data, develop conclusions based on their research and data, and then reflect on the overall experience. These inquiry investigations also include student designed presentations and discussions with adults on a panel.

I believe people can learn from failure. I do not protect my students from all failures, however, I do offer guidance when requested or needed. At the same time, some groups will falter. Sometimes individual students falter while the rest of the group succeeds. Most often the students that struggle academically (in terms of points earned for their investigations) either did not complete the written tasks required of them, or became disinterested in the investigations and minimized their participation. However, I have high expectations of my students and they know what is required of them.

As I analyze the data, I am unable to completely separate my teacher identity, and often think about the students as I am reading and listening to their work. Keeping in mind the person behind the words certainly influences my analysis. However, being cognizant of this conflict, I repeatedly reflect on the data I chose to analyze, and the decisions I am making about the data, and made conscious efforts to report accurately.

Research Design

The epistemological ideas that students hold are implicit (Berland et al, 2015; Sandoval, 2005). I used discourse and artifacts created and presented by students to infer what epistemological considerations students employ while engaged in the inquiry investigations. I used the audio recordings from the groups during data collection to analyze the discourse among students for evidence of epistemic considerations and meaningful use. The final presentations of the inquiry investigations were video-recorded and provided another source for analyzing discourse, particularly as students responded to questions from the adult panel.

In addition to the final presentations, students produced artifacts of their learning in written form. Free-write journal entries, and the final lab report and reflection were analyzed for evidence of implicit or explicit epistemologies. All students participated in the presentation and all students were expected to produce approximately 20 free-write entries, and a final lab report and reflection. I assessed and analyzed a sample of these artifacts as data. Audio and video recordings were transcribed for use in discourse analysis.

Table 2 outlines each of the activities in this research study from brainstorming to final reflections. The purpose of the activity, as well as the scientific practice addressed in the activity are noted. Each activity also corresponds to a source of data for the research.

Table 2

Instructional Activities and Research Connection

Activity by Date	Purpose	Data Source	Scientific Practice
Brainstorming (September)	Generating list of ideas for Inquiry Investigations	Free Write Entry on 9/23	Asking Questions (SP1)
Background Information gathering (October)	Finding, evaluating, and communicating information from reliable resources as they relate to the chosen inquiry investigation	Written Report	Obtaining, evaluating, and communication information (SP8)
Writing procedures and building models (October)	Preparing materials and procedures for use in the OLE	Written Report	Developing and using models (SP2); Planning investigations (SP3)
Data Collection Events (October – March)	Gather data weekly from OLE inquiry investigations	Free Write Entries	Carrying out investigations (SP3); Using models (SP2)
Data analysis, round 1 (January 7)	Create digital data tables and graphs; analyze data	Written Report	Analyzing and interpreting data (SP4); Using mathematical and computational thinking (SP5)

Activity by Date	Purpose	Data Source	Scientific Practice
Audio recordings during data collection (Feb – March)	Capture discourse events while students collected data in the OLE	Audio recordings	Carrying out investigations (SP3); Using models (SP2); analyzing and interpreting data (SP4); constructing arguments (SP6); Engaging in argument from evidence (SP7)
Data analysis, round 2; Conclusions (March 30)	Incorporate latter data into digital tables and graphs; analyze data; discuss and draw conclusions	Written Report; Audio recordings	Analyzing and interpreting data (SP4); Using mathematical and computational thinking (SP5); constructing arguments (SP6); Engaging in argument from evidence (SP7)
Panel Presentations (April)	Present Inquiry Investigations to an adult panel and audience	Video recordings	Engaging in argument from evidence (SP7); Obtaining, evaluating, and communicating information (SP8)
Completion of written report and reflection	Finalize written inquiry investigation report; reflect on experience	Written reports; written reflections	Engaging in argument from evidence (SP7); Obtaining, evaluating, and communicating information (SP8)

Engagement of students in these activities encourages attendance to the scientific practices while learning science content.

Data Analysis

Using data from the above methods of collection, this research looked for evidence to help answer these three research questions:

1. In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?
2. What kinds of knowledge are students constructing as they engage in the OLE?
3. What was learned by using the EIP framework to investigate this OLE experience?

I used the artifacts, presentations, and audio recordings to identify epistemic resources students hold and reasons for their decision making. The epistemologies students utilize may be implicit and examination of the use of language helped uncover those implicit epistemologies. The physical data in the forms of artifacts and transcripts of recordings provided evidence from individuals in the studied groups.

To begin analysis of the transcripts, I selected statements from students that directly connected to the research questions. Upon reviewing these responses, superfluous information was removed, and the remaining text was parceled into statements with evidence of epistemic considerations or other evidence useful in generating an answer for one of the research questions. There was no expectation that all discourse would be useful toward these goals.

To identify epistemologies in practice and evaluate meaningful use, I focused on the four considerations of EIP as described by Berland et al. (2015). These considerations are a part of a person's thinking when they engage in science. The artifacts produced during this engagement often reflect the epistemologies in practice of the participants (Sandoval, 2012). The analysis of the discourse and artifacts were used to infer how these considerations align with meaningful use. In other words, the evidence focused on a student's epistemic considerations indicative of meaningful use of the work being done versus doing the work for a grade. The types of data and their use as evidence of epistemologies are shown in Table 3.

Table 3

Data Source Used to Infer Each Epistemic Consideration

Data Source	Nature	Generality	Justification	Audience
Free-write journal entries	Artifacts; coded written statements			Artifacts; coded written statements
Audio Recordings	Discourse; coded transcribed statements	Discourse; coded transcribed statements		Discourse; coded transcribed statements
Presentation	Discourse; coded personal statements; coded responses	Discourse; coded personal statements; coded responses	Discourse; coded personal statements; coded responses	
Reports with reflections		Artifacts; coded written statements	Artifacts; coded written statements	

Though these considerations were inferred from specified data sources, all considerations were considered when I examined each piece of data. For example, it is possible a free-write journal entry contained a statement representative of a generality consideration. This entry was coded along with all other pertinent statements. I categorized statements of discourse and artifacts to uncover evidence for the first research question: In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?

Before I could begin analysis of the data, I created a table based on Berland et al. (2015) to categorize students' artifacts and discourse as classroom practice or meaningful use within each of the epistemic considerations (see Table 4).

Table 4

Coding Scheme

Epistemic Consideration	Classroom performance	Scientific sense-making Goals (Meaningful Use)
What kind of answer should our knowledge product provide? (Nature)	Describe or show (Code: NC)	Explain how or why (Code: NM)
How does our knowledge product relate to other scientific phenomena and ideas? (Generality)	Specific case only (Code: GC)	Knowledge products are generalized, OR Use other general ideas to create knowledge product (Code: GM)
How do we justify the ideas in our knowledge products? (Justification)	Task completed without need for interpretation (i.e. information is enough) (Code: JC)	Requires interpretation and synthesis by the student (Code: JM)
Who will use our knowledge products and how? (Audience)	Teacher (Code: AC)	External audience, or Audience as collaborator (Code: AM)

Using Table 4, I began analysis by reading and coding the FWEs. With the coding scheme in front of me, I read each FWE of one student from the first entry in September through the last entry in March. I read through an entire student's journal before moving onto the next student. In this initial round of coding, I was looking for evidence in the students' work indicative of thinking about a knowledge product. At that time, I was defining a knowledge product too narrowly and, as a result, left much data not coded because it did not fit the criteria. After much discussion and concern from my advisor about the limitations of my analysis, I revisited Berland et al. (2015) to better understand their use of the term knowledge product. With an improved understanding of this term, a recognition that its definition is much more broad than I originally thought and applied, I revisited my data. I used the same coding scheme of Table 4 and found many more statements within the FWEs included evidence of students thinking about a knowledge product and, therefore, could be analyzed and coded.

Table 5 offers example data from each scientific practice categorized by consideration. Coding for each response appears after the statement with abbreviations of CP for "classroom performance" and MU for "meaningful use." The responses were coded in these categories based on the classifications established in Table 1 of Chapter 1.

Table 5

Scientific Practices and Example Statements of Evidence for Epistemic Considerations

NGSS Scientific Practice	Nature	Generality	Justification	Audience
Asking questions and defining problems	"Is this question good enough for a good grade?" *CP*	"How can this help scientists in the future?" *MU*	"We want to explain the meaning and effect of erosion to people that don't know what erosion is." *MU*	"Could we be able to find someone to help us in this experiment?" *MU*

NGSS Scientific Practice	Nature	Generality	Justification	Audience
Developing and using models	"Does this clearly explain the components of the filter?" *MU*	"This diagram shows our filter. It is similar to the filter used on other rivers." *MU*	"The model clearly shows a green roof." *CP*	"I hope Mrs. HR thinks our model works." *CP*
Planning and carrying out investigations	List of steps alone *CP*	"This procedure is based on previous studies." *MU*		
Analyzing and interpreting data	"The data suggests the worms preferred the DIY bin because they produced more worm juice." *MU*	"Our filter worked in our stream." *CP*	"The data shows the filter worked." *CP*	

NGSS Scientific Practice	Nature	Generality	Justification	Audience
Using mathematics and computational thinking			"We removed the first 10 weeks of data from our graphs because we determined those readings were in error from the tools not working properly." *MU*	
Constructing explanations and designing solutions	"Based on our data, our hypothesis was supported." *CP*	"We learned there is more in water than the eye can see."	"I made my own scale because I needed a method of comparison." *MU*	"We hope other scientists will be able to use our information." *MU*
Engaging in Argument from science	"The open-dump landfill was the worst because there was black ooze at the bottom." *MU*	"The sanitary landfill may be better in real-life, based on the results from my model." *MU*		

NGSS Scientific Practice	Nature	Generality	Justification	Audience
Obtaining, evaluating, and communicating information				"How will we know what questions the judges are going to ask?" *CP*

Additionally, the analysis highlights the role of the OLE on the students' epistemologies in practice. As students' epistemic considerations change with context, the outdoor experience provided a unique context in which to view the epistemic resources students utilized while learning science through inquiry.

All of the sources of data were expected to provide evidence for the second research question, "What kinds of knowledge are students constructing as they engage in the OLE?" Artifacts and discourse statements were parceled with an eye toward specific reference to knowledge construction or personal learning. For example, a student might explain during the final presentation, "I never knew pH could be measured in every liquid, even our blood!" This statement indicates knowledge construction related to pH, a science topic that spans most science disciplines. The statements related to knowledge construction were coded by general science topic. Additionally, the coding included the aspect of the OLE inquiry investigation that led to the knowledge construction, when possible.

Chapter 4: Results

52 students in the 8th grade class took part in the OLE inquiry investigations. Of those, 46 students signed the IRB consent forms to participate in this study. When preparing for the investigations, students engaged with group members and on their own to establish background information and prepare for their investigation. On data collection days, I observed students on task collecting data and engaging with their investigations and groups. Students readily gathered supplies, changed into boots, and headed outside. In the OLE, the groups went right to task collecting data and checking on their investigations. When equipment was not working properly, students would find me or a classmate to help them rather than simply give up. Students often called me over to show what was happening with their investigations. Upon returning to the classroom, students changed out of their boots and immediately began writing in their free-write journals. There were days when the 5-minutes of free-writing appeared to be a challenge for some students to continue through, but I would coach them through things to think about adding and would always allow the full five minutes to the class. From my observations, the students bought into this experience and gave it their best efforts. As will be explained near the end of this chapter, the students' written reflections suggest this experience was well received as 41 of 43 students would do this again with their classes if they were teachers.

My observations above begin the story of data collection. Data collected consisted of written artifacts and discourse from all students in the class. Written artifacts include free-write journal entries (FWEs), inquiry investigation reports, and written reflections. Analysis of the post-investigation reflections included written responses from all consenting students in the class, while analysis of the FWEs and inquiry investigation reports focused on two select groups. Discourse events were recorded during the last seven data collection days, group conclusion time, and final presentations with an adult panel audience. Discourse events were recorded and then transcribed for two selected inquiry investigation groups, each with three members. Analysis focused on these two groups to enable deeper analysis of select students. The data gathered from these select students provided evidence of student thinking around each of the epistemic considerations evaluated in this study. I chose these groups based on scores on standardized tests completed in October. Each group chosen had a student with a high, middle, or low score on the reading or mathematics standardized tests completed in October, 2015. This criterion for group selection reduced potential for researcher bias (as described in chapter 3) and provided a means to analyze evidence for meaningful engagement in an OLE by students with diverse academic performances. FWEs and inquiry investigation reports were also analyzed for the two selected groups and provided ample evidence to appropriately answer the first research question: In what ways do students perceive the OLE experience as meaningful? This data also provides evidence of student thinking as they engage in the scientific practices. Written reflections from the entire class were analyzed as this larger population (N=46) provided information to answer two of the research questions with more detail than analysis of the two groups (n=6) alone could provide. Analysis of the remaining data may provide evidence for different research studies, as is discussed in chapter 5.

This chapter begins with an overview of the projects from the two selected groups, then presents the data from the groups' FWEs, data collection recordings, panel presentations, and inquiry investigation reports. Data from the written reflections, including analysis of responses from all students, is presented last in this chapter. A brief description of each of the two selected projects and the student workgroups for each is used to provide a context of student work during the project. Data analysis follows after setting the stage.

Roofing Temperatures Project Description

The first group of focus investigated "Which roofing material is the better insulator?" The group decided to investigate this topic because one of the members of the group has a parent in the roofing industry. The group is composed of three Latina females, one of which scored the lowest on the standardized tests in the fall in both mathematics and reading (see Table 6). The other two students scored in the middle to high-middle range of the class for both tests.

Table 6

Standardized Test Scores for Students in the Roof Temperatures Group

Student	Mathematics Score			Reading Score		
	Fall	Winter	Spring	Fall	Winter	Spring
Class Range	193-252	199-250	192-253	205-245	175-246	188-248
Sofia	193	199	192	205	215	221
Isabella	222	232	230	225	221	233
Valentina	241	239	245	238	238	231

Before beginning their investigation in the OLE, students in the group researched a variety of topics related to roofing and thermodynamics. Through this background research, students made the connection between roofing and insulation, providing a purpose for having an appropriate roof. This led to the question and an approach to data collection to determine which roofing material provided the most insulation.

The group worked with one of the parents to build four model roofs, two of each type of roofing material. The models consisted of plywood with roofing material attached, and propping stick in the back of the plywood to keep the roof upright. There were no side walls on these models (see Figures 2 and 3).

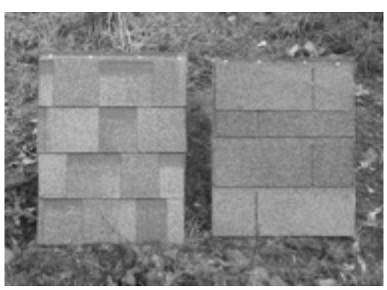

Figure 2. Roof models placed near streambed in the OLE.

Figure 3. Roof models placed on a bench in the OLE.

The students set up the roof models in the OLE at two separate locations, one near the stream and one up on a bench. In both areas, the roofs were propped at a similar angle which was built into the model. Each week, the students collected temperature data using Vernier equipment. Temperatures of the outside air, air above the roof, and air under the roof were collected at both sites. At the stream site, the students measured soil temperature in front of and underneath the roof as well.

Students in this group used the data collected to draw a conclusion about the insulation properties of each roof. The group determined the roof with the temperatures under the roof measuring closest to the soil temperatures was the better insulator.

Solar Heater Panels Project Description

The second group for this analysis investigated the questions, "How does the color black affect the heat output of solar heaters? What other factors contribute to the temperature?" The standardized test scores in the Fall placed one member of the group at the top of his class for mathematics and near the top of his class in reading. The other two group members scored in the middle to high end of the class range for both tests (see Table 7). All members are boys and are non-Hispanic white.

Table 7

Standardized Test Scores of Students in the Solar Heater Group

Standardized Test Scores of Students in the Solar Heater Group

Student	Mathematics Score			Reading Score		
	Fall	Winter	Spring	Fall	Winter	Spring
Class Range	193-252	199-250	192-253	205-245	175-246	188-248
Aiden	252	248	253	240	241	238
Jackson	244	249	244	226	226	220
Liam	224	226	228	225	237	229

The group decided to investigate solar heaters for a variety of reasons. Several other groups in their class were investigating water filters and this group wanted to be different. The boys were also interested in constructing something. I offered a few ideas to the classes at the beginning of the topic selection time. One of the topics was DIY (do it yourself) solar heaters. Though the topic was generated by me, the group determined what questions to ask and how to investigate their questions.

The students investigated a variety of topics related to solar energy. The relationship between color and heat absorption led the group to investigate how much of a difference using the color black would make in terms of heat collection. In their background research, students found designs for do-it-yourself solar heaters and developed their own design based on those found online. Two of the boys worked together to construct two solar heaters, each of the same materials with the exception of color. One of the solar heaters was painted black on the entire inside while the other remained unpainted (see Figures 4 & 5). Construction took place at one boy's house and some parental involvement occurred.

Figure 4. Solar Heater Models. Black painted solar heater (left) and unpainted solar heater (right).

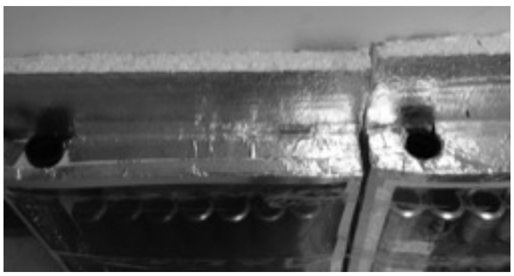

Figure 5. Top View of Solar Heaters. The air vent is the black PVC elbow joint on the left of each model.

Modifications to the solar heaters became necessary once they were installed in the OLE. The group problem solved to reduce air holes from malfunctioning components of their original design.

Each week, this group collected temperature data. Using Vernier equipment, the group measured the air temperature outside and within each of the solar heaters. The data allowed them to draw conclusions about the heat collecting potential of a solar heater and the impact of using black paint.

Data Analysis

Analysis of data collected focused on answering the three research questions:

1. In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?
2. What kinds of knowledge are students constructing as they engage in the OLE?

3. What was learned by using the EIP framework to investigate this OLE experience?

Written artifacts and recordings of discourse were analyzed in terms of these research questions. The artifacts and discourse provided data to answer the three research question.

Free-Write journal entries. I introduced the use of free-write journal entries after student groups decided on topics, but before they had done background research. The format for FWEs had been introduced earlier in the school year providing students with experience in this learning strategy prior to its use during the inquiry investigations. The FWEs were not graded for length, format, grammar, or accuracy. The purpose of the FWE was to prepare students to think about the topics they had chosen in a safe, non-committal format. The writing provided a chance for students to write down their thoughts in the moment about their topics. These FWEs included what was known, as well as questions the students had about the topics. Students wrote FWEs for the first time on September 28 during a class in the computer lab. I provided the following prompt for this first entry:

> For seven minutes, type everything that comes to your mind about your inquiry investigation – what you know, what you worry about, your group, ideas for the project, etc. Do not stop typing, even if you repeat yourself. Keep it on topic, and type!

The FWEs from students in the two selected groups were analyzed for evidence of student thinking aimed toward a classroom practice goal or a goal of scientific sense-making (referred to as meaningful use throughout the rest of the analysis). This separation of classroom from meaningful is not meant to imply a dichotomy or indicate thinking in relation to classroom practice is not meaningful. Classroom practice is used here as Berland et al. (2015) used the construct - that students perceive the purpose of their actions as directed toward a classroom learning goal. Meaningful use indicates student thinking related to engaging in scientific practices with a purpose of knowledge building toward the goals of the classroom *and* science communities. Statements indicative of thinking related to a knowledge product were coded based on the criteria established using Berland, et al. (2015) and explained in chapter 1. I used Table 4 as a guide for coding such statements.

Statements from each student's free-write entries were coded based on evidence of one of the four epistemic considerations in regard to knowledge products. As discussed in Chapter 3, my understanding of this term evolved as this research developed. According to Ford and Forman (2006), building knowledge by distinguishing what knowledge "counts" from what does not is a central aim of practice. In this paper, the term "knowledge product" is used as Berland, et al. (2015) used the term in their *Epistemologies in Practice* framework. It is "the shared knowledge that students construct, evaluate, and revise . . . . a 'knowledge product' could be an explanation, a model, an argument, or a research question and could be represented physically, pictorially, verbally, or with computational tools" (p. 8). Students may consider a knowledge product to be a "right answer" as determined by the teacher, or they may consider a knowledge product to be one that is explained by the evidence. The coding of statements for each consideration used the categories of classroom (C) or meaningful (M). Examples of statements categorized within each coding category are given in Table 8. Excerpts from student artifacts and discourse are identified with the first initial of the student followed by the date the artifact was written or the discourse occurred. If an additional excerpt from a single student on the same date is provided in this text, the date is followed by a number signifying its order among multiple entries.

Table 8

Coded Free-Write Entries

Epistemic Consideration	Quote from free-write entry	Researcher notes
Nature Classroom	J0114: “The solar panels are holding up and the temperatures are warmer than the outside temperature” [NC]	Describes without explanation of how or why
Nature Meaningful	A1029: “The reason that it is above outside temp is because the panels can shield the air from the wind and cold.” [NM]	Explains how or why with clause “because . . .”
Nature Meaningful	L0303: “I think the unpainted can has less heat because the sun reflects off the shiny metal surfaces. This is why if you see an airplane in the sky on a clear day you will see a twinkle or flash because the sun is reflecting off the bare metal. This will reduce the heat being absorbed by the cans because the light bounces off.” [NM, GM]	Explains how or why; GM coding based on reference to general idea about metal’s reflective properties
Generality classroom	I0928: “Will this experiment even work?” [GC]	Specific case – “this experiment”
Generality meaningful	A0203: “In my research I talked about how each panel absorbs and retains heat differently. This information will be helpful.” [GM]	Generalizes with reference to background info
	I1210: “Have students done this before us? If so, what can we do the same or different?”[GM]	Generalization from previous years

Epistemic Consideration	Quote from free-write entry	Researcher notes
Justification classroom	J0114: "The data we collected was good so the black painted cans are doing good." [JC]	Empirical evidence only
Justification meaningful	V0106: "We take the soil temperature to see the Earth's heat." [JM]	Explains why a procedure is done
Audience classroom	I1105: "What if Mrs. HR doesn't think the project will work?" [AC]	Audience is teacher
Audience Meaningful	J0317: "if you wanted to use this panel to heat your home you would need a lot more cans than we used." [AM]	Audience is external – "to heat your home"

Students wrote their FWE on September 28th and included concerns about logistics of the project as well as concerns about the group dynamics. For example, Isabella from the roof group wrote, [I0928-1] "What will Mrs. HR think of how we work together as a group?" and [I0928-2] "Will we get a good grade?" indicating epistemologies consistent with classroom practice, particularly in consideration of nature and audience. She also mentioned logistical concerns such as [I0928-3] "How will we put the roofing material on?" and [I0928-4] "How will we stay organized?" The other group mates had similar logistics concerns as seen in the questions [V0928-1] "What kind of roofing material do we put on the structure?" and [S0928-1] "Where are we going to get the roofing material from?" In the course of the investigations, concerns about logistics appeared 70 times in the FWEs. The majority of logistics statements (50 of 70) occurred during the first two free-write opportunities which were both prior to initial set-up of the investigations in the OLE.

Besides logistics concerns, students' FWEs included references to the weather, statements of learning, and concerns about the groups. Table 9 indicates coding categories for these entries and the number of times each category appeared in the FWEs over the course of the investigation.

Table 9

Other Categories of Student Responses in FWE (n=6)

Category	Entries prior to first data collection event	Entries after first data collection event	Total
Logistics	53	17	70
Weather	5	41	46
Learned, understand, realize	1	34	35
Group Concerns	9	17	26
Procedure and set-up	16	7	23
Think	1	22	23
Model	2	19	21
emotion *	2	16	18
concern for end result	3	10	13
recording device	0	7	7
Hope	0	5	5
problem only	0	4	4
problem & solution	0	5	5
family	1	1	2

*emotions included excited, frustrated, surprised, mad, sad, glad, etc.

The data in Table 9 capture the kinds of things students thought and wrote about beyond the knowledge product, or task associated with the learning objective, when completing the FWEs. Students included thoughts on the weather, the physical components of their models, how they were feelings in terms of emotions, and problems and solutions they encountered during the data collection event. Students used the words think, realized, or learned 35 times in their FWEs. For example, on March 17th, the second to last data collection event, Valentina wrote, [V0317] "With this OLE project I have learned about thermodynamics." On March 10th, Jackson wrote, [J0310] "I really enjoyed this project because it helped me understand how and what materials are able to absorb heat." The terminology used in the FWEs provides insight into the students' thinking as they report out after data collection events. Student thinking inferred from the FWEs was further analyzed in terms of epistemic considerations.

The roof temperatures group members wrote questions and statements in the first FWE related to knowledge products. Entries contained independent statements or sentences, rather than paragraphs or related statements and sentences. Examples given are the statements or sentences from the FWE as written. Some statements read as if they are missing context or before and after statements. These are presented *as written* by the student. I relied on my experience with the students to interpret the written statements, resulting in a high level of inference in some of the analysis. Statements from the roof temperature group during the first FWE event were coded using Table 4. For example, on September 28th Valentina wrote:

> [V0928-2] "How does this help anyone in their daily lives?" [AM, GM]

This question indicates Valentina thinking about her investigation as it relates to other people. This was coded as meaningful in the categories of Audience: considering an audience beyond the classroom. It also indicated Generality: thinking about the usefulness of the potential outcome for others. Sofia also provided a statement indicative of meaningful use:

> [S0928-2] "When we have a question about roofing we can ask people that know about roofing." [Code: AM]

This statement was coded AM (audience meaningful) as it indicates Sofia's consideration of an audience as collaborator. Isabella provided statements indicative of classroom practice, such as:

> [I0928-5] "Will we collect enough data?" [Code: AC]

The use of "enough data" indicates an epistemic consideration of the teacher as the audience for the knowledge product, receiving a code of AC. Isabella's FWE included a question that indicated an epistemic consideration of Generality.

> [I0928-5] "Will this experiment even work?" [Code: GC]

In this case, Isabella is not suggesting the result of her investigation will be generalized, but instead references "this experiment," indicating only this specific case as an end goal of the investigation. This question was coded as GC (Generality classroom). Though this statement was coded as classroom practice, the thinking behind this statement is valid and important. The student indicates consideration of an end result as she begins her research. A perceived purpose of classroom experiments is that they *work*. Isabella's statement indicates her thinking directed toward this classroom goal.

FWEs from the solar heater group also indicated concerns about logistics and group dynamics. For example, Jackson stated, [J0928-1] "The materials are difficult to get because they cost a lot" and [J0928-2] "[A concern is] If we will work together and everyone pitch in." Aiden and Liam shared in concerns about the cost of the materials and how the expense would be divided among members. The members of this group provided fewer statements indicative of epistemic considerations in relation to knowledge products. Only the nature consideration was evident, and in all instances that consideration fell in the realm of classroom practice. For example, Jackson stated,

> [J0928-3] "A worry is if we will not get a big solar panel to get the information we need." [Code: NC]

This statement received a code of NC (Nature Classroom) because it suggests his thinking was about being able to show an end result rather than being able to explain or understand how or why. Similar to Isabella's statement (I0928-5), this was coded as classroom practice and demonstrates thinking beyond the immediate and toward an end result. This approach to design with the end in mind is important and valid, and in this case indicates thinking toward a classroom goal.

Students completed one more FWE before setting up their investigations in the OLE. Once the investigations were set-up, students wrote FWEs after each data collection period, approximately once per week. The nature consideration is the most frequently coded consideration, with 38 responses indicating classroom practice and 48 indicating meaningful use. Students indicated thinking in terms of justification in 49 statements, with similar numbers of responses in classroom practice (26 responses) and meaningful use (23 responses). The audience consideration was the least evident of the four, with 23 total statements coded in this category. The generality consideration provides interesting data in terms of classroom practice compared to meaningful use. The only indication of generality in a classroom practice way of thinking was in the first FWE of one student. All other generality statements (26 of them) indicated thinking in terms of meaningful use. These statements received a coding of meaningful use when the students generalized their investigations to a broader scope or when they used ideas and information from a general understanding and applied it to their own learning. Table 10 indicates the number of statements coded from the FWE into each epistemic consideration category.

Table 10

Epistemic Considerations Coded for Each Free-Write Entry (n=6)

Date	Nature		Generality		Justification		Audience	
	C	M	C	M	C	M	C	M
9/28	5	1	1	1			3	2
10/13	1	2		1			1	
10/29	3	3			1		3	
11/5	1	1			1	3		
11/12	4	2			1	3	1	
11/20	1	4			1	2	1	
11/24	4	1			2	1	1	
12/4	1	3			2	2		
12/10	5			3	2	1	1	2
1/6	2	1		2	1	2		3
1/11	1	1				1		1
1/14	3	2			5	1		

Date	Nature		Generality		Justification		Audience	
	C	M	C	M	C	M	C	M
1/27	2	4		2		2		1
2/3	1	3		4	2			
2/18	1	2			1	2		
2/23	1	4		1	2	1		
3/3	1	4		2				
3/10		2		4	1	1		
3/17		4		2	3	1	1	1
3/31	1	4		4	1		1	
Total	38	48	1	26	26	23	13	10

Note. C = classroom practice, M = meaningful use

Table 11 shows the same data in two groups with entries prior to the first round of data analysis compared with entries after initial data analysis by students. I chose to separate the entries into these two groups because of the introduction of the data analysis component to the inquiry investigation. Beginning January 7th, inquiry groups met in the computer lab to review their data, create data tables and graphs in Excel, and write individual analyses from the data. This assignment incorporated SP4, analyzing and interpreting data, formally into the students' investigations at this point in the OLE experience. I divided the FWE coding groups based on this event. Though opportunity for discussion within groups about the data occurred during data collection time each week, those conversations were not mandatory. Conversations in the OLE may have focused on classroom and inquiry investigation logistics, or simply collecting the data to get done. It was possible the students had not looked at the data and thought about what it might be indicating until the required data and analysis session in the computer lab. Thinking about the data may have changed students' approaches to their FWEs. For instance, if looking at the data enabled students to begin to see a pattern that had not previously emerged, then students might change the way they thought about data collection during seceding data collection events. Changes in their thinking might present itself in the FWEs. The table indicates totals for each category prior to the data and analysis assignment beginning January 7th and those entries written after that assignment.

Table 11

FWEs Before and After Initial Analysis by Students (n=6)

Epistemic Consideration	Coding Category	Response Before Initial Analysis	Responses After Initial Analysis	Total Responses
Nature	Classroom	27	11	38
	Meaningful	18	30	48
Generality	Classroom	1	0	1
	Meaningful	7	19	26
Justification	Classroom	11	15	26
	Meaningful	14	9	23
Audience	Classroom	11	2	13
	Meaningful	7	3	10

The number of instances of the Nature consideration reflecting a classroom practice decreased over time, from 27 occurrences in the first half of the investigation to only 11 in the second half. In the same time frame, the number of occurrences of epistemic considerations of a meaningful tone in relation to Nature increased from 18 to 30. The Nature consideration was the most commonly coded consideration in the FWEs. Analysis of these data indicates students perceive their work in the OLE to be directed toward classroom goals, particularly early on in the investigations. However, as the investigations continued, FWEs suggested students perceived the experience as directed toward classroom *and* scientific sense-making goals, particularly in the epistemic considerations of Nature and Generality. Students' statements pertaining to Audience considerations were most often of a meaningful nature throughout the investigations. The Justification consideration suggested a change in perceptions, from meaningful toward classroom practice. This is an interesting shift and may be due to the continued expectation of FWEs after each data collection. In other words, it could be students stopped justifying why they were doing what they were doing or why they were concluding what they were simply because they had already justified their choices in earlier entries. Based on the FWEs alone, this is a difficult argument to defend with confidence. The data does suggest, though, that after the initial round of data analysis by students on January 7th, their perceptions of the knowledge products in terms of the epistemic considerations of Nature and Generality shifted from primarily classroom goal oriented to primarily meaningful use.

Audio recordings. Beginning the first week in February, groups brought audio recorders to the OLE to document their conversations during data collection time. Data collection recordings began after students had completed their first round of data analysis, as well as both background information reports. The recording devices were provided during the last seven trips to the OLE for data collection. The audio recorders were also used on March 30th to document the groups' conversations in the computer lab as they looked at their data for analysis and to draw conclusions. These two scenarios, in the OLE collecting data and in the computer lab discussing data, were analyzed separately in terms of counts for categorical coding.

Audio recordings from the two selected group were transcribed in their entirety. In the same manner as the FWEs, the data from the recordings were analyzed based on evidence of epistemic considerations using the criteria for coding established in Table 4. The recordings on data collection days varied in content. Some days the groups used the recording device as if it were keeping track of their performance of the task of collecting data. For example, some recordings are of a student simply stating the data collected that day. One such recording occurred on February 5th from the roof temperatures group:

Valentina introduces group

V0205-1: "The temperature of day is 52.8"

I0205-1: "52.2"

> V0205-2: "Scratch that, it's 52.8. Scratch that, it's 52.2. The soil temperature for outside is 45.7. The temperature inside of Iko [one of the roofing materials]"
> I0205-2: "No, Treetop [the other roofing material]."
> V0205-3: "Scratch that. Iko is 47.3. The outside air temperature of Treetop was 53.0. And, Isabella's giving me an attitude. The outside temperature is 45.0 of Iko. Wait, the inside air temperature of what?"
> V0205-4: "Take 2." Introduces group again. "The temperature of the streambed is 52.2 on February 5th. The outside temperature of Treetop is 53.0 and it's also February 5th and the inside temperature is 57.3 of Treetop. . . [continuation of reporting data]. Thank you."

This recording suggests epistemic considerations consistent with a classroom goal of recording data *as is* rather than scientific sense-making which might include an explanation of how or why the data was as recorded on this specific date. The conversation was coded as classroom practice in both the consideration of nature and justification. The reporting of data in this manner suggests the data itself is enough to show and justify a knowledge product, or information, for their investigation.

The intent of providing students with the recording devices was to capture discourse, or conversations, among students within a group. Recordings such as the one above provide little in terms of capturing conversations. In these cases, the recorder is talked to rather than simply a mechanism for recording conversations. Though these types of recordings were not what I intended to collect, they were transcribed and coded as the conversations included statements indicative of student thinking.

Looking at the FWEs written immediately following the data collection event from the recording provides additional information about the students' thinking. Isabella's first sentence in her FWE was coded JC because she states there is a big difference in the temperatures in a manner that suggests the information collected is enough to justify an eventual conclusion or to show classroom-oriented work. The last sentence speaks to concerns about the recording device and has been included here for that reason.

> I0205: "Today was the first time there was a pretty big difference in the temperatures between Iko and Treetop. [JC] Today we also started recording our conversations about the OLE and it was kind of bad because Valentina wouldn't let me say the data I collected and it was kinda bad because she didn't know what to say."

Each of the members of this group mentioned the recording device in their FWEs for February 5th. This information provided feedback to me about this particular method of data collection. Valentina's entry indicates her concerns with the recording device. The last sentence was coded GM because Valentina expressed confusion about a general understanding of the Earth having heat and its application to her project as seen in measuring the temperature of the soil. Though this is presented as a question, indicating she may be struggling to understand what is happening, the thinking behind the question suggests attempts to use a general idea in connection with her collected data.

> V0205: "I don't like the recording device. I don't like my voice so recording myself wasn't fun. Isabella didn't make recording easy because she would give me the wrong numbers. If heat from the Earth goes into the soil why is it colder than the air" [code: GM]

Sofia's entry also indicated a meaningful response. The first part of the entry was coded as meaningful in the Nature consideration. Sofia's inclusion of the weather as a cause for the temperature change indicates her thinking around this set of data included why or what might cause the change in the data set from previous data collection events. The last sentence indicates Sofia's feelings about the recording device.

> S0205: "Today the numbers change by a lot specially in Iko and Treetop. I think it has to do [with] how the weather is going. [Code: NM] I think the recording device works but it can also cause problems. It felt strange [to] have the recording device."

Sofia is a very shy and soft spoken student. In most of the audio recordings, her voice is not heard. Her proclamation of "It felt strange" indicated to me that Sofia was uncomfortable with the use of the recording device. Lack of her voice on most of the recordings confirms this inference.

The recordings continued for seven weeks. Many recordings were of conversations among group members. Some of the conversations were related to the functioning of the model apart from data gathering and analysis. For example, during the first data collection event a portion of the solar heater group's reporting contained the following:

J0203-1: Hey Aiden, is there damage?

A0203-1: No, I think we're good. No it's not, we're fine.

J0203-2: Okay, Put the tape on that.

. . .

L0203: Aiden, you need to fix it right now.

A0203-2: No, there's no reason to fix it.

A0203-3: My name is Aiden, and I was checking for damage. And, I only saw on the black painted one I only saw a tiny bit. I put this tape on it. [Giggles]

This portion of the conversation is interesting to consider in terms of their concern for the model they built. It does not, though, relate directly to thinking about the knowledge product in this context. That is not to say the conversation, activity, or thinking are off topic or inappropriate for their work in the OLE. Being aware of the status of the model is an important aspect of an investigation like this one. Later conversations will connect the functionality of the model to the data collection, however, this portion of the conversation does not provide direct evidence of their thinking in terms of a knowledge product or learning outcome. Other portions of the conversation from this group on the same day provided evidence of student thinking in the considerations of Nature, Generality, and Justification. These are included in the counts presented in Table 12.

Many conversations related to the knowledge products and sense making while students collected data. These conversations were coded using the same criteria as the coding of the FWEs (see Table 4), identifying the epistemic consideration and identification as classroom practice or meaningful use. There were seven data collection days the students had recording devices to use. However, each of the groups missed recording on two of those days, possibly due to forgetting to record or erasing the file. For each group, five conversations were recorded, transcribed and analyzed. The numbers of instances of discourse within these epistemic considerations are identified in Table 12.

Table 12

Instances of Epistemic Considerations During Recorded Conversations

Epistemic Consideration Coding Category	Data Collection Discourse		Data Analysis Discourse	
	Classroom	Meaningful	Classroom	Meaningful
Nature	9	7	0	6
Generality	0	5	0	4
Justification	2	6	0	4
Audience	1	0	0	2

Recorded discourse indicated the nature consideration was most prevalent. During data collection events, conversations contained evidence of student thinking in the category of classroom practice as well as meaningful use. However, during the discourse focused on drawing conclusions in the computer lab, all conversations indicated students thinking in terms of scientific sense-making while working toward the goals of the classroom. Audience was the least prevalent consideration.

Examples of discourse from the data collection events and the category I assigned to the discourse are given below. Discourse that included an explanation in terms of how or why those results occurred, were coded as Nature meaningful (NM). In the example conversation below, the group members discuss the data and what might be causing the results obtained.

> J0203-1: "So we got the other solar panel here and it looks like it stopped going down at 48 degrees flat. So, looks like we're gonna take this temperature. It went down."
>
> A0203: "We figured out that during the sunny days, the results are a lot more prominent than they are during the cloudy days like today."

> L0203: "Our project doesn't put out that much heat unless the sun is on the panels. They absorb the heat."
>
> J0203-2: "Yeah, that's actually true. So, on colder days like this, with no sun, with all the clouds covering it, it doesn't get that warm. It only gets about three degrees difference with the outside temperature and the panel."

This excerpt included all three group members discussing why the temperatures were lower than other days. The conversation is coded as meaningful because the students are thinking about the data in terms of explanation and not simply reporting of results. The roof temperature group engaged in discourse on March 3rd. In this portion of the recording for that day, Isabella offers her experience with a roof on a summer day to help make sense of the idea of the roof trapping or attracting heat. Though the mechanism for insulating and heat absorption is not yet clearly understood, this conversation indicates thinking about that process in relation to other experiences and was coded as Generality meaningful.

> V0303: "It's like the solar is like heating something and it like traps the heat in or something like that."
>
> I0303-1: "Oh. So, at least in the summer it like, most roofs are like darker . . . I can go on the roof and stuff, and in the summer it gets like really warm 'cause like black like attracts the sun. And, maybe that's like, the roofing material somehow helps insulate depending on, since it's black, at least for the summer."

The conversation included use of a prior experience to make sense of the current investigation data. This conversation received a code of Generality meaningful (GM). The group also engaged in discourse coded as Justification meaningful (JM) on the same day. This portion of the conversation includes Isabella providing me an explanation of the data dependent on the presence and interpretation by the students.

> I0303-2: "Today, the temperature over there was 59.1 and [looking at data book] and the outside of Treetop was 59.0 which I could kind of see, but then the sun came out like really strong and then so the inside of it was 53.3."
>
> Me: "Wow - "

I0303-3: “Which we were confused about ’cause the inside is supposed to be warmer.”

Me: “It is? Is it?”

I0303-4: “Yeah, because it was an insulator. But, since I think, I feel like because we didn’t kind of have like something to trap it in with like maybe four walls or at least two on the side, there’s more room for the air to come out and go through and so it doesn’t capture as much heat.”

In this segment, Isabella provides temperature data followed by a justification of why the data is accurate but not what might be expected. Her explanation suggests the temperature readings themselves are not enough to make sense of what is happening in the investigation. Similar discourse events where the students interpreted the data rather than indicating the data alone was enough for sense-making of the investigation were coded as Justification meaningful.

These recordings occurred as students engaged in scientific practices. As discussed in chapter 1, the scientific practices in this research refer to those described in NGSS (see Figure 1). While in the OLE on these data collection days, students were carrying out their investigations (SP3), using their models (SP2), and on some days constructing explanations (SP6), analyzing and interpreting data (SP4), and engaging in argument (SP7). Considering the engagement of the students in these practices while thinking in a meaningful way during their inquiry investigations in the OLE suggests evidence toward the first research question of this study: In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences? It is not appropriate to separate one practice from another in order to identify student participation as meaningful. Instead, this evidence suggests students do perceive their experience in the OLE while engaging in the identified practices as meaningful in the epistemic considerations of Nature, Generality, and Justification. Further, when asked to discuss the data collected by the group in order to draw conclusions (SP4, SP6, and SP7) on March 30th, evidence exists to support meaningful use in all epistemic considerations including Audience (see Table 12).

Analysis of the recordings on data collection days suggests students perceived the OLE experience as meaningful most often, particularly in the epistemic considerations of Nature, Generality, and Justification. Statements indicative of an Audience consideration were only evident in one conversation. On several occasions, the recording device was treated as its own entity rather than a mechanism for recording a conversation between people. As such, the data collected from this method was not what I had expected when designing this method of data collection. Recognizing the concern about the manner in which the recording device was being used, I pre-empted recordings of conversations during group discussions while drawing conclusions. These recordings occurred on March 30th and were analyzed separate from the discourse during data collection events.

As the students began to conclude their inquiry investigations, groups met in the computer lab on March 30th. To begin this class session, I asked the students to have on their computer screens the data tables and graphs constructed to date. The groups were then asked to record a conversation discussing conclusions each member was beginning to draw based on the data gathered. These discourse events were recorded using the same devices as in the OLE on collection days. I transcribed these conversations in their entirety and analyzed the transcripts for evidence of epistemic considerations. As shown in Table 12, the transcribed discourse suggested no instances of student thinking indicative of classroom practice alone. All of the coded events indicated meaningful use – students were engaged in scientific sense-making while working towards a classroom goal. Portions of the transcription of the discourse from the solar heater group is given below. I spoke with all groups during this discourse event and my interactions are indicated with “Me” in the transcript before each of my statements.

In this segment, Aiden relates temperature data to sunlight data. This relationship provides an explanation of the temperature data gathered. Aiden explains why the temperatures are different based on this relationship and the absorption of heat by the color black. Liam is thinking with Aiden and clarifies Aiden in the middle of the sentence.

A0330-1 “I think we can conclude that the black ones absorb a lot more heat than the other ones because even on the days that weren’t that sunny, they were warmer than –”

L0330-1: “Still warmer”

A0330-2: “Still warmer than the other panel and by far warmer than the outside temperature.”

The use of an explanation to make sense of the data, rather than a reporting of the data alone, indicates meaningful use and is coded as Nature meaningful. Next in the conversation, Jackson justifies the group’s thinking about the effect of black color on temperature by comparing temperature differences on the sunny days. Aiden continues this line of justification and concludes there are similar results on cloudy days.

J0330-1: “You can definitely see it when we had the sunny days because it was like a 30-degree difference between the two, and a 50-degree difference between the outside temperature and the black solar heater. The black solar heater always got to like 90 to 100 degrees while the other one stayed at lower 70s.”

L0330-2/A0330-3: “Yeah, yeah.”

A0330-4: “But, you could also see the, um, even though those are our extremes, you could also see it even on our regular days.”

L0330-3: “When it wasn’t sunny.”

In this discourse event, all three group members engaged in the conversation and agreed with the interpretation of the data. This portion of the conversation was coded as Justification meaningful. After the justification segment, Jackson and Aiden discuss how their investigation might be useful outside of this instance. The group members generalize about the benefits and uses of a solar heater in a different application.

J0330-2: “Even though it was a low temperature, but our solar panels weren’t even that big in size, and if you make a bigger one, if you want to, you could get a lot more heat out of it and a lot more heat. That could be your like heating source for a small apartment or something. ’Cause I don’t think you could heat your whole house. If you had multiple, maybe, but that would look kind of weird all over the house.”

A0330-5: "You would have to have an air vent going into the house."

J0330-3: "A ton of like heaters hanging on the outside of your house."

L0330-4: "Yeah, that wouldn't look good."

A0330-6: "No, it wouldn't."

This portion of the conversation was coded Generality meaningful because the students indicated thinking about a more general use of the information they were developing. The discussion about use of solar panels for heating small apartments implies thinking about further application of the knowledge product. Another aspect of Generality meaningful is the use of a more general idea to explain or understand the instances of the investigation. This generalization is seen in the following discourse segment when Aiden discusses the non-effect of changing data collection days from Thursday to Wednesday. This segment of the conversation occurred when the teacher engaged with the group.

Me: "I heard you earlier say when it's a sunny day you had greater temperatures. Have you considered looking up how many sunny days we generally have in the [location]. I wonder if that would be something interesting. Because it seemed like when we went out, except for three days, it was overcast or raining, right?"

A0330-7: "Well, that's what you kind of expect with [location]."

Me: "OK, so that's a good question, K. Is that typical for [location]? Or, did we just happen to pick bad days, right? That might be interesting, right?"

A0330-8: "It doesn't seem like it was any different than any other day. I mean I don't think if we did it on a Wednesday every week it would make any difference."

[Different conversation, then returns to this discussion on line L0330-5]

[Looking at screens]

Discussion of days of sun from website

J0330-4: "186 days. That's like almost half."

A0330-9: "That's not average though. No."

In addition to Aiden's thinking on the specific days of data collection, there is discussion about average sunny days. This segment also suggests the group taking a general idea and applying it to make sense of the data collected. The group next discusses why the temperature data differs between the solar heaters. This explanatory component indicates the students are engaged in meaningful sense-making in the epistemic consideration of Nature. The segment continues directly into an instance of meaningful Justification in the latter half of J0330-6 when Jackson justifies the conclusions the group is drawing from the data.

J0330-5: "So, I would say the project was a success."

A0330-10: "Yeah, I would say it was a success, too."

J0330-6: "'Cause it got to show us that the black painted solar panel and our hypothesis was a success 'cause it showed that our hypothesis was to see which, our hypothesis was that the black painted solar heater would produce the most heat because it's painted black, and our hypothesis was correct. And, I would say our project was correct 'cause it showed in the temperatures in the sun 'cause the temperatures sky-rocketed and showed vast difference of the temperatures."

The segment above explained the reason for the data as well as justified the conclusions being drawn. Nature meaningful and Justification meaningful codes were recorded for this section of discourse. Next, the group returned to their conversation about number of sunny days. This segment received a code of Generality meaningful because the group is using general weather patterns and applying them to their data records in order to make conclusions.

[Continuation of conversation about number of cloudy days]

L0330-5: "Whoa, look at this. In January, we had 24 cloudy days."

A0330-11: "that's almost the whole month."

L0330-6: "Yeah, so, how many times did we go out to the garden."

Discussion of determining percentage of days that are cloudy

Me: "So, 80% of the days are cloudy in January. Is that consistent with your data? 80% of the time that you collected data it was cloudy? Interesting."

J0330-7: "The temperature, it's not the same temperature, but it's going to be close to the outside temperature when it's cloudy."

Me: "Does that impact how you would answer your question? [pause] So, the solar heater works best under what conditions?"

A0330-12: “Sunny weather”

Following this discussion of general weather patterns and their effect on the efficiency of solar heaters, the group and I discussed the potential for use of the solar heaters.

Me: “And the purpose of the solar heater is to - ?”

J0330-8: “Probably to like get heat to small apartments or something like that.”

Me: “OK, so when we have our sunniest weather, what months are those?”

A0330-13: “During the summer, generally.”

Me: “And are those days we want to be heating our small apartments or garages?”

A0330-14: “It depends where you are.”

This portion was coded Audience meaningful. Jackson explains the usefulness of a solar heater in a small apartment. This indicates an audience beyond the teacher. The Audience consideration is further evidenced in the last line as Aiden suggests the location of the solar heater matters. Aiden is considering application of the solar heater to others in different locations. The conversation concludes with discussion of how others have built and used solar heaters. Jackson takes a general idea and applies it to this investigation:

J0330-9: “It would work better if you built a bigger one ’cause we built a really tiny one. And even though it was really small, it got to 100 degrees in it.”

A0330-15: “’Cause it’s very good on -”

J0330-10: “The people that build them got like 20 by 20 something and they’re really big”

Recording ended mid-sentence.

[My recollection is the conversation continued with the boys pointing out the temperature increased even on cloudy days so the solar heater would be useful in the winter months.]

This latter portion of discourse suggests meaningful use in the epistemic considerations of Audience, Generality, and Nature.

The discourse recorded in this portion of the research suggests students perceived the OLE experience as meaningful while they engaged in the scientific practices. In all epistemic considerations, group conversations indicated students thinking about the class activity – the inquiry investigation – in terms of scientific sense-making goals. Though the use of the recording device was meant to be the same as its use on data collection days, this particular event produced recordings more in-line with my goal of the device being a mechanism to capture discourse.

Video recordings from panel presentations. In addition to the audio recordings, discourse between students and the adult panel members were recorded on video during their presentations on April 13th. The adult panel consisted of four adults with varying association to the school. One white male (MM) interacted with the students earlier in the school year during a data collection day. I have collaborated with him for the inquiry investigations for the last five years and he has served on every adult panel over the last four years. He is a retired educator and administrator. The other white male (MR) works in the health care industry and had no prior interaction with these students. This was his first time serving on the panel. He is my husband and has some familiarity with the intent of the inquiry investigations in general. One female (FN) is of Indian descent. She is a business woman working on communications infrastructure for the city. Though she has not had direct interaction with the students in this year's class, she has two children in the school, both of which participated in previous inquiry investigations with me. This is the second time she has served on the panel. The final adult (FB) is a white female. She is an educator and worked with this year's class to develop logos for their inquiry investigations. In that capacity, she had some familiarity with the students and their projects, however, she had not seen them in the OLE, only in the classroom. This is her second panel to serve on. Consent for recording was obtained from all adults on the panel.

The panel presentations offered students an opportunity to engage in several scientific practices. To prepare for the presentations, students constructed explanations (SP6) and engaged in arguments (SP7) based on these explanations during the presentations. Students also communicated information (SP8) to the audience. Within the presentation to the panel, students provided evidence of participating in other scientific practices while engaged in the OLE investigations. These instances are noted with the identified scientific practice in parentheses after the quoted statements. Both groups chose the web-based program Prezi to create and present their inquiry investigations to the adult panel. Each member of each group participated in the presentation and answered questions from the panel members. However, in both groups, one student dominated the question and answer portion of the presentation. Interestingly, the dominant student in the presentations was not the dominant student in the discourse recordings from data collection days. Typical of many classrooms, students in these groups developed different strengths; some students may be more interested and engaged in the data collection events while others prefer to converse with an audience about their learning. The instructional design of this study allowed opportunities for all students to participate, though not all in the same way. For both of these groups, I observed the overall requirements or duties of this investigation being equally split among group members. All group members presented to the panel members and each student answered at least one question from an adult on the panel.

The question and answer segment of these recordings was transcribed and coded. All coded segments indicated meaningful use. The transcriptions of the question and answer discourse are provided below, along with the coding category assigned to each segment.

The question and answer session for the roofing temperatures group began with a question relating to the functionality of the design of the roofing materials. For the adult panel members, the letter R secedes the initials identifying the adult and the number indicating the order of the individual's statements during this session for the roof temperatures group. The responses from the group and the follow up questions suggest this segment focused on clarifying the construction and components of the model. This suggests engagement in SP2 during the investigation itself.

> MM1-R: Did you see something about the Iko roof that made you think it was going to work better?
>
> [found picture of roof on Prezi]

I0413-1: [pointing to pictures] The Iko one has more slits, and one's a little bit more forward and one's a little behind. And, the Treetop, this, it only has one slit and it's longer (SP2)

MM2-R: So, it's flatter and this one [Iko] has more layers?

I0413-2: Yeah

MM3-R: Is it thicker? So, when they are layered on top is it thicker there or is there a layer of air there? I'm just wondering why it's insulating better.

I0413-3: Well, I don't think they had a pocket of air under, but we had plywood under them. So, that kept there wouldn't be any air pockets, and the plywood helped with the insulation.

MM4-R: But you had plywood under both, right?

I0413-4: Yeah

The next segment of this session was coded as Nature meaningful. In this segment, Isabella reasons through the design of the roofing material and answers the question with an explanation of why the roofing material was designed in a certain way. Her reference to her dad's explanation indicates Isabella was thinking about the reasoning behind her response on functionality and reflecting on previous experience with her dad on the same topic.

FB1-R: Working on that same question, on just the visual design of it, the Iko on the left, right? [referencing image on the screen] Do you think that was just they think it looks nice to have it broken up into smaller pieces or is there a function, why it's important to have more cuts or slits in the shingles?

I0413-5: With the Treetop, it has different slits in different locations, so, my dad was explaining, so the rain it won't go all in one line because then the rain would get in and it would start leaking. And with this one [Iko], the different layers it would back each other up and so the water would not go through.

Isabella referenced her work with her dad for this inquiry investigation multiple times throughout the year. The opportunity for her to connect with her dad made a significant impact on Isabella and her connection to the inquiry investigation. This may have been the first time she was able to access her dad's career to assist her in understanding and participating in a school activity. The positive response, in terms of motivation and engagement for Isabella, suggests inclusion of family as resources benefits student learning and should be considered as teachers design science activities.

The next section of the session was coded as Justification meaningful. Valentina uses her own interpretation of components of the investigation to explain the movement of air through the model.

> FB2-R: And do you think that the air, the wind flow, the air circulating through each of the shingles, does that help maybe the cooling effect?
>
> V0413-1: Yeah, I think that helps because in the Iko, it wasn't able to get the cold air through and then in the Treetop the cold air would then go through.

Valentina justifies her response of "yeah" by explaining how the design of the shingles effects air flow. In this example, and in others during the panel presentations, the adult asked a leading question. Scaffolding in this way enabled the students to think about and answer the questions with more explanatory responses, offering expressions indicative of thinking toward scientific sense-making. The adult panel members understood their role in these presentations was to listen and learn, but also to elicit or uncover student learning and understanding developed from the OLE experience that was not brought out in the Prezi itself. Scaffolding strategies with questions that build or lead help students to convey those learnings. The line of questioning about the functionality based on design ends here.

The following question prompted a response coded as Nature meaningful. Isabella follows Valentina's response with an explanation of how the glue on the roofing material works to reduce heat loss.

> FB4-R: Does the coloration change at all? I see more light to dark contrast on Iko. Do you think that has an effect on the heat, temperature?
>
> V0413-2: Yeah, we don't think so. It's just what it's made out of, so
>
> I0413-7: Well, on the color probably not, but on each layer right here [pointing to picture] both of them they have this glue right here so when it gets hotter it melts it so it makes all these roof layers stick together so that nothing can go under it or through

Though Isabella's response does not directly answer the question, it does indicate thinking about why a particular aspect of the design of the roofing material might be important. The inclusion of an explanation suggests meaningful thinking in the Nature consideration.

The last section of this question and answer session was also coded as meaningful. In this section, the adult asks a question related to the experience of going outside, not a question directly tied to their specific investigation. This segment provided instances of both Generality and Audience meaningful. Isabella relates her learnings from this investigation to her dad's job, demonstrating a generalization of the learning from the specific investigation to the broader realm of her dad's profession. She also references connection to other people as audience to the function and importance of roofs.

> MM5-R: You said thank you to Mrs. HR for allowing you to go outside. So, even though sometimes it was rainy and cold, were you glad you got to do this outside?
>
> S0413-2 and V0413-3: Yeah [nodding]
>
> I0413-8: Especially for me, I got to experience what my dad does for a living and it kind of made me realize, oh his job is important because without his doing that people would have leaking roofs and -
>
> [End of presentation]

All three girls are involved in the response to the question, though Isabella provides the most spoken words. Isabella was the dominant voice for this group during the presentation, though all three girls participated by answering at least one panel question. Isabella was also a dominant voice in the classroom outside of the inquiry investigations, but not in an obnoxious or over-powering way. In the beginning of the year, she would often ask questions that seemed a distraction from the intended learning – the types of questions that elicit a teacher's story and gets the class off track from the day's objective. However, as the year progressed, her participation in class discussions evolved. Her comments and questions were often borne of a desire to participate and learn, rather than boasting or "showing off" intelligence. Isabella worked hard to understand. She shared with the class at the end of the year that she had been told the previous summer that she would not like this science class, but it turned out to be her favorite.

The solar heater group also presented their investigations via the web-based program Prezi. The same adult panel asked them follow-up questions. For the adult panel members, the letter S secedes the initials identifying the adult and the number indicating the order of the individual's statements for this session with the solar heater group. The first section of the question and answer session was coded Nature meaningful. Aiden provides an explanation of how the color relates to heat absorption.

> MM1-S: I guess it's not a surprise a solar heater works better when it's sunny, but going a little beyond that, what is it about black that works?
>
> A0413-1: So, I think the main thing about the color black is, the brighter colors all reflect it and the black absorbs it. It's something about the colors of the light going in. Something happens when the color of the light goes in and reflects it in a certain way. How our eyes see it, that's how we see different colors and stuff. But, when there's a certain color light going in, it reflects it more when it's lighter, and when it's darker it helps absorb it more.

The question asked prompts for an explanatory response. The answer is coded as meaningful because of its explanatory nature. In this sense, the question helped make more explicit the student's thinking behind the properties of the color black and its connection to this investigation. The next question is different in its leading potential because the response could have been a single word. Instead, the student's response about the color of solar panels goes well beyond what was expected of the questioner. This segment was coded Generality meaningful. Aiden used his understanding of solar panels and related it to his investigation by contrasting the two. Aiden further connects his investigation to solar heater use in the broader field of industry.

> MM2-S: What color are solar panels when you see them on roofs?
>
> A0413-2: Well that's a different, that type of solar panel is a photovoltaic solar panel and it's usually blue because of the material they use. One of the things we researched is there are big industries of this, not like this, of solar air heaters and

instead of using the photons to collect energy, they use the heat from light for that.

MM3-S: OK, so we're talking about apples and oranges here

A0413-3: Yeah, there's different types

MM4-S: Got it

This segment demonstrates Aiden's elevated understanding of his group's project. Though Aiden was not vocal on much of the audio recordings during data collection events, in the presentations he dominated the conversation. His sophisticated responses to multiple questions seemed to shut out his group mates. From my knowledge as the teacher, I do not believe he intended to dominate the conversation or have his group mates feel they could not answer. Instead, Aiden was excited to be able to communicate his level of understanding with the adult panel members. He enjoyed being able to teach them. Aiden's contributions to this portion of the inquiry investigation and his written report are a contrast to his general participation in the science class. He often was distracted during class discussions and activities, would ask redundant, clarifying questions, and seemed to struggle with picking up concepts quickly. His participation during data collection events was minimal. His designated responsibility (chosen by the group at the beginning of the investigations) during data collection was to check the model for any needed repairs. He was often heard talking and laughing with the groups around him while the other group members were collecting data and speaking into the recording device. However, when asked about the inquiry investigations, his responses matched the level exhibited in the panel presentations and written report. This could indicate Aiden needed time to learn and developed the level of understanding exhibited in the panel presentations because the inquiry investigations allowed for the time he needed to process and make sense of the science involved.

The next section also includes evidence of thinking in the Generality consideration as well as the Audience consideration. In this section, the adult asks about the importance of solar heaters. Jackson and Liam respond with references to their background research. Aiden takes the response further with application of the technology on a larger scale.

MR1-S: I really like this design. It's a great design you guys put together. So, that collects heat, but why is that important? What are we going to use that for?

J0413-1: When we looked up background information and how to build it on the internet, we saw people were actually building much bigger solar heaters to heat their small apartments, and they actually hang up on the side of their apartment and they're using them to heat their house.

L0413-1: And, on a bigger model they would also have a computerized fan that would circulate the air through it to get it going into your house.

A0413-4: And I think there's another side to this too. Of course there's the do-it-yourself version like we made, but this is also a way to understand there is a big application for the general industry. There are large solar, thermal industries, not exactly like this, but they take the same idea where they take the light and they reflect it so you can get temperature out of that and convert it into energy. (SP2)

Within each of the group members' responses, there is evidence of meaningful thinking in the considerations of Generality and Audience. Jackson and Liam reference their learning in the background information indicating an approach of using general ideas to construct understandings of their specific investigation. They also reference how people use solar heaters to heat their homes. This suggests thinking about an audience beyond the classroom. Aiden also provides evidence of thinking in the same considerations. For Aiden, the importance of solar heaters extends beyond personal use and into the industry. Aiden continues to provide evidence of thinking toward scientific sense-making goals in his response to the next question, this time in the epistemic considerations of Nature and Justification. This question pertains to the use of the background research. In his response, Aiden explains how the background information helped the group understand aspects of their investigation. His thinking centered on the considerations of Nature and Justification at a meaningful level.

FN1-S: In your first slide, you talked about doing research on thermodynamics for this project. So, tell me how you used your research.

A0413-5: Thermodynamics and what materials to use helped us because originally we were thinking of using just a black panel, and that was made of a different kind of metal and stuff. And the thermodynamics kind of helped us understand what was solar radiation, what was conduction, what was convection, and helped us know how to hold all the heat inside our solar panel.

Aiden did not reply with a simple statement such as, “The background information helped us make the panels.” Instead, he explained how the research helped with construction and continued with a justification of why the background information was helpful for the group.

In the next section, the students were asked about their future plans in light of this investigation. The response from Liam suggests his interest in applying the learning from this investigation to a more general field.

FN2-S: And the one thing you put in here [brochure] about different colors of light have different wavelengths and different amounts of energy and all that, now that you have learned a little about that, what scientific field do you think you guys want to go into?

All: Ummm

FN3-S: What interested you? Based on this experiment, what are some areas that you would like to experiment more?

L0413-2: Renewable energy because you could use that to cut down on – instead of using like coal power plants, use solar panels for energy instead and make more efficient solar panels to collect more energy.

Liam’s response was coded as Generality meaningful because he connects his learning from this experience to the general area of renewable energy. His ability to generalize, as well as his consideration of future investigations related to this inquiry suggest his thinking connects his learning from a classroom activity to sense-making of science. The last portion of the question and answer session did not fall within an epistemic consideration coding category. The responses focused on the construction and functionality of the model. This segment demonstrates engagement in the scientific practices, especially developing and using models.

FB1-S: At some point in the construction, you were speaking about you used metal duct tape and that was helpful. What was the problem before that that the metal duct tape solved?

A0413-6: We used the two tubes of Liquid Nails first to try to hold the Styrofoam together. We thought it worked and then after like two weeks, something went wrong in like the drying, and it started cracking and the two pieces of Styrofoam started coming apart from each other. Since it was cold days in November, we were thinking, since there were holes on the sides, that heat was escaping. So, we used the metal duct tape and then we decided to wrap the whole thing with packaging tape to close all the gaps and hold all the things together so none of the heat escapes. (SP2, SP3)

FB2-S: So, question on that: heat escapes. The fact that it's metal and it's reflecting, do you think that changed anything? You were trying to collect heat with the black, right? Do you think metal tape might have reflected some of that precious heat and affected the data in any way?

J0413-2: I don't think. It might have done something in the non-painted solar heater because in this one [holding up black panel] we spray painted all of it inside of it and I think that might of kind of helped, not just within the cans but we painted all of it.

FB3-S: On a not very serious note, do you think it got hot enough you could fry an egg on it?

A0413-7: Our best results on one of the days got like 104, it was actually 104 ½ I think, you probably couldn't, I don't know. But, you could feel how hot it was on the top. (SP4)

This section of the Q&A session allowed students to explain their model and modifications made during the investigation. The dialogue is interesting and informative in terms of thinking about their construction and functionality of the model. It is informative in terms of thinking about how the students engage in the scientific practice of developing and using models. For the sake of this research, this segment provides evidence of engagement in that practice, though the engagement occurred earlier in the inquiry investigation.

Analysis of these recordings suggests students perceived their experiences in the OLE as meaningful for bridging a classroom activity with the goals of scientific sense-making. Table 13 indicates the total number of responses coded within each epistemic consideration. Each coded response indicated meaningful use.

Table 13

Epistemic Considerations Coded for Each Group's Panel Presentation

Epistemic Consideration	Roof Temperatures Group	Solar Heater Group	Total responses
What kind of answer should our knowledge product provide? (Nature)	2	1	3
How does our knowledge product relate to other scientific phenomena and ideas? (Generality)	1	5	6
How do we justify the ideas in our knowledge products? (Justification)	1	1	2
Who will use our knowledge products and how? (Audience)	1	2	3

Though the solar heater group provided more responses to questions from the panel members, both groups responded with discourse indicative of thinking within each consideration. These conversations were part of a presentation in which students engaged in multiple scientific practices, including engaging in argument (SP7) and communicating information (SP8). Prior to the question and answer session, students presented their inquiry investigations to the adult panel members. These presentations followed a template provided by me to include each general aspect of an investigation: question, background research, procedure, data and analysis, and conclusion. The information provided in this portion of the presentation is duplicated and expanded upon in the written inquiry investigation reports. I focused analysis of the video recordings on the question and answer session, with particular attention toward evidence of meaningfulness in relation to the four established epistemic considerations.

Written inquiry investigation reports. Two days after the presentations, students turned in final inquiry investigation reports and written reflections. The final lab reports contained edited versions of all of the components previously evaluated by me. Students received a checklist of the parts of the lab report, including portions expected from each individual and those expected one per group:

Due April 15th:

All of the items in the report must be final draft quality. This means you took the time to improve your rough drafts based on your learning and feedback provided. The two background information reports must be combined into one, unified section of this final report. All sections of the final report must be on separate pieces of paper.

One per person, unique to you:	One per group:
____ Background information	___ Question
____ Analysis	___ Hypothesis
____ Conclusion	___ Procedure
____ Reflection	___ Data tables and graphs
____ Bibliography	

Each student in the two groups of focus in this research completed and turned in a final lab report. The lab report provides written artifacts connecting scientific practices (indicated by SP#) to epistemic considerations. Below is a synopsis of the lab reports for each group.

Roofing Temperatures project

Question: Which roofing material is the better insulator? (SP1) This question was decided upon by the group because one of the members of the group has a parent in the roofing industry.

Background information: Students in the group researched a variety of topics related to roofing and thermodynamics (SP8). Topics included roofing styles, materials, lifespan and cost, history of roofing, and the purpose of a roof. The research also connected roofing materials and styles to local weather patterns with the students recognizing the importance of researching a roof before making a purchase. One of the group members researched green roofs. This connected an aspect of her project to a broader concept of environmental support. Thermodynamics was also researched and students made the connection between roofing and insulation, providing another purpose of having an appropriate roof. This led to the question and approach to data collection in order to determine which roofing material provided the most insulation.

Procedure: The group worked with one of the parents to build four model roofs, two of each type of roofing material (SP2). The students set up the roof models in the OLE at two separate locations, one near the stream and one up on benches. In both areas, the roofs were propped at a similar angle which was built into the model. Each week, the students collected temperature data using Vernier equipment. Temperatures of the outside air, air above the roof, and air under roof were collected at both sites. At the stream site, the students measured soil temperature in front of and underneath the roof as well (SP3).

Data and Analysis: Students kept the data in a logbook and later converted it into a spreadsheet and graphs. The data tables and graphs separated the two sites' data in order to compare the roofs at each site rather than the difference between sites. Analysis reports of the data included only reference to highest and lowest overall temperatures (SP3, SP4, SP5).

Conclusion: Students in this group used the data collected to draw a conclusion about the insulation properties of each roof. The group determined the roof with the temperatures underneath measuring closest to the soil temperatures was the better insulator (SP6). This approach to analyzing their data to draw a conclusion was discussed in the reports, as was the process for analyzing data from the other site of their experiment (SP4). Students also reported what they learned from doing this investigation, their sources of error, what they would do differently, and what suggestions they would make for future students interested in doing a similar experiment (SP8).

The written lab report provided evidence of student epistemological considerations particularly in the conclusion sections. Below are portions of the lab reports that were coded for epistemic consideration. These are only a sample of the coded pieces from this group. Evidence of meaningful use in the consideration of nature was evident in the hypotheses as the group explained why they hypothesized what they did. This consideration was also evident in Isabella's conclusion:

> I0415-1: ". . . if I were to do this project again I would maybe have had more locations and more types of roofing material and picked a spot where it both had soil to take temperature because the roof serves as a barrier between the air and the soil also I would have also built some sort of small house structure so that the air could be more trapped."

This segment of her conclusion demonstrates Isabella's thinking about the areas of the investigation she could have done differently and includes an explanation of why those adjustments would improve the investigation. The inclusion of an explanation for her choices indicates meaningful use, or sense-making beyond the goals of the classroom, as described in the coding scheme for this research, Table 4. Meaningful use was also seen in Valentina's background research section in the category of generality. In this segment, Valentina generalizes about how weather in different areas would change the roofing needs of inhabitants.

> V0415: "Weather in [town name] where we have been doing this project has been in the 60°s F and below. If we did this project somewhere else, somewhere by the coast, the whole project would have to be altered a little bit. We put four nails in each piece of roofing we put on the plywood because [town name] isn't a coastal city. When we were building the roofs Isabella's dad (who works in roofing) told

> us that in coastal cities they put six nails into every piece of roofing material while we only had to put four nails. If we did this project in Miami, Florida, which is a coastal city the roofs would have to be altered and the data would be different. The weather in Miami, Florida is in the high 70°s F. The data would have a higher temperature rate in Miami than [town name]. The end result would differ in another region."

In this segment, Valentina communicates a thinking in terms of generality. She explains why the model they built had 4 nails and how that would be different if it were built in a coastal town. This thinking is coded meaningful because Valentina is indicating thinking beyond her individual project. Sofia also demonstrated meaningful thinking in her report. In the conclusion section, Sofia discussed why the group concluded one roof was a better insulator than the other:

> S0415: "a way we figured Iko was a better insulator is by comparing which roof shingles (Iko, Treetop) had the highest temperature and Iko was the one that was closer and the one that gave better results and the one that was closer to the air temperature."

This segment was coded in the category of justification because Sofia is justifying the choice of roof in her conclusion, rather than presenting the data as if it speaks for itself.

For the fourth epistemic consideration, audience, Isabella provided evidence of her thinking about an audience beyond the classroom in her conclusion. She writes to an audience interested in roofing.

> I0415-2 "Knowing the typical climate in your local area is important because some roofs might be better for a specific weather . . . . because of the weather in your local area check to see if there's a roof especially made for your local weather."

This segment suggests Isabella is thinking about an audience beyond the classroom, an audience interested in roofing for their home. This indicates Isabella thought about the audience in a meaningful way as she communicated through writing about her investigation.

The solar heater group also wrote inquiry investigation reports. Analysis of these begins with a synopsis of the reports from the group followed by individual excerpts to example coding for epistemic considerations.

Solar Heater project

Questions: How does the color black affect the heat output of our solar heaters? What other factors contribute to the temperature? (SP1) The group decided to investigate solar heaters for a variety of reasons. Several other groups in their class were investigating water filters and this group wanted to be different. The boys were also interested in constructing something. The teacher offered a few ideas to the classes at the beginning of the topic selection time. One of the topics was DIY solar heaters. This group was the only group to choose an offered topic from the group. Though the topic was generated by the teacher, the group determined what question to ask and how to investigate their question.

Background information: The students investigated a variety of topics related to solar energy (SP8). These included solar thermal energy, solar panels, photovoltaic cells and photons, as well as the benefits of solar energy and solar panels. The background research also addressed environmental issues such as global warming from greenhouse gases released from power plants and the benefits of using renewable energy such as solar energy to reduce these pollutants. Thermodynamics, conservation of energy, the light spectrum, and the heat absorption of the color black were also included. The group also researched how to design and build a DIY solar heater, including materials to use.

Procedure: The group used the research to design and then build two solar heaters (SP2). One of the models used unpainted soda cans. The other model was built with the same materials in the same design, however, the interior of the model was painted black. The group chose to use insulation, Plexiglas, and metal duct tape, as well as PVC pipe elbows to allow air to flow in through the bottom of the panel and out of the top of the panel. The researched models used fans to assist with air circulation in the solar heater. This group, however, did not use any fans. Instead, the group relied on convection currents to bring warm air to the top of the heater. The openings with the PVC elbows provided an area the group could access to collect temperature data. The group used a Vernier LabQuest 2 and temperature probe to collect data (SP3).

Data: The data included outside air temperature and air temperature inside each of the models. The inside temperature was collected through the PVC elbow opening at the top of the model panels. Data tables and graphs were constructed with all of the data included. Analysis reports included reference to the difference in temperature between the outside and each of the solar heaters. This comparison included days with minimal differences (cloudy days) and those with considerable differences (sunny days) (SP3, SP4, SP5).

Conclusions: The group concluded their hypothesis was supported by the data collected. Both solar heaters measured air temperatures higher than the outside temperature on every data collection day and the black solar heater always had the greatest temperature. On the sunny days, the difference in temperature was remarkable (SP6). Sources of error, suggestions for improvement, what they learned, and how this knowledge could be helpful for others were discussed in the conclusion section (SP8).

The written lab report provided evidence of student epistemological considerations particularly in the conclusion sections. Examples of these statements are provided below. Similar to the roof temperatures group, the hypothesis for this group provided an explanation of why they believed the result they predicted would happen was likely. This was coded as nature meaningful. Aiden provided another instance of thinking in the consideration of nature with the purpose of making sense of the science while engaging in the classroom activity of writing his report. In his conclusion, he explains why the black painted panel provided the results they gathered:

> A0415-1: “All this happens because when there is more direct sunlight, the metal and the black paint of the cans can absorb more light energy, which creates more heat. The black painted panel can produce more heat because of the light absorbing properties of the color black.”

Aiden's inclusion of an explanation of why the black painted panel measured higher temperatures indicates thinking beyond showing the results and into describing why those results were obtained. This level of thinking is indicative of meaningful use. Jackson also provided instances of thinking in terms of meaningful use in his report. In his conclusion, Jackson wrote a segment categorized in the generality consideration:

> J0415: "Something that these panels can be used for is heating small apartments or homes . . . I learned a lot about how solar panels work, how colors absorb energy, and the importance of solar power as a reusable form of energy."

This portion of his report demonstrates Jackson thinking about his learning in terms of its usefulness and applicability to others. He generalizes from his experience to the use of solar heaters in an apartment and, further, as a source of renewable energy. Thinking about a knowledge product, in this case the understanding of the workings of solar heaters, as it applies beyond an individual project indicates meaningful use in terms of generality. Aiden also provided further examples of meaningful use in his written report. In his background research, Aiden explains how the group decided to construct the panels. In this segment, Aiden justifies their choices of materials and design:

> A0415-2 "In our panels, we have constructed the frame out of Styrofoam, a material that conducts heat poorly, in order to trap the heat produced inside. We also put a layer of fiberglass insulation inside the panel, also a bad conductor, push the cans up against the glass and get rid of any extra room. By doing this we are isolating any air inside to go through the cans, and when the air is hot, trap the heat in by not letting it escape through heat transfer."
>
> ". . . This is why black is used to absorb light and make heat. Black cans on a solar panel should create more heat than non-black cans. Even though black is better at absorbing light to create heat, all metallic materials, including soda cans used in our heaters, are very good at retaining heat from the sun."
>
> "Using our knowledge on solar energy, we are able to compare and contrast the models we create to get reliable results that we can work, and reflect upon."

In the first section of this example, Aiden justifies the group's choice of materials by including the group's reasoning for using specific products. In the latter portion, Aiden indicates the need for the background research in enhancing the group's ability to make conclusions. The latter portion also indicates Aiden thinking about the group as being part of the interpretation of the data when it comes time to draw conclusions.

The fourth epistemic consideration, audience, was evidenced in portions of the inquiry report for each of the three students. In their writing, they suggest thinking about an audience beyond the classroom. In the example from his background research, Liam extends his learning to applicability for all people in order to improve the planet:

> L0415: "Surprisingly we can even use this solar energy to heat our homes. If we could all find ways to implement solar energy into our daily lives, our planet would be a better healthier place."

This example indicates Liam thinking about his investigation being useful at home and for all people. He extends beyond the classroom as an audience and implies anyone on the planet could be a potential audience for this research. Because of this extension of his audience, this segment was coded meaningful in the consideration of audience.

The data collected from the inquiry investigation reports provides evidence to answer the first research question for this paper: In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences? All four epistemic considerations are evidenced as meaningful, indicating student thinking connecting the classroom activity with goals of scientific sense-making. These reports reflect the participation of the students in the scientific practices as part of the inquiry investigations in the OLE. The written reports include evidence of participation in seven of the scientific practices. The only practice not explicitly addressed is SP7: Engaging in argument from evidence. This SP was addressed during the panel presentations. As students engaged in these practices, their artifacts indicated thinking about their investigations in terms of scientific sense-making. The reports extend beyond reporting of what was done and the data collected, and include evidence of thinking about reasons behind the data, what the data means to others and on a larger scale, and how they can justify their conclusions. The context of the OLE provided a time and place to connect the students to their learning. In typical classroom science, often constructed similar to bench science, students follow a prescribed procedure to collect data in order to collect data. The context of the OLE – taking the students outside into a place where the investigation applies to and is influenced by the place - provided a reason behind the data and helped the students understand what causes the variations in the data, what the numbers mean, and how this information is helpful. The data from the reports suggests students perceived the OLE investigations as meaningful in each of the four considerations.

Written artifacts, including the inquiry investigation reports, and discourse events from the two selected groups provided evidence of student thinking. Table 14 indicates the coding of these data sources in terms of epistemic considerations.

Table 14

Coding for Epistemic Consideration Within Each Data Source (n=6)

Epistemic consideration	Coding	Free-write entries	Discourse Recordings	Panel Q&A	Written Reports	Total
Nature	Classroom	38	9	0	0	47
	Meaningful	48	13	3	6	70
Generality	Classroom	1	0	0	0	1
	Meaningful	26	9	6	4	45
Justification	Classroom	26	2	0	1	29
	Meaningful	23	10	2	5	40
Audience	Classroom	13	1	0	0	14
	Meaningful	10	2	3	5	20

From all of the data sources, the Nature consideration was the most frequently evidenced consideration, followed by Justification, Generality, and Audience. Student thinking within each consideration was most often classified as meaningful use – engaging in scientific sense-making while working toward a classroom goal. In addition to examining student thinking while engaging in scientific practices, this current study aimed to determine the kinds of knowledge students constructed while in the OLE.

Though limited to only these two groups, the inquiry investigation reports also provided evidence to answer the second research question, what kinds of knowledge are students constructing as they engage in the OLE? Groups designed their investigations beginning with their choice of topics. These decisions directed the content considered within the investigation. In these two groups, the written reports indicate the knowledge they constructed included science concepts of thermodynamics, environmental science, solar energy, photovoltaic cells and photons, renewable energy, conservation of energy, the light spectrum, and more. Students included these concepts in their background research and then used them as they developed their conclusions. These topics were also included in their presentations to the adult panel. Further evidence used to answer this research question was obtained from the written reflections.

Written Reflections. The final data collected came from the entire class. Students completed a reflection on their inquiry investigation experiences. I provided a worksheet for students to complete as their reflections (see Appendix C). I analyzed these worksheets for specific information related to the research questions of this paper. In particular, student responses to "Explain 10 things you learned by participating in this inquiry investigation" and two other questions on the worksheet – What did you learn about yourself? What did you learn about science in general? – provided information about content and personal learning. Responses to these questions were categorized into science content areas, general science, other content areas, personal skills, or social skills. This data offers a response to the second research question, "What kinds of knowledge are the students constructing as they engage in the OLE?"

Students reported learning about general science, such as use of lab equipment and writing reports. They also included references of what they perceive as what scientists do. Physical science, biology, and chemistry topics were reported as learned, including thermodynamics, nutrient cycles, and pH scales. Earth Science content was prevalent, as would be expected based on the requirements of the investigation. Topics included in their lists of learning were soil, weather, erosion, environmental concerns, and water quality. Beyond science, students reported learning content related to mathematics and language arts. Aside from classroom specific content, many students mentioned learning personal and social skills, such as taking responsibility and being prepared, and teamwork.

Specific responses from members of the two groups of focus included:

Aiden: “We learned the process of making a good design and carrying it out and building it.”

Aiden: “We learned about how the sun relates to heat, thermodynamics, and what materials work for retaining and conducting heat. We learned about the light absorption properties of the color black and about metal in general.”

Liam: “I learned that science isn’t always on your side. Sometimes you’ll go out and it will be raining or your experiment isn’t working. That is what makes science fun you can always try new things no matter how much you mess up and get it right.”

Jackson: “I learned that science is not boring like I thought it was. I learned that there are many fields of scientists”

Jackson: “Solar energy is a form of energy we should be utilizing more”

Sofia: I learned “how to take better data and to be organized with your data”

Sofia: “I also learned that there are roofs that help the environment.”

Isabella: “Insulating regulates the temperature inside and outside of a structure.”

Valentina: “An insulator regulates the heat inside and outside of the structure.”

Items learned also included the following non-science topics:

Aiden: “We learned to apply our project to other things.”

Aiden: “I can step forward as a leader in tough situations”

Liam: “I learned that when I work hard I am capable of things that I did not think I could do in the first place. I also learned that I can catch onto things fast.”

Jackson: “I thought that making the solar panels was the most interesting part of the project. The [background] research wasn’t nearly as exciting, but it was important so we knew how to build the solar panels and how and why the temperature was changing."

Jackson: "I learned that I like science a lot"

The responses from the class suggest learning a large array of science content. Because each group chose their own investigations, the content learned was different from one group, and even one person, to another. This analysis suggests, however, science content was included in each of the inquiry investigations. Several students also mentioned learning content from other groups' investigations. In addition to science content, students stated learning connected to other content areas, as well as personal and social skills. This indicates the kinds of knowledge constructed during the OLE experience include science content as well as other forms of learning.

In addition to learning science content, the instructional design of the OLE curriculum provided opportunity for students to engage in each of the scientific practices described in NGSS. I explicitly addressed in the instructional design expectations for development of each of the scientific practices for students in middle school as outlined in the NGSS (see Appendix D). Student participation in these expectations were observed by me throughout the OLE inquiry investigations. The practices developed as the students engaged with the science content chosen for their investigations. These practices did not occur in isolation. The purpose of drawing them out separately here is to express the explicit attention given to each of these expectations while allowing students to choose the science content addressed during the investigation.

The second section of the reflection worksheet asked students to identify the NGSS scientific practice they felt they most developed as a result of this inquiry investigation, followed by a question asking which other scientific practices they felt improved from their participation. This section read:

Explain what scientific practice or skill you think you **most developed** during your inquiry investigation? How did you improve your skill as a result of this project? Please be specific and detailed.

Scientific practices include:

1. Asking questions

2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematical and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Describe how the inquiry investigation experience helped you improve in the other scientific practices. Again, please be specific and explain in detail.

Responses to these questions were tallied according to identified scientific practices. The total number of students identifying each practice is listed in Table 15.

Table 15

Students Self-Reporting of Developed and Improved Scientific Practices (n=45)

Scientific Practice	Most Developed	Improved
Asking Questions	7	7
Developing and Using Models	1	1
Planning and carrying out investigations	9	8
Analyzing and interpreting data	13	4
Using mathematical and computational thinking	0	3
Constructing explanations	3	9
Engaging in argument from evidence	3	4
Obtaining, evaluating, and communicating information	9	7

In addition to the numerical data above, written explanations from the students were collected. The written responses from the students in the two selected groups are below:

Aiden: "Over the course of this project, I think I learned a lot about how to efficiently follow a procedure, and carry out the things we make. Before this project, all science labs included a procedure and question given to you. I learned how to make a question and a procedure and taking the steps to make the project a success. I thought it would be difficult to actually build the panels, but through design and planning we got it done." [chose SP3 as most developed]

Liam: "Planning and carrying out investigations – Before we started this I had no idea which project to choose. I also didn't know how to set up an experiment on my own. When we did this project it took a lot of work and we all participated in making this project work. It was especially hard because at first we didn't want to do it we wanted to do a filtration system." [chose SP3 as most developed]

Jackson: "Asking questions is one of the things that I worked on. I improved it when we went to take data and saw problems or wanted solutions." [chose #1 as most developed]

Sofia: "A scientific practice that I learned was analyzing and interpreting data, I improved this skill by seeing how to take data and reading the data that was on the waterproof book. Another way I improved is on taking data." [chose SP4 for most developed]

Isabella: "Asking question and we had to complete it with the time we had. Our question at first was just something we thought of but then our project sprung from it." [chose SP1 for most developed]

Valentina: "I think I developed analyzing and interpreting data during my inquiry investigation. To find out which roof was a better insulator we had to analyze the data to see which roof was closer to the air temperature. Sometimes the data wasn't significantly different and we had to really look to see which had less of a difference." [chose SP4 for most developed]

Aiden: "It helped us learn other scientific practices like asking questions and obtaining and communicating information. This project helped me ask questions and find the answers when we encountered problems, or saw abnormal results. This investigation helped us to be better at following a procedure over and over to get large amounts of data and how to show it as a graph. It also helped us to learn how to make conclusions off data, and to think of ways to improve. Finally, it

> helped us know how to apply math and logic to build a model and project we can get reliable data from." [Chose SP1, SP8, SP2, SP6, SP5 for improved]
>
> Liam: "The OLE investigation also helped me improve on constructing explanations. I really had no idea about how solar panels worked before we started. Once we got going on the project I realized that I was better able to explain it to people and it also made the project easier for me when I explained it." [chose SP6 for improved]
>
> Jackson: "It helped me in other practices when we measured temperature because temperature is measured in a lot of things." [not included in tally because specific practice not identified in student response]
>
> Sofia: "Inquiry investigation helped me improve planning and carrying my investigations by helping me see what I was going to do and what I was going to write like my analysis. It also helped me keep the data well. Another thing it helped me in is obtaining the information I will use for my background research and other thing I got to type up for OLE." [chose SP3, SP8 for improved]
>
> Isabella: "Constructing explanations the roofs we had to build we had to explain and include in the procedure. The roof building was really fun and that was one of my favorite parts." [chose SP6 for improved]
>
> Valentina: "The inquiry investigation helped me improve in planning and carrying out investigations because in the past I had only done science projects in a day or two. This project helped me learn how to plan and carry out an investigation. Also, I learned how to engage in arguments from evidence because Isabelle and I had to see from our data which one was a better insulator and we disagreed sometimes but with facts we came up with conclusions." [chose SP3 & SP7 for improved]

These responses, as well as the tallied information from the whole class, provided data to suggest students further developed their scientific practices through this experience in the OLE. Developing and using models was only mentioned by two students. This is curious to me because 13 of the 17 groups this year designed and/or built models to use during their inquiry investigations. Though this scientific practice is not exclusive to physical models, it is interesting to me that students did not connect their own work with physical models as a demonstration of developing or improving this scientific practice. The data collected does not allow for analysis of why students did not choose this practice when answering the above questions.

The final section of the reflection asked students:

> If you decided to become a science teacher, would you have your students do a similar learning activity in an outdoor learning environment? Why or why not? Explain.

41 students responded "Yes" and two responded they would not do this project. This suggests students found this experience to be beneficial and see its value as an educational component of a science classroom. Examples of explanatory responses are included for students in the two selected groups.

> Liam: "I will never become a teacher but I would have people do this experiment. Doing these projects taught us responsibility and how to work with other people. It also helped us to understand that when your project doesn't work you can work and keep trying to fix it or get data with what you have."
>
> Jackson: "I would have my students doing a project because it was really fun. It also helped me understand heat better. And it also helps to get to know your group mates more."
>
> Aiden: "I definitely would let my students do something like this for many reasons. It helps them form a question and procedure and carry through with the procedures from using their own background research. It helps them to use ideas of their own rather than following someone else's question and procedure. It can be helpful to go collect data every week so the students are responsible at getting data. It also helps develop skills of drawing conclusions."
>
> Sofia: "If I was a science teacher I would have my students go out and investigate and make a project that involves the outdoor 'cause I think it will help them learn more of how we can help the environment in many ways, also they can learn something new, and it will also help them practice some skills they will need for the future."

> Isabella: “If I become a science teacher I would have them do this because one it relates to the real world. Second because it lets us be able to do something other than book work and class discussions. I’m glad I was able to do this project because I got to experience what my dad does and I got to try new things.”
>
> Valentina: “Yes, I would have my students do a similar learning activity. This activity could help them get a deep understanding with a hands-on experiment. They also learn to make their own mistakes and learn from them. My students would also learn how to communicate with others in a group. This experiment would also help them learn different aspects of earth science.”

The responses above indicate students perceive the OLE experiences as meaningful to the extent that 41 of 43 students that responded to this question would have their own students perform similar investigations in an OLE. The written reasons as to why helped me understand the students’ perceived benefits of this experience. Students in the two selected groups mentioned learning responsibility and learning from mistakes, having fun, learning in a new way different from classroom learning, ownership of the projects, environmental awareness, real-world connection, hands-on experience, communication skills, and familial connections. These benefits speak to the instructional design. The length of the investigations afforded students the opportunity to learn from their mistakes and make adjustments as they deemed necessary. Requirement of communication components such as the discourse opportunities and the panel presentations appear to be another valued part of the instructional design. The question was specific to taking students outside. The responses did not require a comparison of inside to outside learning, however, some responses did compare by suggesting the preference of learning in the manner presented here over learning in a classroom through textbooks and class discussions. Finally, having fun is an important part of learning.

Answering the research questions. The data gathered during this research project was used to answer the three research questions. The written artifacts and discourse recordings provided data to answer the first research question, “In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?" The written reflections offer student perceptions of their own development and improvement in scientific practices as a result of the OLE experience. Though this is helpful information to have, it does not directly answer the question about their connection between the scientific practice and perceiving the OLE experience as meaningful. This information provides insight about what scientific practices the students perceived themselves developing or improving during the OLE experience. Given the data from the focus groups indicative of meaningful experiences in the OLE and the whole class responses to the development of NGSS scientific practices, these two data sources together answer the question. The written reports in particular provide evidence to answer this question about scientific practices in the OLE . The conclusion sections of the written laboratory reports provided the greatest amount of coded material. In those sections, the coded segments indicated students thinking in a meaningful way in terms of epistemic considerations as they participated in the NGSS scientific practices. Because of the design of this curriculum component, it would not be possible to separate a learning event from the scientific practices performed during this investigation. The instructional design purposefully included opportunities to engage in each of the eight scientific practices. It is interesting to note the students did not perceive their own development or improvement in developing and using models, especially given at least 13 of the groups clearly participated in that scientific practice through the design and construction of physical models. This suggests students may not be aware of their own participation in learning events as they are defined by the scientific education community (Osborne and Freyberg, 1985). Science class often overemphasizes teaching students about scientific practices at the expense of supporting their thinking about science (Driver, Newton, & Osborne, 2000). The lack of recognition of participating in the SP of modeling suggests teaching efforts directed at defining scientific practices may not translate to recognition of participation in the same practice.

The written reflections from the whole class were used to answer the second research question, "What kinds of knowledge are students constructing as they engage in the OLE?" These responses generated a list of science content, non-science content, personal, and social skills students self-reported as learning from this experience. The science content learned through the investigations varied from characteristics of water quality (pH, nitrates, dissolved oxygen) to benefits and needs of worms, and a plethora of topics in between. The written reports from the students in the selected groups further identified specific aspects of science they learned through this experience. In every inquiry investigation, students demonstrated learning through discussion groups, free writes, lab reports, reflections, and panel presentations.

A third research question evolved as this study developed. Use of the EIP framework aided me in narrowing an approach to determining a way to classify student thinking as *meaningful*. The four epistemic considerations provided that approach. However, these considerations were difficult to define in a highly reliable way between researchers in the open-ended, student-defined inquiry project in an OLE. The rich and complex discussions generated by students created an amount of overlap between considerations when analyzing a transcript or written artifact. Efforts to achieve a common understanding with other experts, itself generated rich discussions about the value of these categorical considerations in framing an epistemology. There was agreement that the framework was useful in terms of classifying student thinking as classroom practice oriented or indicative of scientific science-making while engaging in classroom practice goals. There was also agreement, that no matter how difficult it may be to reach inter-rater agreement on how a specific, transcribed excerpt fit one particular consideration (e.g. Nature), these considerations were evident if somewhat overlapping and shed light on student approaches to building knowledge. For example, there was agreement that Nature as one of the considerations, was the most common element observed.

The third research question, then, builds on theory of student thinking in science education: What was learned by using the EIP framework to investigate this experience? The framework provided a means to identify student thinking as meaningful beyond classroom task fulfillment. This research provides evidence to suggest a hierarchy or progression of student thinking through these considerations. This hierarchy has not been previously established in the EIP literature, though the suggestion that students work through epistemological considerations in a progression, where the earlier considerations are more accessible than the later ones, has implications for science teachers and curriculum developers. Specifically, for students to be able to develop their thinking toward a particular task or learning experience, there must be provided tasks that require and allow time for student thinking to develop in particular ways. For example, the data suggesting that students spent more time thinking and talking about what constitutes a knowledge product than generalizing (or transferring) that knowledge to other related ideas or situations. This elevates the importance of curricular and instructional scaffolding that supports student discourse around the “nature” of the evidence they generate during an investigation and what other ideas or concepts might be brought to bear on the investigation. If, as these data suggest, Justification precedes Generality and Audience in its accessibility to student epistemological efforts, then curricular and instructional scaffolding can be most productive in strengthening the thinking that students are beginning to engage in and help extend it appropriately. These results lend support in being more concrete in recognizing Vygotsky’s Zone of Proximal Development (Vygotsky, 1962) by examining a progression in epistemological considerations that are possible stepping stones in a zone of proximal development.

The OLE experience provides a new arena for employing the EIP framework to science education research. This framework and the study presented here focus on student epistemologies. The data presented helps researchers think about how students use the OLE experience to learn science, as well as other lessons related both to science and classroom work as seen in their written reflections. Students engaged in the OLE as a means to build knowledge. I used the EIP framework to build a meta-knowledge, that is knowledge about the framework, its use in understanding and classifying student thinking in an OLE, and its advancement with the potential inclusion of a hierarchy or progression of student thinking over time.

Chapter 5: Discussion

Summary of Project

Improved understanding of students' knowledge construction while engaged in an outdoor learning environment (OLE) can help improve theory about student's knowledge building work in science. Additionally, improved understanding of student thinking can help teachers, administrators, and policy makers understand how to structure better contexts for learning involving scientific practices. Using the *Epistemologies in Practice* (EIP) framework developed by Berland et al. (2015), this research provides descriptive evidence of student's epistemological moves and science practices as they engage in an inquiry investigation in an OLE on campus. This study suggests that there may be a productive hierarchy or progression in the epistemological considerations that students use in building knowledge.

The research presented in this paper centers on student thinking during an instructional component of an Earth Science class at the middle school level. This component, inquiry investigations in an outdoor learning environment, was established five years ago and has evolved each year to improve and meet the needs of current students. The teacher involved in this research is also the researcher. Having had five years of experience with this curriculum, and being the developer of the curriculum, increased my confidence in presenting the inquiry investigations to this year's students.

The students participating in this research attend a parochial school in the Pacific Northwest. All students in the 8th grade science class (52 students) participated in the OLE experience, the focus of this research. The instructional design of the curriculum provided students a six-month long inquiry investigation opportunity. NGSS scientific practices were embedded within the curriculum and developed alongside science content chosen by the student groups. Data collection for the inquiry investigations took place in the OLE on campus for 20 weeks. Written components of the experience and oral presentations occurred within the school building. Students produced written artifacts in the form of free-write journal entries, inquiry investigation reports, and reflections. Discourse events were recorded. These included audio recordings of discourse within student groups during data collection for seven weeks and video recordings of final presentations to an adult panel.

The data collected consisted of written artifacts (free-write journal entries, inquiry investigation reports, and reflections) and discourse from all students in the class. 52 students enrolled in the class and 46 of them consented to be part of this research. Analysis of the post-investigation reflections included written responses from all consenting students in the class (N=46), while analysis of the free-write journal entries and inquiry investigation reports focused on two select groups (n=6). Students self-selected groups creating 17 total groups in the class, two of which became the focus of this current study. Discourse events were recorded during the last seven data collection days, group conclusion time, and final presentations with an adult panel audience. The framework of this study is complex and requires an interpretive process reliant on heavy inferences. As such, discourse events were recorded and then transcribed for two selected inquiry investigation groups, each with three members. Analysis focused on these two groups to enable the deeper analysis of student thinking around each of the epistemic considerations evaluated in this study. I chose these groups based on scores on standardized tests completed in October (see Tables 6 and 7). Each group chosen had a student with a high, middle, or low score on the reading or mathematics standardized tests completed in October, 2015. This criterion for group selection reduced potential for researcher bias (as described in chapter 3).

Three research questions guided this study:

1. In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?
2. What kinds of knowledge are students constructing as they engage in the OLE?
3. What was learned by using the EIP framework to investigate this OLE experience?

Classifying Student Thinking

Allowing students to participate in inquiry investigations, with opportunities for them to make choices and design their own experiences, increases the meaningfulness of the learning task (NRC, 2012; Waite, 2011). The inquiry investigations are a component of the classroom curriculum and students respond to this kind of instruction partly by thinking toward the goals and aims of the classroom. However, in addition to thinking about the activity in terms of classroom goals, students begin to think about their actions and decisions in terms of scientific sense-making goals. The cogitation of the inquiry investigations being part of the science class does not disappear when students think of their work in terms of scientific sense-making. Instead, students begin to think with goals consistent of the science community *as they engage* in the work as a student. By meaningful, then, I mean students are thinking with the goals of the classroom and the science community in the same experience. In this way, the knowledge product they create holds meaning for them beyond satisfying a requirement of the teacher. In all considerations, students' thinking indicated meaningful use more often than classroom practice when all data points are considered together (see Table 14).

Research Question 1: In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences?

This study centered on the use of an OLE as the means by which students engaged in scientific practices through an inquiry investigation. Using the EIP framework as a lens to examine student thinking, this study links engagement in scientific practices in an OLE through the design of inquiry. Inquiry may be a new experience in school for some students. Aiden's reflection speaks directly to this as he said, "Before this project, all science labs included a procedure and question given to you. I learned how to make a question and a procedure and taking the steps to make the project a success." Students appreciated the opportunity to design their own investigations and to learn from their mistakes, an attribute mentioned in several reflections. The intent of including scientific inquiry in school was to provide students opportunities to explore as scientists – asking questions, seeking answers, and making sense of the data they collect.

Unfortunately, as Aiden's remark suggests, this type of inquiry is not what students experience in the science classroom. Instead, they are given someone else's question to answer, or provided steps to follow to find "the answer." The OLE experience becomes meaningful for these students because they are engaging in their learning by participating in inquiry. The benefits of this are highlighted in comments like Jackson's reflection, "I learned that science is not boring like I thought it was . . . I learned that I like science a lot."

An important component of inquiry in an OLE is student choice and interest. The main intent of science enactment in any inquiry-type activity is to allow students ownership of their learning. "From an epistemological perspective, inquiry is simply the process of doing science… An understanding of the epistemological frame of inquiry will help students do it better" (Sandoval, 2005, p. 636-637). Inquiry provides the opportunity for students to engage in doing science, an overarching goal of the NGSS. The OLE inquiry investigations embedded the scientific practices described in NGSS. NGSS encourages and expects students to become proficient in the practices of science. "Students learn science in large part through their active involvement in the practices of science" (NRC, 2012). As demonstrated in this research, the OLE offered an authentic situation to embed all of the scientific practices into a science learning activity. By using the OLE, I was able to observe the student thinking through analysis of EIP as they engaged in scientific practices.

The questions asked by students (SP1) and the inquiry choices made in this research study are often borne from personal interests of the students. Engaging students in science through the use of personal interest has been demonstrated to be effective for all groups of students, particularly those who generally feel disconnected from science when it disregards personal inclinations (NRC, 2012). Interest, experience and enthusiasm are critical to the domain of science (NGSS Lead States, 2013). The importance of the connection to a personal interest was clear in Isabella's comments about understanding the importance of her father's job based on her investigation in the OLE. This personal interest led Isabella to a greater connection to the learning opportunity. Isabella came into the class in September with apprehension about this course – a preconceived notion that she would not like science this year. She shared several times through the investigation how being able to learn more about her father's job and being able to work with him during this project impacted her and pushed her to learn. The EIP framework allowed me to examine Isabella's approach to the learning activity to include thinking of an external audience, not only her father but also the people served by her father – anyone with a roof. Thinking about an external audience suggests Isabella was thinking beyond the immediate task and advancing through the EIP hierarchy discussed later in this chapter.

The written reflections offered student perceptions of their own development and improvement in scientific practices while in the OLE experience (see Table 15). Engagement in the practices improves the quality of student learning and helps make the content meaningful by engaging the learner in the act of doing science, rather than memorizing pieces of information handed down. According to Osborne (2014), "The primary purpose of engaging in practice is to develop students' knowledge and understanding required by that practice, how that practice contributes to how we know what we know, and how that practice helps to build reliable knowledge" (p. 189). Natural settings found in the outdoors provide opportunities for students to engage in the practices. This engagement was perceived at different levels for the students. The reflection responses indicated students gauged their own development and improvement in the practices. Interestingly, different students perceived themselves progressing in different practices. Though analyzing and interpreting data was the most frequently noted practice, all of the practices were noted by at least one student, and usually more, as developed or improved while in the OLE experience (see Table 15).

The scientific practice most often cited in student reflections as the most developed was analyzing and interpreting data (13 of 43 students) followed by planning and carrying out investigations, and obtaining, evaluating, and communicating information, each cited by nine students (see Table 15). The instructional design provided opportunities for students to develop the expectations (see Appendix D) at the 6^{th}-8^{th} grade level for these scientific practices. Constructing explanations was most frequently cited as the most improved scientific practice (for nine of 43 students).

Aiden’s explanatory response to this question provided evidence of improvement in multiple scientific practices, including constructing explanations:

> “It helped us learn other scientific practices like asking questions and obtaining and communicating information. This project helped me ask questions and find the answers when we encountered problems, or saw abnormal results. This investigation helped us to be better at following a procedure over and over to get large amounts of data and how to show it as a graph. It also helped us to learn how to make conclusions off data, and to think of ways to improve. Finally, it helped us know how to apply math and logic to build a model and project we can get reliable data from.”

Information from the students’ reflections provides insight about what scientific practices the students perceived themselves developing or improving during the OLE experience. Given the data from the focus groups indicative of meaningful experiences in the OLE and the whole class responses to the development of NGSS scientific practices, these two data sources together answer the first research question: In what ways does participation in scientific practices in the OLE lead to meaningful learning experiences? The written reports in particular provide evidence to answer this question. Isabella’s conclusion provided evidence of meaningful use in terms of thinking about her end result:

> “. . . if I were to do this project again I would maybe have had more locations and more types of roofing material and picked a spot where it both had soil to take temperature because the roof serves as a barrier between the air and the soil also I would have also built some sort of small house structure so that the air could be more trapped.” [NM]

This segment of her conclusion demonstrates Isabella’s thinking about the areas of the investigation she could have done differently and includes an explanation of why those adjustments would improve the investigation. The inclusion of an explanation for her choices indicates meaningful use. Using the EIP framework, the written reports provided instances of student thinking toward a science sense-making goal in all four epistemic considerations, suggesting meaningful experiences occurred for these students through participation in the scientific practices.

It is interesting to note the students did not perceive their own development or improvement in developing and using models, especially given at least 13 of the groups clearly participated in that scientific practice through the design, construction, and use of physical models. Only one student indicated this scientific practice as most developed and Aiden was the only student to indicate this scientific practice improved for him. This suggests students may not be aware of their own participation in learning events as they are defined by the scientific education community. I suggest that although students do not connect their engagement with the terminology, they are engaged in the SP of modeling. This is likely true with other SPs; students participate in the practice whether or not they can identify or define the practice in the same terms as science education researchers. At this level of science learning it is far more important that students engage in the SPs than to be able to recognize the labels as indicated in the NGSS. It is a natural role of teachers to help students use the language of science and scientific practices as part of instruction but the use of this terminology is not always of high importance at this stage. Based on this current study, student thinking analyzed using the EIP framework indicates students engaged in these practices were thinking with a goal of scientific sense-making while pursuing the goals of the classroom activity - *meaningful use*.

As the scientific practices become integrated into science classrooms from adoption of NGSS, teachers should consider how they implement curricular strategies to engage students in learning science content while engaging in the practices. Students will not benefit from their inclusion in the classroom if the practices become the content themselves. In other words, teaching students “scientists do this” loses the intent of including the practices in the standards. Instead teachers design opportunities for students to learn content while engaging in the practices, an opportunity that will encourage thinking in a meaningful way – an integration of the goals of the classroom with those of scientific sense-making. Inquiry investigations in an OLE is one way of providing those opportunities for students.

This study highlights that students engaged in scientific practices apply science in meaningful ways. "The integration of rigorous content and application reflects how science and engineering [are] practiced in the real world" (NGSS Lead States, 2013).

When students engage in authentic practice, particularly in science outside, they find the concepts learned in the classroom to be real and believable, not suspect out of a textbook (Waite, 2011). Outdoor learning provides an authentic, real-world context for science content learning. In this research study, students, like scientists and engineers, engaged in real, authentic science outside, and learned science content through engaging in scientific practices.

Research Question 2: What kinds of knowledge are students constructing as they engage in the OLE?

Though scientific practices were explicitly addressed in the curriculum of the OLE experience, science content varied between groups. As expected in NGSS, content and practice were intertwined in the individual OLE inquiry investigations.

The written reflections from the whole class (N=46) were used to answer the second research question, “What kinds of knowledge are students constructing as they engage in the OLE?” These responses generated a list of science content, non-science content, personal, and social skills students self-reported as learning from this experience. It is noteworthy that students were able to identify relevant content correctly associated with the projects they designed. While it was self-report and no specific measures were used to assess content learned, the transcripts and written artifacts are persuasive in the coherent use of science language in relation to the inquiry projects. The written reports from the students in the selected groups (n=6) further identified specific aspects of science they learned through this experience. The Roof Temperatures group learned about thermodynamics, the effect of color on heat absorption, information about weather, data collection and analysis methods, team work, and communication skills. The Solar Heater group included reference to learning those same topics, as well as learning about the solar panel and solar heater industries, photovoltaic cells, properties of the materials they chose, and how to problem solve. In every inquiry investigation, science content was learned, though the specific content depended on the designed investigation.

The OLE takes school science and brings it outside. By doing so, students connect the content of their learning to a place and time – out of the abstract and into a personal experience. Development and use of an OLE is difficult. Many teachers believe these experiences take too much time, particularly in schools with an emphasis on preparing students for standardized tests (DiBiase & McDonald, 2015). Teachers are also concerned with the safety of students and their ability to manage student behaviors in an open area. Administrators also perceive risks to students when they leave the confinement of the classroom. The weather plays its own role in hindering outdoor experiences. In my own experience teaching using an OLE, I have witnessed all of these fears and concerns from administration, parents, and students as well. However, this research study provided evidence for how students make meaning from an OLE. Many students have only experienced school science in a classroom, through notes, textbooks, worksheets, and pre-determined laboratory exercises. In many of these cases, the content belongs to the activity – the textbook holds the answers to the worksheet, the notes are the teacher's thoughts and understandings, and a laboratory experiment has a known solution. In each of these classroom-based science activities, the content to be learned may be perceived as existing outside of their experience. This may be true even where students are engaged in so-called "bench" science using unfamiliar instruments. There are good reasons for engaging students in bench science but an OLE provides a different approach for student knowledge building work. The content is not pre-determined and somewhere to be found, the learning develops *through* the experience and connects to the environment in which the learning activity takes place. Students construct their learning and develop content knowledge in the process.

The OLE provided a context for learning science different from previous experiences for these students. Barker (2005) evidenced in his research that providing learning opportunities in a novel environment, outside doing field-work rather than in a classroom, alters the process of learning and increases the motivation of the learner. Outdoor experiences provide the context for science content to be realized and constructed into knowledge (Giamellaro, 2014). The inquiry investigations in this research study provide evidence of content learning and development of scientific practices in an outdoor context, the OLE. The written artifacts and discourse events suggest students' thinking about the purpose or end result of their investigation, and the data being collected toward those ends, progressed over time from instances of classroom practice thinking toward more instances of inclusion of scientific sense-making.

The span of time of the OLE projects appears to be a significant component in terms of the progression of student thinking. As shown by Braund and Reiss (2004), students participating in outdoor experiences have been shown to change their attitudes about science and increase the value given to learning science. The benefits of the outdoor experience are most apparent when schools embed the curriculum with long-term outdoor experiences and closely link those experiences to the classroom (Ofsted, 2008). The instructional design of the OLE curriculum provides connection between the outdoor learning and the science classroom, particularly as students worked to analyze their data and write reports. The progression of the free-write entries from before the initial data analysis to those written after the analysis show a shift in student thinking from classroom practice before analysis to meaningful use afterward (see Table 11). This shift relied on the connection between classroom and the outdoor experience while engaging in scientific practices. When tasked with viewing their data in order to write an analysis, the approach to the data and its use changed for the students as they made sense of the purpose of gathering data. This transformation took place in the classroom (or computer lab) using the data collected in the OLE. This represents one example of the explicit connection between classroom and the OLE, important for the development of student thinking.

Research Question 3: What was learned by using the EIP framework to investigate this OLE experience?

The third research question evolved as this study developed. Use of the EIP framework aided me in narrowing an approach to defining for this study a way to classify student thinking as *meaningful*. The four epistemic considerations provided that approach. However, these considerations were difficult to define in a highly reliable way between researchers. The amount of overlap between considerations when analyzing a transcript or written artifact played a part in the challenge of reaching agreement. The framework was useful, though, in terms of classifying student thinking as classroom practice oriented or indicative of scientific science-making while engaging in classroom practice goals. Future studies will examine validation of classification of student thinking in each of the epistemic considerations.

The third research question, then, builds on theory of student thinking in science education. The EIP framework provided a means to identify student thinking as meaningful beyond classroom task fulfillment. In this study, I examined whether students' thinking was meaningful within four considerations: Nature, Generality, Justification, and Audience. Written artifacts and discourse events were analyzed for evidence of *epistemic considerations* as described in Berland's et al. theory (2015). These were coded according to the consideration and whether it was presented as classroom practice or meaningful use. Again, meaningful use indicates evidence of students thinking with the goals of the classroom and the science community in the same experience. This research provides evidence of a hierarchy or progression of student thinking through these considerations. This hierarchy has not been previously established in the EIP literature, though its existence, if validated by further study, suggests implications for science teachers and curriculum developers. Specifically, for students to be able to develop their thinking toward a particular task or learning experience, they must be provided tasks that require and allow time for student thinking to develop. In his work to develop a framework of learning through outdoor experiences, Brody (2005) examined variables that influence this learning. His case study demonstrated meaningful learning occurs over time through direct experience, and this learning is context dependent, or connected to the environment in which it occurs. In the current study, time allowed students to progress from thinking mainly about the end result, to thinking about how the result might be justified, where it might apply in other situations, and who might benefit from this learning. For example, student thinking in the epistemic consideration of generality appeared in the first two free-write entries (9/28 and 10/13) but then was not evident again until December 10th, the ninth free-write entry opportunity. On that date, December 10th, a community member came to visit and assist the class with their investigations. At the end of the visit, the FWEs also included evidence of student thinking in terms of an external audience – the first time student thinking in terms of this consideration indicated meaningful use since the first FWE on September 28th. This shift in student thinking suggests time may have allowed them to develop their understandings about their investigations in such a way that the introduction of an outsider encouraged FWEs to include their thinking in terms of scientific sense-making. In other words, they needed time to develop their thinking to the point that it could be expressed in writing and appeared in their writing once an external audience provided the need for communication.

The amount of time spent performing the inquiry investigations allowed students' thinking to progress from goals of classroom practice to include scientific sense-making. Time also allowed their thinking to use their epistemic resources in multiple considerations. The audience consideration appeared in their writing more frequently toward the middle of the investigation, while the generality consideration was missing from their artifacts until much later in the investigation. The factor of time encouraged students to go beyond thinking about finding an answer to a question, to thinking about how the answer and the process would be useful to others and in other ways than the task at hand. Both of these approaches to thinking suggest a deeper commitment to the learning task and a deeper connection through the context of the learning environment. In this way, this study suggests student thinking in the four epistemic considerations occurs along a hierarchy. This hierarchy, as discussed next, provides information to teachers and curriculum developers about the opportunities necessary to allow time for student thinking to develop. Initially, student thinking centers on seeking an answer (Nature), then progresses to interpreting the data needed to support the answer (Justification), followed by consideration of how the knowledge product can be used elsewhere (Generality) and by whom (Audience).

The epistemic consideration of Nature – What kind of answer should our knowledge product provide? – was coded most frequently, especially in the written artifacts. It seems logical this consideration would be the most frequently observed. Students approach learning tasks with the goal of finding an answer. The inquiry investigation was a learning task where students developed their own questions. The starting point of a question implies an ending point of an answer. Therefore, evidence that students thought about the answer while engaging in the inquiry investigations makes sense. What distinguishes classroom practice type engagement from meaningful engagement in this consideration is the thinking about what constitutes an answer. In the free-write entries, student thinking indicated, especially earlier in the investigation, consideration of an answer as showing or describing the outcome. For example, on November 12th, Sofia wrote:

> S1112: “What I learned today is that our data was more cold.” [Code: NC]

This type of thinking suggests goals of classroom practice. Sofia is relaying the data indicated it was cold, a simple description of results from the day’s learning task. To go beyond that goal, students needed to seek an explanation of how or why an outcome was reported. As the investigations progressed from initial data collection to analysis and through drawing conclusions, evidence suggests student thinking about the learning activity in a manner consistent with scientific sense-making. For example, on February 5th, Sofia wrote:

> S0205: “Today the numbers change by a lot specially in Iko and Treetop. I think it has to do [with] how the weather is going. [Code: NM]

This segment suggests Sofia approaching the learning activity with a goal of scientific sense-making – connecting the day’s data collection with an explanation of why the data was changing – coded as meaningful use in this study. This demonstrates an advancement from her November 12th entry to thinking about the weather as a reason for the changes in the data.

Throughout the dataset, students were most commonly found to be discussing measured results or other observations in terms that implied what they thought a “knowledge product” was and by contrast what was not a knowledge product, what Berland et al. (2015) called the Nature consideration. The analysis suggests that students spent more time discussing what they thought was useful and meaningful knowledge than with thinking about what justified this knowledge, how this knowledge connected to other ideas, or with the audience to whom they would explain this knowledge. The counts of instances of each consideration suggest that Justification of ideas and decision making follows next in the hierarchy.

The Justification consideration – How do we justify the ideas in our knowledge products? – follows the Nature consideration in this proposed hierarchy. First, students think about what an appropriate knowledge product will look like, then they think about how to justify that outcome, or justify the decisions made leading to that outcome. A portion of the conversation between the Solar Heater group provided evidence of Justification. Jackson justifies the group's thinking about the effect of black color on temperature by comparing temperature differences on the sunny days. Aiden continues this line of Justification and concludes there are similar results on cloudy days.

> J0330-1: "You can definitely see it when we had the sunny days because it was like a 30-degree difference between the two, and a 50-degree difference between the outside temperature and the black solar heater. The black solar heater always got to like 90 to 100 degrees while the other one stayed at lower 70s."
>
> L0330-2/A0330-3: "Yeah, yeah."
>
> A0330-4: "But, you could also see the, um, even though those are our extremes, you could also see it even on our regular days."
>
> L0330-3: "When it wasn't sunny."

In this discourse event, all three group members engage in the conversation and agree with the interpretation of the data. This portion of the conversation was coded as Justification meaningful because the conclusions being developed by the group rely on the interpretation from the students. The conversation suggests the group members do not expect the data alone to justify their conclusions, but instead offer their interpretation as support, or justification, for their conclusion.

Evidence of this consideration appeared in all data sources in this study. Free-write entries suggested student thinking in terms of classroom practice with similar frequency as scientific sense-making (see Table 14). Indications of the data being enough to justify a conclusion or decision made indicated student thinking geared toward classroom practice. Students' expressions of further explanation of how the data was used to draw a conclusion, or why they made specific decisions in their investigation, suggested thinking inclusive of scientific sense-making goals. Data from discourse events and the written reports suggest students thinking about their investigations included a scientific sense-making goal more often than a classroom practice goal alone.

The epistemic consideration, "How does our knowledge product relate to other scientific phenomena and ideas?", referred to as the *Generality* consideration, was also seen throughout the inquiry investigations. Statements or discourse in this category were coded meaningful if they demonstrated one of two approaches: use of a general idea to make sense of their own work, or demonstration of their own work as applicable to more general instances. An example of Generality meaningful came from Aiden on February 3rd in his free-write entry:

> A0203: "In my research I talked about how each panel absorbs and retains heat differently. This information will be helpful."

In this entry, Aiden generalizes with reference to his background information. He explains his intention to use what he learned from his background information (general idea) to help him with his own project. Valentina provides an example of Generality meaningful through the second approach:

> V0928: "How does this help anyone in their daily lives?"

This question indicates Valentina thinking about her investigation as it relates to other people. This was coded as meaningful in the categories of Audience (considering an audience beyond the classroom) and Generality (thinking about the usefulness of the potential outcome for others). Artifacts and discourse included 45 instances of students thinking in terms of scientific sense-making, while only one instance of classroom practice. This is a very interesting result and warrants further studies into student thinking using the data set from this current study. If students' thinking progresses through the epistemic considerations in a hierarchy, then their thinking at that point in their learning activity would likely be beyond classroom practice alone. The data suggests their thinking, once at the level of considering Generality, includes scientific sense-making as they engage in a classroom-based learning activity.

The final epistemic consideration examined in this research was, "Who will use our knowledge products and how?", referred to as *Audience*. This consideration was the least coded of all four during the data collection discourse events. The criteria for a meaningful code for this consideration was thinking of an external audience or audience as collaborator. In Valentina's free-write entry noted previously (V0928), an external audience is considered in her thinking. Sofia also provided a statement indicative of meaningful use in the Audience consideration in her free-write entry on September 28th.

> S0928: "When we have a question about roofing we can ask people that know about roofing."

This statement was coded AM (Audience meaningful) as it indicates Sofia's consideration of an audience as collaborator. Though classroom practice was evident in the discourse and artifacts as well, the occurrence of meaningful use was greater, particularly as the investigations progressed through time.

A hierarchy does not suggest one consideration is more important than another. The Nature consideration may be the first epistemic resource students pull from as they begin a task. That does not imply using that resource is less significant than thinking about the intended audience of one's discoveries. On the contrary, it is necessary to consider what your knowledge product will be and how it will come to be as you begin any investigation. It is a continuation of that thinking that draws in consideration of how to justify your conclusions and decisions, how to understand and explain how your learning and process may be used by others and in other situations, and finally to consider who might want to know about your discoveries, who might benefit from these learnings. If a student is given 20 minutes to complete a worksheet from a textbook, the thinking likely will center on completing the task by finding the "right answers" in the book. This limits their potential for thinking about the connections between the science content in the worksheet and how it might be justified or applied outside the classroom. Teachers can provide opportunities to think in order to make sense of the world even when working on more didactic activities.

Implications

The findings in this research study are applicable to several audiences. Teachers, administrators and policy makers would benefit from examining the creation and implementation of an outdoor space for science learning. Implications one and two speak to the suggested benefits of OLEs and implications for schools in their design and inclusion in the curriculum. Implications three and four speak to teachers and curriculum developers as they would benefit from further understanding of students' use of epistemic considerations as they engage in educational activities. Finally, educational researchers would benefit from further exploration of the EIP framework and identification of a hierarchy as suggested by this research.

- Implication 1: If long-term, student-generated inquiry experiences result in student exercise of epistemological moves, then designs such as an OLE will result in greater student learning.
- Implication 2: If the context of an OLE provides students with a time and place to connect personally with content, then OLE can be a model for designing opportunities for students to engage in science learning through scientific practices.
- Implication 3: If students think in terms of epistemic considerations along a hierarchy, then teachers can use this progression to support knowledge building.
- Implication 4: If Nature is the most common epistemic consideration, then providing curricular strategies to promote student thinking in meaningful use scaffolds a start into deeper epistemological moves.

As decision makers in schools and school districts begin to examine implementation of NGSS for classrooms across the nation, understanding how scientific practices help students build knowledge becomes essential. The research in this study suggests the use of an OLE on campus provides a context for students to engage with science content and practices in a meaningful way. Though other venues exist for students to engage in science outdoors, such as through outdoor school and field trips, an OLE provides a familiar environment, easily accessible, with opportunities for multiple visits. The context of an OLE also allows for longer-term investigations to take place within a classroom's curriculum. This research suggests time is important in the progression of students' thinking through the epistemic considerations of the EIP framework, a result educational researchers should examine through further studies.

Further studies

The research in this paper gathered more data than was analyzed. This data could provide evidence for future studies with a different focus. Using part of the EIP framework, a study focused on the epistemic consideration of generality would provide evidence of how students see their work as meaningful in a broader scope. According to Chinn & Malhotra (2002), students are not often asked to generalize during inquiry activities. However, from the two groups of focus in this study, student thinking in terms of generality was observed 36 times. A further study should look at data from all of the students in terms of the generality consideration. This further study could provide information about what ways students generalize their learnings from an inquiry investigation outside. Thinking in this way indicates students making connections between their specific investigations to something beyond the immediate task. A study such as this would further develop the EIP framework.

Another study using the collected data in cooperation with the students in the study would be to examine their metacognition as the engaged in the inquiry investigations in the OLE. Uncovering whether they would agree with the interpretation of their thinking in terms of epistemic considerations would be of interest. Further, having been presented with an interpretation of their thinking, examining how this explicit account of their thinking changes future epistemic considerations would be of interest and could provide valuable information to teachers and researchers about the use and benefits of making thinking and metacognition explicit and part of the discourse of the classroom.

Use of the recording devices may have altered the inquiry experiences for students. Free-write entries in particular reference students' concerns and apprehension toward using these devices. It would be interesting to further study how introducing research tools such as the recording device alter the learning process for the students. In the current study, the recording devices were introduced as a means for the students to keep track of their own conversations in order to return to them later during analysis and conclusion discussions. However, the groups did not listen to their conversations after recording them and did not appear to see them as a beneficial tool for their investigations.

As such, a further study might uncover how tools of research such as recording devices, audio and video, alter student behaviors and thinking.

Inquiry investigations in the OLE have been implemented for the Earth Science class for five consecutive years. Though modifications have been made each successive year, the overall design of the curriculum remained consistent. The school in this study provides education to students through senior year. Therefore, many of the students of previous Earth Science classes that participated in the OLE curriculum continue in the same school. Access to these students provides an opportunity for a longitudinal study about the effects of the OLE experience. Interviews of the students could provide information about their perceptions of the inquiry investigations, what they found helpful or useful from that experience in later classes, and in what ways they perceived the investigations helping them develop their scientific practices.

The teacher in this study is an experienced teacher, both in the classroom and with the OLE inquiry investigation curriculum. A further study of interest would be to follow a novice teacher as she implements an inquiry investigation in an OLE. Inquiry investigations in an OLE provide one method for introducing and integrating NGSS scientific practices into an 8^{th} grade Earth Science curriculum. As NGSS is adopted across the nation, implementation in the classrooms may take various paths. A study to look at how SPs are integrated into existing curriculum, both by novice and experienced teachers, would provide information to curriculum developers and researchers about teaching practices in response to new mandates.

The OLE experience provides a new arena for employing the EIP framework to science education research. This framework and the study presented here focus on student epistemologies. The data presented helps researchers think about how students use the OLE experience to learn science, as well as other lessons as seen in their written reflections. Students engaged in the OLE as a means to build knowledge. I used the EIP framework to build knowledge, as well, to build knowledge about the framework, its use in understanding and classifying student thinking in an OLE, and its advancement with the potential inclusion of a hierarchy or progression of student thinking over time.

Bibliography

Bailey, L. H. (1909). *The nature-study idea: An interpretation of the new school-movement to put the young into relation and sympathy with nature* (3rd Ed.). New York: The Macmillan Company.

Barker, S. (2005). Student-centered ecology: authentic contexts and sustainable science. In McLoughlin, C. & Taji, A. (Eds.) *Teaching in the sciences: learner-centered approaches* (pp 9-25). New York: Food Products Press.

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, *72*(7), 30-33.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2015). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*. doi: 10.1002/tea.21257

Biological Sciences Curriculum Study. (2009). *The Biology Teacher's Handbook, 4th Edition*. Arlington, VA: NSTA Press.

Braund, M., & Reiss, M. J. (Eds.). (2004). *Learning science outside the classroom*. New York, NY: RoutledgeFalmer.

Brody, M. (2005). Learning in nature. *Environmental Education Research*, *11*(5), 603-621.

Capps, D. K., & Crawford, B. A. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education*, *24*(3), 497-526.

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*(13), 2195-2220.

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.

Comstock, A. B. (1918). *Handbook of nature-study for teachers and parents: based on the Cornell nature-study leaflets, with much additional material and many new illustrations*. Ithaca, NY: Comstock Publishing Company.

Department for Education and Skills (DfES). (2006). Learning outside the classroom manifesto.

Dhanapal, S., & Lim, C. C. Y. (2013, December). A comparative study of the impacts and students' perceptions of indoor and outdoor learning in the science classroom. In *Asia-Pacific Forum on Science Learning and Teaching*, *14*(2).

DiBiase, W., & McDonald, J. R. (2015). Science Teacher Attitudes Toward Inquiry-Based Teaching and Learning. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *88*(2), 29-38.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.

Duffy, T., & Cunningham, D. (1996). Constructivism: Implications for the design and delivery of instruction. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 170-198). New York: Macmillan.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(1), 268-291.

Fagerstam, E., & Blom, J. (2013). Learning biology and mathematics outdoors: effects and attitudes in a Swedish high school context. *Journal of Adventure Education & Outdoor Learning*, *13*(1), 56-75.

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education*, *30*, 1-32.

Garrison, J. (1995). Deweyan pragmatism and the epistemology of contemporary social constructivism. *American Educational Research Journal*, *32*(4), 716-740.

Giamellaro, M. (2014). Primary contextualization of science learning through immersion in content-rich settings. *International Journal of Science Education*, *36*(17), 2848-2871.

Hammer, D. & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences,* 12(1), 53-90.

Hermann & Miranda (2010) A template for open inquiry. *The Science Teacher, 77*(8), 26-30.

Herron, M. D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171-212.

Hodge, C. F. (1902). *Nature study and life*. Boston: Ginn & Company.

Jackman, W. S. (1894). *Nature study for the common schools*. New York: H. Holt and Company.

Jiang F., & McComas, W. F. (2015). The effects of inquiry teaching on student science achievement and attitudes: Evidence from propensity score analysis of PISA data. *International Journal of Science Education*, *37*(3), 554-576.

Kenney, J. L., Militana, H. P., & Donohue, M. H. (2003). Helping teachers to use their school's backyard as an outdoor classroom: A report on the watershed learning center program. *The Journal of Environmental Education*, *35*(1), 18-26.

Lebak, K. (2015). Unpacking the Complex Relationship Between Beliefs, Practice, and Change Related to Inquiry-Based Instruction of One Science Teacher. *Journal of Science Teacher Education*, *26*(8), 695-713.

Lehrer, R., Schauble, L., & Lucas, D. (2008). Supporting development of the epistemology of inquiry. *Cognitive development*, *23*(4), 512-529.

Lieberman, G. A., & Hoody, L. L. (1998). Closing the achievement gap. *State Education and Environment Roundtable Report*.

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.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In *Examining pedagogical content knowledge* (pp. 95-132). Springer Netherlands.

Malone, K. (2008). Every Experience Matters: An evidence based research report on the role of learning outside the classroom for children's whole development from birth to eighteen years. *Report commissioned by Farming and Countryside Education for UK Department Children, School and Families,* Wollongong, Australia.

Marx, R., Blumenfeld, P., Krajcik, J., & Soloway, E. (1997). Enacting Project-Based Science. *The elementary school journal*, 97(4), 341-358.

Maxwell, J. (2013). *Qualitative research design: An interactive approach* (3rd ed.). Los Angeles, CA: Sage.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, set, science. Putting research to work in K-8 science classrooms.* Washington, DC: National Academies Press.

Morag, O., & Tal, T. (2012). Assessing learning in the outdoors with the field trip in natural environments (FiNE) framework. *International Journal of Science Education*, *34*(5), 745-777.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press. doi:10.17226/13165.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, DC: The National Academies Press. doi:10.17226/9596

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Office for Standards in Education (Ofsted). (2008). *Learning outside the classroom.* Retrieved from http://www.ofsted.gov.uk/resources/learning-outside-classroom

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, *25*(2), 177-196.

Osborne, R., & Freyberg, P. (1985). *Learning in Science. The Implications of Children's Science*. New Hampshire: Heinemann Educational Books, Inc.

Rickinson, M., Dillon, J., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., Benefield, P. (2004). *A review of research on outdoor learning*. National Foundation for Educational Research and King's College.

Rios, J. M., & Brewer, J. (2014). Outdoor Education and Science Achievement. *Applied Environmental Education & Communication*, *13*(4), 234-240.

Russ, R. S. (2014). Epistemology of Science vs. Epistemology for Science. *Science Education*, *98*(3), 388-396.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634-656.

Sandoval, W. A. (2012). Situating epistemological development. In *The future of learning: Proceedings of the 10th international conference of the learning sciences.* Sydney, Australia: International Society of the Learning Sciences.

Sandoval, W. (2014). Science education's need for a theory of epistemological development. *Science Education*, *98*(3), 383-387.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*(3), 345-372.

Schwartz, D. L. & Martin, T. (2004) Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction. *Cognition and Instruction, 22*, 129-184

Tal, T., & Dierking, L. D. (2014). Learning science in everyday life. *Journal of Research in Science Teaching*, *51*(3), 251-259.

Tan, E., & Barton, A. C. (2008). Unpacking science for all through the lens of identities-in-practice: The stories of Amelia and Ginny. *Cultural Studies of Science Education*, *3*(1), 43-71.

Vygotsky, L. S. (1962). *Thought and Language.* (Eugenia Hanfmann & Gertrude Vakar, trans.). Cambridge, MA: The M.I.T. Press.

Waite, S. (2011). Teaching and learning outside the classroom: Personal values, alternative pedagogies and standards. *Education 3–13*, *39*(1), 65-82.

Waite, S. (2007). 'Memories are made of this': some reflections on outdoor learning and recall. *Education 3–13*, *35*(4), 333-347.

Weilbacher, M. (2009). The window into green. *Challenging the Whole Child: Reflections on Best Practices in Learning, Teaching, and Leadership*, 171.

Windschitl, M., Ryken, A. E., Tudor, M., Koehler, G. & Dvornich, K. (2007). A comparative model of field investigations: Aligning school science inquiry with the practices of contemporary science. *School Science and Mathematics 107*(1), 382-390.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941-967.

Yager R. E., & Akcay, H. (2010). The advantages of an inquiry approach for science instruction in middle grades. *School Science and Mathematics*, *110*(1), 5-12.

APPENDICES

Appendix A

Inquiry Investigation Report Guidelines

The intent of a laboratory report is to convey information to the reader about what you did, why you did it, and your results. As with all scientific endeavors, lab reports must be organized. As your teacher, I am asking you to write reports you turn into me in the following format. There is no one way to write an appropriate lab report, however, following this template will help me understand your experiment and results.

Question

Develop a question to guide your investigation. The entire lab experience will be designed to find answers to this question. When brainstorming ideas for a question, consider the following criteria: data gathered has to be measurable, the procedure must be ethical (no harm to animals or environment), the experiment needs to be doable within our garden and swale area, and the experiment must relate to Earth Science concepts.

Background Information

Include in this section information gathered about the problem you are investigating. The information in this section should answer the questions so what? Who cares? Why is this important? Why? Why? Why? What are the implications of this experiment? Prior knowledge and experience should be included as well. Begin your research with general information about the broad topic and then narrow the conversation to your particular question. What you learn during your research should lead you toward a logical, informed hypothesis. This section should be 3-5 pages and reference 4-6 sources.

Hypothesis

This is a statement about what you anticipate the outcome to be based on your background information. Include a sentence or two explaining why you expect the outcome proposed. The information in the statement must be testable.

Procedure

1. Write a procedure in step by step form. This is the HOW section of your report.
2. These are directions for conducting your experiment.
3. Detail, detail, detail
4. These steps should be written so anyone could follow them exactly and come up with comparable results.
5. There is no limit on the number of steps in a procedure.
6. Try the procedure after you write your steps. If it does not work, refine it and try again.

Appendix A (cont'd)

Data and Analysis

Gather data in the field using materials specific to your investigation. Photographs are useful for gathering data when used appropriately (same spot, time, focus, etc). Organize your data in a table or chart and create graphs to illustrate the information. Remember to include titles, labels, and units, as well as color when helpful.

After you have gathered and organized data, write an analysis. In this section, use words to describe the data shown. This is not a conclusion, but a chance to explain the data in words rather than charts and tables.

Conclusion

Write a page or two about your results. Be sure to state whether your hypothesis was supported or not. Remember not to use the term proven; a single experiment cannot prove or disprove anything. Refer back to your background information. This section ties the entire lab together. Discuss the implications of your findings, as well as the limits of your investigation. If I wanted to learn the results of someone's experiment and did not want to read the whole thing, this is the section I would turn to. Therefore, it needs to be thorough and to the point. Also, state any possible sources of error in your lab. Provide suggestions for what should be the next steps for this investigation and propose what the next group of students investigating this question should do.

Reflection

Tell me what you learned in this lab. This part of the lab report is for me only and can be written in first person. What could you have done differently? What could I have done differently? Include anything else you would like to share with me. Also, use this as a reflection (hence the name) on your own work and learning.

Appendix B

Background Research Round 2

You have been in your investigation for three months now. At this point, you have some new ideas or new questions about your inquiry. This is an opportunity for you to find some information to help you work through the new questions or ideas you have developed. You are not starting over; you are expanding your knowledge base.

First, read your original question, background information, and hypothesis. Take the time to read this completely before you begin round 2. As you read, make notes on your paper where you find something interesting, something confusing, or something missing.

Question

Has your original question changed? What is your current investigation meant to answer?

Background Information Part 2

Include in this section new information gathered about the problem you are investigating. The information in this section should answer the questions so what? Who cares? Why is this important? Why? Why? Why? What are the implications of this experiment? This is your chance to dig deeper into what you have been investigating in the field. This section should be at least two pages and reference 3 sources.

Bibliography

You must cite your sources. All websites and books you refer to in the background information must be included in your bibliography. Write down the website, name of the page, and date you accessed the information. Using someone else's work and not giving them credit is a type of plagiarism. Be sure to give credit where credit is due.

Appendix C

*Spaces from original document omitted to reduce space

Reflection

Tell me what you learned in this lab. This part of the lab report is for me only and can be written in first person. Use this as a reflection (hence the name) on your own work and learning.

Complete the following questions with **complete sentences** on this paper.

Explain 10 things you learned by participating in your inquiry investigation.

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

Explain what scientific practice or skill you think you **most developed** during your inquiry investigation? How did you improve your skill as a result of this project? Please be specific and detailed.

Scientific practices include:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematical and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Describe how the inquiry investigation experience helped you improve in the other scientific practices. Again, please be specific and explain in detail.

Write at least two sentences for each of the following prompts about this inquiry investigation:

What did you learn about yourself?
What did you learn about science in general?
What did you enjoy?
What do you wish you would have done differently?

Please write at least a paragraph to answer this last prompt.

If you decided to become a science teacher, would you have your students do a similar learning activity in an outdoor learning environment? Why or why not? Explain.

Appendix D

NGSS Scientific Practices Expectations for 6-8 grade students; bold statements were addressed in the instructional design

Asking questions and defining problems in 6–8 builds on K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.
• **Ask questions**
  o that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information.
  o **to identify and/or clarify evidence and/or the premise(s) of an argument.**
  o **to determine relationships between independent and dependent variables and relationships in models.**
  o to clarify and/or refine a model, an explanation, or an engineering problem.
  o **that require sufficient and appropriate empirical evidence to answer.**
  o **that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.**
  o that challenge the premise(s) of an argument or the interpretation of a data set.
• Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • **Evaluate limitations of a model for a proposed object or tool.** • **Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed.** • Use and/or develop a model of simple systems with uncertain and less predictable factors. • **Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.** • **Develop and/or use a model to predict and/or describe phenomena.** • **Develop a model to describe unobservable mechanisms.** • **Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.**

Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions. • **Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.** • **Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.** • **Evaluate the accuracy of various methods for collecting data.** • **Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.** • **Collect data about the performance of a proposed object, tool, process or system under a range of conditions.**
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • **Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.** • Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships. • Distinguish between causal and correlational relationships in data. • **Analyze and interpret data to provide evidence for phenomena.** • **Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible.** • **Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).** • **Analyze and interpret data to determine similarities and differences in findings.** • **Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria for success.**

Mathematical and computational thinking in 6–8 builds on K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • **Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.** • **Use mathematical representations to describe and/or support scientific conclusions and design solutions.** • Create algorithms (a series of ordered steps) to solve a problem. • Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems. • Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.
Constructing explanations and designing solutions in 6–8 builds on K– 5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • **Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.** • Construct an explanation using models or representations. • **Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.** • **Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real- world phenomena, examples, or events.** • **Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.** • **Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.** • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re- testing.

Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s). • Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • **Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail.** • **Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.** • Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.
Obtaining, evaluating, and communicating information in 6–8 builds on K–5 experiences and progresses to evaluating the merit and validity of ideas and methods. • **Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).** • **Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings.** • Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. • Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts. • **Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.**

Adapted from NGSS Appendix F