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The Struggle Is Real: Exploring Epistemological Change Through the Use of the Next Generation Science Standards in a High School Chemistry Classroom

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THE STRUGGLE IS REAL: EXPLORING EPISTEMOLOGICAL CHANGE THROUGH THE USE OF THE NEXT GENERATION SCIENCE STANDARDS IN A HIGH SCHOOL CHEMISTRY CLASSROOM

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DEDICATION

To my husband Tamer for continuing to be the best decision I have ever made, my children Adam and Sara for infusing my life with pure love, and my beloved Kitty, Cairo, and Cookie for changing my entire world.

Also, to my Dad Dr. Tawfik Nasr, who motivated me to continue his legacy of achievement and become the next surviving Dr. Nasr.

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ABSTRACT

This qualitative action research study examines my resistance to implementing the Next Generation Science Standards (NGSS) in my high school chemistry classroom, which is not uncommon among teachers. This resistance highlighted my conflicting epistemological beliefs, which, as a product of my own experiences as a student, among other factors, are deep-rooted and difficult to change. The dilemma for many science teachers, like me, is that the NGSS approaches the teaching of science in a constructivist manner, which attempts to move science instruction away from traditional pedagogies. Science teachers whose epistemological beliefs are rooted in traditional pedagogies may understand the inherent benefits of constructivist inquiry in the classroom, but struggle with how to implement it.

From data collected through observations, student artifacts, focus group interviews, and a personal teaching journal, this qualitative action research study investigated how NGSS-aligned learning tasks impacted my students' engagement and conceptual understanding, as well as my epistemological beliefs. While I found that a complete epistemological shift in favor of constructivist pedagogies was not possible without the use of traditional pedagogies to support the transition, I also learned that student struggle during constructivist learning tasks still results in demonstrated conceptual understanding and engagement. These findings have significant implications for both science teachers and science teacher educators as the findings may inspire those

science teachers wishing to enact epistemological change in favor of constructivism confidently and strategically, as well as improve science methods courses by establishing the need to expose pre-service teachers to the constructivist theory of learning and provide opportunities for them to practice using constructivist methods to prepare for 21st-century science teaching. Serving as a model for these audiences, my study illustrates a greater transition toward constructivist pedagogies, and an improved understanding of the true meaning of constructivist student learning in the context of the NGSS.

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LIST OF ABBREVIATIONS

AAAS... American Association for the Advancement of Science

ADI .... Argument Driven Inquiry

AP ....Advanced Placement

CCC...Cross Cutting Concept

CCSS..Common Core State Standards

CER...Claim Evidence Reasoning

CP.. College Preparatory

DCI...Disciplinary Core Idea

IBI ....Inquiry Based Instruction

ILD..Individual Learning Differences

NAEP ....National Assessment of Educational Progress

NGSS ....Next Generation Science Standards

NOS...Nature of Science

NRC .... National Research Council

NSTA ....National Science Teachers' Association

PD .... Professional Development

PE...Performance Expectation

PISA ....Program for International Student Assessment

RET ....Research Experience for Teachers

SEP...Science and Engineering Practice

STEM..Science Technology Engineering Mathematics

CHAPTER 1

INTRODUCTION

When the Next Generation Science Standards (NGSS) were adopted by my school prior to the start of the 2015-16 year, I viewed the impending change with equal parts trepidation and dread. I had just survived my first year as a high school chemistry teacher, during which I relied heavily on traditional pedagogies to teach my students the course content, and the thought of discarding my traditional lessons in favor of constructivist ones did not sound appealing. However, with my school's push to implement the NGSS, I had no choice but to embrace the change.

The National Research Council's (NRC, 2012) publication of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* preceded the development of the NGSS. The framework integrated three dimensions of science learning intended to aid all students with accessing science content through the *process* of science. In accordance with the framework (NRC, 2012) 26 lead states and 41 writers developed the NGSS, a set of K-12 science standards released for states to consider adopting (NGSS Lead States, 2013). Without any prior professional development experiences, I spent the summer before the 2015-16 school year scouring the internet to learn as much as possible about the NGSS and their implementation. During my online research, I noticed a prominent theme emerging. The NGSS required a significant shift in teaching such that students are provided opportunities not only to behave like scientists,

but also to drive their own scientific learning. I concluded that since the NGSS emphasized the need for students to construct their own scientific learning, I must provide them with opportunities to engage in activities that promoted the constructivist theory of learning.

When the school year started, I felt confident in my planned NGSS-aligned, inquiry-oriented activities. After my students and I settled in to the routine of school, I introduced my very first NGSS-aligned, inquiry-oriented activity by inviting students to use a computer simulation developed by Concord Consortium, wherein students collected evidence to make scientifically sound conclusions about the structure of the atom. When students submitted their inquiry responses, I was surprised at the dismal lack of understanding they demonstrated. I felt that the inquiry activity addressed the very essence of the NGSS, yet students did not demonstrate strong conceptual understandings; on the contrary, student misconceptions abounded. Moreover, as I was reading student responses, I noticed they seemed to decline in quality as the activity went on; in essence, it had appeared that students no longer felt engaged with the activity and perhaps were frustrated with their own struggle to understand the underlying principles. Even more discouraging, when it came time to provide students with a lecture-based presentation of the appropriate scientific concepts, I spent much of my time "reprogramming" students' conceptual understandings to ensure they were in fact scientifically sound.

Following this experience, I no longer felt confident in the NGSS. I could not help but believe that student learning would be more effective with direct instruction, a hallmark of traditional pedagogies. I believed that implementing the NGSS only resulted in confusion and significant struggle for students. I felt lost and confused, and I

desperately wanted to revert to the traditional pedagogies that had me in perceived control of what students learned. As I was still in my second year of teaching at the time, I was desperate to prove my effectiveness as a secondary chemistry teacher. I believed that my effectiveness was directly tied to the academic performance and engagement of my students, without struggle, and that my students would perform better if I presented the content in a traditional format. As a result, I returned to the familiarity of traditional lesson sequences and structured inquiry pedagogies (Zion & Mendelovici, 2012) rather than implementing learning activities that truly aligned to the NGSS.

Problem of Practice

Reverting to traditional teaching pedagogies gave rise to a significant problem of practice in my classroom. I struggled with how to implement the NGSS in my classroom when I believed that traditional pedagogies best promoted the conceptual learning of students. In essence, my beliefs regarding how students acquire knowledge, or my epistemological beliefs, were in direct conflict with the NGSS. My epistemological beliefs were deeply in favor of traditional pedagogies; however, I knew that as a science teacher in the state of California, I had no choice but to adopt the NGSS and implement constructivist, reform-based learning opportunities in my classroom. Not only did I feel pressured by state reforms, but I also felt pressure to conform to the constructivist pedagogies confidently employed by some of my colleagues. The pressure to conform was prominent at my school, a school with a strong culture of academic excellence, as those teachers who confidently implemented the NGSS did so in a seemingly seamless fashion, which also contributed to my feelings of inadequacy as a teacher. Feeling ineffective with my first experience implementing the NGSS in my classroom, coupled

with the impact of comparing myself to my colleagues led to a sense of helplessness and a desire to return to traditional pedagogies. I believed returning to traditional pedagogies would assure me my students were learning the necessary content of the course, and would also help me avoid feelings of inadequacy brought on by comparisons to my peers. Indeed, the desire to continue implementing traditional pedagogies despite the emergence of the constructivist NGSS led to significant professional and epistemological struggle.

For the purposes of this dissertation, reform-based science learning is defined as the opportunities for all students to engage in the "acquisition of scientific practices, understanding of core science ideas, and meaning-making from collaborative investigation of scientific questions" (Mangiante, 2018, p. 208), which aligns with the constructivist theory of learning. Furthermore, traditional pedagogies in the science classroom are defined as those pedagogies in which "teachers assume the overriding authority and responsibility in the classroom because they believe that they know the students' needs" (Khalaf, 2018, p. 549). Building on this definition, I believed traditional science teaching to reflect a classroom dynamic wherein the teacher provides direct instruction and structured inquiry to students to passively transmit science content from teacher to student. With these definitions in mind, my problem of practice centered on the need to provide my students with reform-based learning opportunities through the use of the NGSS in my classroom, in spite of my epistemological resistance due to my beliefs that traditional pedagogies are best suited for student learning in the science classroom.

Background Literature

My problem of practice to be investigated by way of a qualitative action research study approach is not unique. As a science teacher, in my second year of teaching, I

struggled to move away from traditional pedagogies and adopt an inquiry-based approach to teaching, and this experience mirrors the findings presented in a study by Roehrig and Luft (2004). As Roehrig and Luft (2004) describe the struggles to adopt inquiry-based approaches to teaching for early-career science teachers, Zion and Mendelovici (2012) assert that many science teachers, like me, are in fact aware of the inherent benefits of inquiry-oriented pedagogies. Though Roehrig and Luft's (2004) and Zion and Mendelovici's (2012) studies provide insight into the complexity of implementing inquiry-oriented pedagogies in the science classroom, there still exists significant teacher resistance to implementing these inquiry-oriented approaches as outlined in the NGSS. Often, this resistance is due to the complex relationship between teacher beliefs and practice (Lebak, 2015).

Practice may not Reflect Constructivist Beliefs

Savasci and Berlin (2012) examined the relationship between science teachers' beliefs and how those beliefs influence their implementation of constructivist pedagogies. As a science teacher who experienced significant student struggle during my early experience implementing the NGSS in my classroom, my beliefs regarding student capabilities and how students acquire knowledge influenced my decision to revert to traditional pedagogies. The findings of Savasci and Berlin's (2012) study indicate that while some teachers may hold strong opinions in favor of constructivist pedagogies, these teachers may not implement these pedagogies as often as their beliefs would suggest. They assert that many science teachers, like me, avoid the use of constructivist pedagogies in the classroom and instead rely on traditional methods of instruction for a variety of reasons. One such reason is teachers' strong desire to ensure that students are

well prepared for standardized assessments (Savasci & Berlin, 2012). Additionally, the science teachers studied indicated that how they perceived student ability and behavior were also factors that influenced their practice, which mirrors my personal experience implementing the NGSS with my own students. Together, the findings of Savasci and Berlin's (2012) study suggest that even with opinions that are in support of constructivism, many science teachers still hesitate to adopt constructivist pedagogies in the science classroom because of deep-rooted epistemological beliefs that conflict with their support of constructivism.

Beliefs Influence Practice

Taking a deeper dive with a single participant, Lebak (2015) conducted a qualitative case study to examine the influence an individual teacher's belief system has on the implementation of inquiry-based pedagogies in the science classroom. Though the teacher expressed beliefs that were in favor of constructivist pedagogies, the teacher's enacted practice "reflected a teacher-centered approach to instruction" (p. 709). The teacher's beliefs in favor of constructivism were ultimately trumped by beliefs regarding low student capability. In this regard, the teacher's "beliefs [regarding student capability] influenced practice, but [traditional] practice also served to reinforce and influence [those] beliefs" (Lebak, 2015, p. 709). This finding is particularly notable as it echoes my own experience initially implementing the NGSS and subsequently reverting to traditional pedagogies. Furthermore, as the teacher "worked to enact a more inquiry-based approach to science instruction" (Lebak, 2015, p. 710), his beliefs regarding low student capability were further strengthened. In effect, the teacher struggled to move away from traditional pedagogies because his epistemological beliefs overshadowed his

confidence to implement constructivist pedagogies in a way that negated those beliefs. Lebak's (2015) participants' struggle is similar to my own struggle to move toward constructivist pedagogies, as my struggle resulted from my students' struggling to construct their own conceptually correct understandings of the content.

Constructivist Implementation Requires Support

Like the teacher in Lebak's (2015) study, I was hesitant to implement constructivist pedagogies in my classroom for a variety of reasons, some of which were also reported in Haag and Megowan's (2015) study. Haag and Megowan (2015) studied secondary science teachers and found they were anxious about inadequate training, a lack of appropriate instructional resources, and a presumed lack of content knowledge to support their implementation of the NGSS in their classrooms. Additionally, most of these secondary science teachers felt uncomfortable specifically implementing the Science and Engineering Practice (SEP) component of the NGSS, which includes: asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information (Achieve, Inc., 2013). Of the secondary science teachers surveyed, about 66% stated that greater professional development is required to successfully integrate the SEPs into their classroom curricula (Haag & Megowan, 2015). In essence, without adequate professional development in the area of the SEPs specifically, many secondary science teachers felt their efforts to implement the NGSS in their classroom would not be successful (Haag & Megowan, 2015), and this finding is significant as I did not have any NGSS-specific

professional development prior to my first experience implementing the NGSS in my own classroom.

Reflection Facilitates Epistemological Transition

While making the transition from traditional to constructivist, inquiry-based pedagogies can be initially difficult for science teachers like me, reflecting on choices of pedagogical strategies and the criteria used to indicate student demonstration of understanding and engagement can ultimately promote teacher confidence (Gabriele & Joram, 2007; Lebak, 2015). In other words, a teacher in the process of implementing new teaching methods must regularly reflect on their practices to enhance their confidence and influence their epistemological beliefs, and in doing so encourage themselves to continue their efforts to enact pedagogical change in their classroom. Gabriele and Joram (2007) also indicate that teachers wishing to transition from traditional to reform-based teaching ought to be cognizant of the differing measures of student success that each approach to teaching emphasizes because the "typical sources of evidence that teachers use to judge their teaching success [in traditional classroom settings], which in turn support their senses of [confidence], are no longer operative [in reformed classrooms]" (p. 63). Thus, teachers regularly reflecting on their teaching performance in the context of reform-based evidence of student learning are more likely to develop the confidence to transition to constructivist pedagogies in the classroom. Consequently, in this qualitative action research study I reflected on the learning of my students by analyzing reform-based assessment artifacts and using those reflections to better understand my epistemological beliefs in the context of reform-based science teaching and promote an epistemological shift that favors the use of constructivist pedagogies in my classroom.

Theoretical Framework

My problem of practice highlights the important role that teacher beliefs have on teacher practice, as well as the role that teacher practice has on teacher beliefs. Indeed, teacher epistemological beliefs, ultimately impact how teachers present content to their students (Arce et al., 2014; Bennett & Park, 2011; Boesdorfer, 2017; Hutner & Markman, 2016; Lebak, 2015; Mansour, 2013; Wallace & Kang, 2004), and these epistemological beliefs are often deeply rooted and not easily changed (Wall, 2018). The reciprocal relationship between teacher practice and beliefs draws on two intertwining theories: the theory of constructivism and the theoretical construct of beliefs.

Constructivist Theory

The theory of constructivism is an important underpinning in this study in that science teachers' beliefs about how students acquire knowledge are "associated with [their] philosophy or opinion about constructivism" (Savasci & Berlin, 2012, p. 66). The constructivist theory of learning can be traced to the work of John Dewey (1902/2011). Dewey's progressivist movement in education is rooted in the notion that students should be active participants in their own learning. Building on this idea, the contributions of Piaget and Vygotsky, via differing influences, led to the development of a greater understanding of constructivism as it is employed in contemporary education. Inquiry in the science classroom is not typically an individual effort, but rather a collective effort wherein collaborative groups work together to investigate a problem. In the context of the constructivist theory of learning, "Piaget and Vygotsky…stressed the social nature of learning, and both suggested the use of mixed-ability learning groups" (Slavin, 2012, p. 219). In this regard, both Piaget and Vygotsky contributed to the development of social

constructivist theory wherein “learners construct their own knowledge and understandings based on their existing ideas and the sociocultural context in which they find themselves” (Eastwell, 2002, p. 83). In effect, learners in collaborative groups contribute to the collective learning of their peers by bringing their own unique perspectives to solve a problem. The constructivist theory of learning is particularly relevant to this qualitative action research study as student participants engaged in constructivist pedagogies when participating in NGSS-aligned learning tasks, while I constructed my own understandings of my epistemological beliefs as a practitioner researcher.

The Theoretical Construct of Beliefs

According to Nespor (1987), teacher beliefs form from a variety of factors, including feelings about student ability and past experiences in the classroom. Such factors ultimately dictate a teacher’s pedagogical decisions in the classroom (Arce et al., 2014; Bennett & Park, 2011; Boesdorfer, 2017; Hutner & Markman, 2016; Lebak, 2015; Mansour, 2013; Wallace & Kang, 2004). In other words, teachers’ previous experiences in the classroom, as both an educator and student, as well as their personal feelings about student ability ultimately inform their decisions to implement constructivist pedagogies in the classroom.

Like Nespor (1987), other scholars have also described factors that influence teacher beliefs, looking specifically at science teaching contexts. For example, Lebak (2015) asserts, “beliefs can [also] be linked to a [science] teachers’ personal experience with inquiry” (p. 696). The term inquiry is important in this qualitative action research study, as student participants engaged with scientific inquiry via NGSS-aligned learning

tasks while I conducted an inquiry into the transition of my own epistemological beliefs via action research.

Inquiry can be implemented in a variety of ways, from structured, to guided, to open. In structured inquiry, the students investigate a teacher-posed question and follow a series of step-by-step guidelines. Guided and open inquiry approaches, on the other hand, rely on student development of procedures in order to investigate a scientific phenomenon (Zion & Mendelovici, 2012); however, an important distinction between guided and open inquiry must be made. While both forms of inquiry rely on student-developed procedures, guided inquiry approaches require students to develop procedures often in response to a teacher-posed question, whereas open inquiry procedures are developed from questions posed by students themselves. For the purposes of this dissertation, the generic term inquiry will encompass open inquiry approaches, as this inquiry approach aligns most closely to the vision of the NGSS. The term inquiry by this definition is also relevant to my role as a practitioner researcher, as I have identified a problem of practice and devised a research plan aimed at answering defined research questions.

Epistemological Beliefs

As described above, this dissertation draws from both the constructivist theory of learning and the theoretical construct of beliefs as a theoretical framework; however, a discussion of epistemological beliefs further frames this qualitative action research study. Though multiple definitions of epistemological beliefs, in the context of teaching and learning, persist throughout the literature, the definition posited by Fives and Buehl (2017) best reflects the meaning as it relates to this study, and draws on Nespor's (1987)

definition of teacher beliefs, as described above. Fives and Buehl (2017) define epistemological beliefs as the set of beliefs "that influences and are [*sic*] influenced by teachers' learning experiences, practices, and personal and professional contexts" (p. 25). In effect, Fives and Buehl (2017) assert that teachers' beliefs about the acquisition of knowledge are reflected in the "teaching context where individuals make decisions about content, pedagogical approaches, and curriculum sequencing" (p. 26) to aid students with the gaining of content knowledge.

Fives and Buehl's (2017) definition of teachers' epistemological beliefs reflects the inter-relatedness between teachers' views on pedagogical theories of learning and how these views ultimately influence teachers' beliefs, as a result of their own personal and professional experiences. For example, teachers like me, whose epistemological beliefs directly conflict with the constructivist theory of learning, may find changing their epistemological beliefs challenging and difficult and thus may strongly resist the change.

Purpose of Study

The purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. The adoption of the NGSS by many states, including California, has led many teachers to recognize the importance of moving away from traditional science education pedagogies, in favor of ones that provide students opportunities to construct their own scientific understandings. While many educators, like me, may recognize the importance of this pedagogical shift, actually moving away from traditional pedagogies is difficult for science educators whose epistemological beliefs are rooted in traditional pedagogies. Moving toward more

constructivist approaches to student learning puts the science teacher in the uncomfortable position of relinquishing control of direct student learning, which is often in conflict with the teacher's epistemological beliefs, as in my case.

Research Questions

To ameliorate my problem of practice, I conducted a qualitative action research study to answer the following research questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?
2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

Rationale

Many teachers in states where the NGSS have been adopted are tasked with developing lessons and designing activities that are in stark contrast to their prior pedagogies. As NGSS implementation is still in its infancy, and only limited NGSS-aligned resources are available for science teachers, the subsequent implementation of the NGSS will inevitably result in some confusion, failed lesson designs, and perhaps a reinforcement of teacher epistemological beliefs that favor traditional pedagogies over those that are reform-based. As teacher epistemological beliefs are influenced by practice, and practice influences epistemological beliefs (Arce et al., 2014; Bennett & Park, 2011; Boesdorfer, 2017; Hutner & Markman, 2016; Lebak, 2015; Mansour, 2013),

it is important to explore how the implementation of NGSS-aligned learning tasks influences teacher epistemological beliefs. Student experiences with the NGSS that demonstrate effective conceptual understanding and engagement ultimately influence teacher epistemological beliefs, and in turn, these epistemological beliefs inform the next steps of classroom instruction.

Furthermore, as a science teacher in the state of California, I knew that the implementation of the NGSS was necessary in my classroom and thus conducting this qualitative action research study allowed me to better understand my struggles with constructivist pedagogies, as well as the considerations to ensure the successful implementation of the NGSS in my own classroom.

Positionality

To conduct this study, I integrated the Science and Engineering practices (SEPs) outlined in the NGSS into planned lesson sequences, purposively sampled students in class sections within my own classroom, and collected and analyzed data by way of a qualitative action research approach. By studying myself and my own students, in my own classroom, I took the position of an insider practitioner (Herr & Anderson, 2015). My insider status is important, as the design of this qualitative action research study required me to exert caution to ensure its validity. This significance will be discussed in greater depth in Chapter Five.

Identifying one's positionality requires a researcher to ask the question "who am I in relation to my participants and my setting?" (Herr & Anderson, 2015, p. 37). Classifying myself as an insider only serves to shed a broad spotlight on my positionality, whereas, facets of my background and my experiences in the classroom shape a more

specific positionality. I am the daughter of Egyptian immigrants, born and raised in Canada. My father moved to Canada from Egypt to complete his Ph.D. in Nuclear Physics, and thus science and education played a prominent role in my upbringing. My father often told me “school is not a hobby” when I begrudged the need to memorize facts and figures and replicate that information on assessments. He told me “school is not a social club!” when I wanted to socialize and collaborate with peers. My father’s message was clear: school is a place for traditional learning. Success comes from memorization. There is no time to socialize.

I carried my father’s beliefs about school as my own, and I ultimately succeeded; however, in becoming a science educator I found myself in an existential ambivalence. I struggled between relinquishing the traditional approach to schooling and teaching and embracing the research that shows that constructivist, inquiry-oriented learning is the key to academic success for today’s youth (Wilson et al., 2010). As a student and a novice educator, I felt that the traditional approach to teaching provided me with a comfortable familiarity and a degree of control over student learning, while student-centered approaches could yield frustrations and struggles for both students and educators alike. With the recent implementation of the NGSS, I had no choice but to relinquish traditional approaches to teaching; however, my deep-rooted epistemological beliefs made it difficult for me to do so.

As my upbringing strongly influenced my epistemological beliefs, so too did my experiences as a pre-service science teacher. I earned my secondary science teaching credential just as the NGSS were barely on the horizon of the science education reform movement. In fact, lesson plans that I developed for my student teaching experiences

aligned to the science standards that preceded the NGSS, and thus I was a student of science teaching at a time when the NGSS were in their infancy. In effect, my early career experiences relied heavily on the use of traditional pedagogies to ensure that my students were directly learning the content of the course, rather than engaging in the *process* of science learning. Furthermore, during my teacher preparation, my instructors in the program did not express a detectable preference for constructivist pedagogies in the science classroom. Rather than modeling how to provide students with learning opportunities that emphasized the *process* of science, my program focused on the objectives of transmitting the disciplinary content through lectures and structured laboratory activities. Because of this emphasis on the *content* of science rather than *process* of science I viewed student struggle in the science classroom as a direct reflection of inadequate teaching. My pre-service teaching experiences set the stage for me to view science teaching as a means to transmit content to students, and if students struggled to understand the content, then I believed I must develop more direct methods of transmission.

My experiences as both a student and as a pre-service teacher influenced my decision to explore the transition in my epistemological beliefs, and ultimately informed the design of this qualitative action research study.

Research Methodology

As the implementation of the NGSS is a complex process that requires a strategic plan to ensure student conceptual understanding and engagement, and consequently teacher epistemological beliefs, are influenced, this study employed a qualitative action research methodology (Efron & Ravid, 2013). This methodology, as well as the specific

research tradition in which this study is rooted, will be discussed in greater detail in Chapter Three. Qualitative data collection instruments, such as observations, student-generated artifacts, a personal teaching journal, and focus group interviews, can measure the conceptual understanding and engagement of students, while also tracking the transition in my own epistemological beliefs. With these data collection instruments in mind, this qualitative action research study is rooted in the grounded theory research tradition, as "grounded theory methods consist of systematic, yet flexible guidelines for collecting and analyzing qualitative data to construct theories from the data themselves" (Charmaz, 2014, p. 1). Measuring student conceptual understanding and engagement while participating in NGSS-aligned learning tasks provided valuable qualitative data, which, through a constant comparative approach to data analysis (Durdella, 2019) subsequently yielded a theory of their influence on my epistemological beliefs.

Research Setting and Participants

This qualitative action research study investigated the link between the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students while participating in NGSS-aligned learning tasks and the resulting impact this student participation had on my epistemological beliefs. This necessitated collecting data from a purposive sample of students, chosen from three (3) college preparatory (CP) chemistry class sections. As this action research study aimed to understand the transition in my personal epistemological beliefs, it was still important to situate myself as a practitioner in relation to my students. In other words, to adequately understand the transition in my own epistemological beliefs, I sought to "capture the voice of my practice" (Pinnegar & Hamilton, 2010, p. 111) by asking student participants to reflect on

what they have observed of my teaching during focus group interviews. For the purposes of this study, 15 students were purposively sampled from three (3) college preparatory chemistry classes. A CP chemistry course is distinguished from an honors chemistry course, or even an advanced placement (AP) chemistry course, in the level of rigor of the presented course materials as CP chemistry is the most basic of the high school chemistry offerings at my school site. Unlike students in honors or AP chemistry courses, CP chemistry students are provided with additional supports such as formulas and graphic organizers, to aid with their demonstration of disciplinary content knowledge.

Data Collection Instruments

This qualitative action research study was conducted during the spring semester of a high school college preparatory (CP) course, specifically during the Thermochemistry unit, which provided many opportunities to observe students engaged in the Science and Engineering Practices (SEPs) as outlined in the NGSS. Each of the three (3) class sections learned the same conceptual material over the course of the spring semester, and each class conducted investigations that address the SEPs. Semi-structured observations were conducted in each of the class sections for evidence of student conceptual understanding and engagement, and detailed field notes were recorded. Additionally, a purposive sample of students from each class section was selected to participate in semi-structured focus group interviews that addressed student conceptual knowledge and engagement as well as their observations of my own behaviors, following their participation in the NGSS-aligned learning tasks. Fraenkel et al. (2015) assert that no more than eight (8) participants should participate in a focus group interview at one time. With this in mind, a purposive sample of approximately 15 student participants

limited focus group interview sessions to no more than three (3). Detailed field notes were recorded after semi-structured focus group interviews. Finally, student artifacts were collected from participants and analyzed for evidence of student conceptual understanding.

In addition to data collected from the purposive sample of student participants, I collected data from myself throughout this study in the form of daily reflections in a teaching journal. These daily reflections included my responses to specific prompts, and these responses were ultimately coded and analyzed to track the transition in my own epistemological beliefs during lessons wherein students participated in NGSS-aligned learning tasks.

Data Analysis Strategies

Some qualitative researchers opt to "[transform] qualitative data into numerical form" (Efron & Ravid, 2013, p. 214), especially to conduct a content analysis of observation and interview data. In this study, by coding and categorizing the field notes generated from observations and interviews, the qualitative data could then be analyzed quantitatively (Efron & Ravid, 2013) and used to generate a theory regarding my epistemological beliefs. It is important to note that both the manifest and latent content of these observations and interviews was analyzed (Fraenkel et al., 2015).

As noted above, because this qualitative action research study is rooted in grounded theory methodology, a constant comparative data analysis strategy was used. The constant comparative data analysis strategy assumes "data are collected and analyzed; a theory is suggested; more data are collected; the theory is revised; then more data are collected; the theory is further developed, clarified, revised; and the process

continues" (Fraenkel et al., 2015, p. 432); however, following simultaneous data collection and analysis, a theory was not suggested until all data were collected and analyzed from the instruments described above. Though preliminary theories were not explicitly stated following each cycle of data collection and analysis, emergent theories were noted and used to guide subsequent cycles of data collection and analysis.

Limitations

Aside from using a variety of instruments to collect data and a well-established method of analysis, I took other measures to ensure the validity of my study. Additional details regarding the research design, as well as the validity and reliability of this study, will be provided in Chapter Three. In spite of these efforts, there are, of course, limitations.

Unit Objectives may Stifle Epistemological Change

This qualitative action research study was conducted during the Thermochemistry unit of a high school college preparatory (CP) chemistry course because of the unit's ample opportunities to engage in many of the specific components of the SEPs. While the purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning, a significant limitation of this study relates to the rigor of many of the concepts addressed in the spring semester of the course. As a teacher with more than six years of teaching experience, I have noticed that many students struggle with the concepts described during the Thermochemistry unit, and indeed this struggle led to my reliance on traditional pedagogies multiple times throughout the study. Student struggle and the subsequent reliance on traditional

pedagogies to mitigate this struggle resulted in an incomplete epistemological shift. This limitation will be discussed in greater depth in Chapter Five.

Participant Attitudes

As an insider action researcher (Herr & Anderson, 2015), I must further address biases and power struggles associated with this position. The student participants in my study are my own students who likely view me as an authority figure in the classroom. As a result, their behavior during observations and their interview responses may have reflected what participants assumed I wanted to see and hear, rather than their authentic behaviors and feelings. Additionally, because the purpose of this study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning, as an insider action researcher (Herr & Anderson, 2015), I ran the risk of “unconsciously distort[ing] the data in such a way as to make an [epistemological transition more likely]” (Fraenkel et al., 2015, p. 171).

Observation can be a Subjective Data Collection Instrument

Another possible limitation of this study is the subjectivity of observation as a data collection instrument. While I may observe specific student behaviors that I feel demonstrate student engagement or learning, another teacher may argue that the observed phenomena are either inconsequential or in fact not indicative of student learning or engagement. Though qualitative action research is not designed to provide generalizable results, this limitation may impact the perceived transferability of this study to readers.

Significance

In spite of the limitations described above, this qualitative action research study is significant in multiple ways.

Research Experiences can Facilitate Epistemological Change

As has been emphasized throughout this chapter, this study employs a qualitative action research methodology, wherein ongoing actions are studied in a research setting (Herr & Anderson, 2015). More specifically, "[educational] action research can be defined as the process of studying a real school or classroom situation to understand and improve the quality of actions or instruction" (Johnson, 2012, p. 16). Because school and classroom environments vary widely, the purpose of action research is not to provide generalized solutions to common educational problems, but rather to "encourage educators to learn from each other by sharing and advancing their experience-based knowledge" (Efron & Ravid, 2013, p. 234). Furthermore, in the context of this specific action research study, teacher practitioner research experiences have the "potential to be pivotal in achieving the Next Generation Science Standards' (NGSS) vision of science education" (Herrington et al., 2016, p. 184). In other words, using action research in my own classroom provided me with a research experience that can ultimately influence my science teaching practice and epistemological beliefs in a way that further promotes the continued implementation of the NGSS in my classroom. Indeed, as an action researcher, I can "explore the gap between who I am and who I would like to be in my practice" (Pinnegar & Hamilton, 2010, p. 12), which is particularly empowering for a science educator who wishes to reap the benefits the NGSS offers to both teachers and students.

Action Research can be Highly Transferable

Additionally, with the recent implementation of the NGSS, a pedagogical shift from traditional lessons and labs to guided-inquiry lessons and labs is imperative. For many science teachers, the implementation of the NGSS brings with it a sense of uncertainty and immense pressure to reinvent traditional lessons and labs with student-centeredness in mind. As Chapter Two will explain, the literature is rife with evidence of the need to revitalize lab activities so that they are less structured and more guided to promote the conceptual understanding and engagement of students; however, teachers' deep-rooted epistemological beliefs often conflict with and impeded these reform-based pedagogies. This qualitative action research study might compel science educators who are hesitant to adopt the NGSS and implement guided inquiries in the classroom to understand that the transition from traditional pedagogies to the ones outlined in the NGSS is possible despite epistemological beliefs that conflict with constructivist theories of learning. While this qualitative action research study focuses primarily on college preparatory (CP) chemistry students, the findings of the study may also be relevant to educators in other science disciplines. Indeed, biology, physics, and earth science disciplines contain no shortage of opportunities to implement guided-inquiry methods of instruction. As a result, the findings of this study offer biology, physics and earth science teachers who are hesitant to implement the NGSS a snapshot into the implementation of guided-inquiry approaches that best promote a shift in epistemological beliefs that are in favor of constructivism.

Organization of the Dissertation

The remainder of this dissertation will include a literature review, detailed methodology, findings, and a discussion of the study's implications. The literature review will provide an in-depth discussion of studies related to science teachers' hesitance to implement constructivist approaches to learning (specifically guided-inquiry tasks) in their classrooms, as well as the complexity of changing epistemological beliefs. The methodology chapter of the dissertation will provide a detailed description of the data collection instruments and the methods of data analysis. The findings chapter will look across all of my data sources in light of my research questions for evidence of student conceptual understanding and engagement, as well as the resultant impact on my epistemological beliefs. The final chapter will articulate the implications of the findings for my practice and identify potential areas of future research.

Chapter Two situates the problem of practice in related literature to better illustrate the relationship between teacher beliefs and practice in the context of the competing pedagogical philosophies associated with traditional and constructivist science teaching.

CHAPTER 2

LITERATURE REVIEW

As introduced in Chapter One, the purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. The Next Generation Science Standards (NGSS) were adopted by many U.S. states to fundamentally change how students interact with the science disciplines (National Research Council [NRC], 2012). The NGSS transforms the science curriculum from simply a body of knowledge comprised of facts and formulas to a fully experiential means for students to gain both content knowledge and knowledge of the *process* of science (NRC, 2012). Done correctly, these inquiry-based approaches provide students with an immersive science education experience wherein they actively participate in constructing their own science knowledge. Though there undoubtedly exist teachers who have taken these changes to the science standards in stride, other teachers, like me, have reservations regarding how to implement inquiry-oriented teaching (DiBiase & McDonald, 2015; Wallace & Kang, 2004), despite fundamentally believing it is valuable for students. As the literature review will illustrate, science teachers struggle to implement inquiry-oriented pedagogies in their classrooms for a variety of reasons. Some teachers view inquiry-oriented teaching as being in direct contrast with their

epistemological beliefs (Arce et al., 2014; Bennett & Park, 2011; DiBiase & McDonald, 2015; Mangiante, 2018; Rosenfeld & Rosenfeld, 2006; Savasci & Berlin, 2012; Wallace & Kang, 2004; Zambak et al., 2017). Additionally, some teachers are simply unaware of *how* to implement inquiry-oriented pedagogies in their classrooms (Seals et al., 2017; Smithenry, 2010; Zion & Mendelovici, 2012;).

As a secondary science teacher on the path to NGSS implementation, I can relate to these hindrances. As mentioned in Chapter One, my personal epistemological beliefs conflict with the vision of the NGSS, forming the underlying rationale for this qualitative action research study. To investigate this conflict, I posed two distinct action research questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?
2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

These two research questions represent the interrelatedness between the impact of student ability and behavior on teacher beliefs and, in turn, how those beliefs influence teacher practice (Roehrig & Luft, 2004; Savasci & Berlin, 2012). As discussed in Chapter One, the use of student participants in this study provides me with a greater understanding of myself as a teacher, as my epistemological beliefs are dependent on my students' experiences with NGSS-aligned learning tasks.

This chapter provides a synthesis of the literature related to the implementation of the science and engineering practices (SEPs) as outlined in the Next Generation Science Standards (NGSS) in science education. I begin with an overview of the literature related to the roots of the NGSS and a historical overview of the science standards that preceded it. Chapter Two moves on to describe the three dimensions of the NGSS, with an emphasis on the Science and Engineering Practices (SEPs) and how the SEPs address the nature of science (NOS) through inquiry. Additionally, this chapter will provide an in-depth review of the literature related to the hindrances science educators face when implementing inquiry-oriented pedagogies in the classroom. Finally, the chapter concludes with an examination of related literature regarding the strategies science educators may choose to employ to integrate the science and engineering practices into their curricula, and as a result, enact a change in their epistemological beliefs and consequently their practice.

Purpose of the Literature Review

Machi and McEvoy (2016) state, "a literature review is a written argument that supports a thesis position by building a case from credible evidence obtained from previous research" (p. 5). As the purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs in the context of traditional versus reform-based science learning, I reviewed existing literature to understand the case for constructivist teaching pedagogies in the science classroom. In turn, this required a thorough understanding of the birth of the NGSS, as well as the nature of science and inquiry. Furthermore, to better understand how to implement these constructivist pedagogies, I also sought to understand

the hesitancies that some science teachers experience that hinder their receptiveness to implementing these pedagogies in their classrooms.

To conduct the literature review, I used a combination of peer-reviewed journal articles and textbooks. Textbooks included contemporary works related to the implementation of the NGSS, as well as seminal works from authors such as Dewey and Bagley. To conduct the search for peer-reviewed journal articles, I used the EBSCOhost search engine to access both the ERIC and Education Source databases, employing a variety of key words and seminal authors. Common search queries included “inquiry,” “teacher beliefs,” and “nature of science,” to name a few.

The Birth of the NGSS

A central dichotomy that emerges in this qualitative action research study is the competing pedagogical theories associated with traditional and constructivist practice. This dichotomy in the educational landscape has its roots in the late 19th century with the seminal works of John Dewey and William Bagley. Both Dewey and Bagley contributed significant knowledge to the field of curriculum theories, yet both scholars proposed vastly different arguments for and against both traditional and constructivist approaches to curriculum development.

Roots of Constructivism

Dewey’s (1902/2011) constructivist movement in education argued that students should be active participants in their own learning, for “it is the [student’s] present powers which are to assert themselves; [the student’s] present capacities which are to be exercised; [the student’s] present attitudes which are to be realized” (p. 40). In essence, experiential background, knowledge and attitudes ultimately drive the student’s learning

process, rather than the explicit direction of the instructor. Moreover, Dewey (1902/2011) claimed that "the [student] is the starting point, the center, and the end" of the learning cycle, whereas "subject matter never can be got into the child from without" (p. 13). In effect, Dewey's ideas regarding student-centered learning provide the platform for the constructivist education movement. Allowing students the opportunity to construct their own knowledge and understanding of phenomena through guided and open inquiry affords an authentic learning experience that is most beneficial to the student.

Traditional Views of Teaching

Bagley (1939), on the other hand, proposed an entirely different philosophy of teaching and learning and viewed Dewey's ideas about progressive education as permissive of reduced rigor and relaxed standards. Bagley argued that the wave of progressivist reform throughout the United States in the early twentieth century was directly responsible for the significant failure of the American school system at the time, citing the lack of motivation for students to progress past the sixth grade, increasing social promotion, and an expansion of mass-education that was non-selective regarding student ability. He felt strongly that because the expansion of the school system promoted the inclusion of a more heterogeneously able population, the standards of American education had to be relaxed to accommodate these varying academic abilities. To eradicate the weaknesses uncovered by Dewey's progressivist constructivism, Bagley proposed an essentialist movement, arguing the education system ought to return back to the basics, with an emphasis on transmissive knowledge of the core subjects of English, Mathematics, Science, and History. Additionally, Bagley (1911) proposed that the education setting be formalized, wherein student conduct is strictly monitored and

enforced. In contemporary terms, Bagley argued for a traditional approach to teaching and learning, in direct contrast to Dewey's constructivist beliefs.

The Science Reform Movement

The competing philosophies of Dewey and Bagley underpin the reform movement toward the current NGSS. These competing philosophies are so central to the recent debate over the state of American science education that "no less than three major reform documents in science education have emerged since the early 1990s" (Lederman & Lederman, 2016), with each document moving closer to Dewey's vision of student learning, and away from Bagley's views on traditional pedagogy. These documents include the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993), the *National Science Education Standards* (National Research Council [NRC], 1996), and the *Next Generation Science Standards* (NGSS Lead States, 2013). With each set of standards comes a greater emphasis on the nature of science (NOS) (McComas & Nouri, 2016) and the *process* of student participation in science learning. Indeed, with each set of standards comes a vision of science teaching that moves closer and closer to Dewey's philosophy of constructivist education.

The Benchmarks for Science Literacy

The *Benchmarks for Science Literacy* divides the nature of science into three categories: the scientific worldview, scientific inquiry, and the scientific enterprise (AAAS, 1993). A closer look at the category of scientific inquiry reveals that the AAAS' view of scientific inquiry closely aligns with the traditional scientific method. This traditional view of science inquiry, wherein a single, linear approach to scientific

discovery produces results that conform to mainstream ideas in science has been largely refuted by the scientific community (McComas & Nouri, 2016) and thus accounts for an outdated vision of science education. Additionally, the AAAS (1993) delineates the science standards in a set of discrete, separate entities that are prefixed with the phrase "students should know that." Such statements do not encompass the complex nature of science required for students to understand specific concepts.

National Science Education Standards

A mere three years following the publication of the *Benchmarks for Science Literacy*, the National Research Council (NRC) published the *National Science Education Standards* (1996), improving upon the ideas of the nature of science (NOS) put forth by the AAAS (1993) and acknowledging that student inquiry is necessary to fully understand the NOS. Specifically, the NRC (1996) states that students "should have the opportunity to use scientific inquiry…including asking questions, planning and conducting investigations…gather[ing] data…constructing and analyzing explanations and communicating scientific arguments" (p. 105). While such language is an improvement from that used by the AAAS (1993), the specific standards of the disciplines are still preceded with the phrase "students know" (NRC, 1996). Once again, as with the *Benchmarks for Science Literacy*, this phrase de-emphasizes the need for students to engage in inquiry and construct a better understanding of the NOS to achieve specific disciplinary content knowledge.

The Call for Science Education Reform

While the AAAS (1993) and the NRC (1996) had progressively ambitious ideas about the nature of science, unfortunately there was still something lacking in American

science education. Student scientific literacy is imperative to American society as "government leaders associate problems with science education with the future economic vitality of the United States and its position as a global leader" (Anderson, 2012, p. 105). With that said, the need for science education stakeholders to develop science standards that more rigorously challenge American students to develop understandings of science is paramount. These stakeholders, ranging from science teachers and teacher educators, to state board of education members and including members of national science education organizations such as the National Science Teachers' Association (NSTA), all have a vested interest in overcoming weaknesses in American science education associated with a lack of science student literacy and an underappreciation of the beauty of science (NRC, 2012). According to the 2015 National Assessment of Educational Progress (NAEP) published by the United States Department of Education, American students demonstrated weak proficiency in science. Specifically, fourth, eighth, and twelfth-grade students respectively demonstrated 38%, 34%, and 22% proficiency (U.S. Department of Education, 2015). Additionally, American students participated in the Program for International Student Assessment (PISA) in 2015, and ranked 24th in science, out of 71 countries (Kastberg et al., 2016). Science education stakeholders in the U.S. likely view these bleak statistics as further evidence that science education is in desperate need of reform.

The Next Generation Science Standards

The latest effort in the science education reform movement is the development of the current Next Generation Science Standards (NGSS). While the NGSS represent a set of standards for current science education, it is important to first examine the framework

of the NGSS as the foundation for the rationale of these new science education standards. Much of the NRC's (1996) language regarding inquiry, and its relationships to the NOS, endures in the organization's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). Early in the book, the authors assert, "understanding science and engineering now more than ever, is essential for every American citizen. Science, engineering, and the technologies they influence permeate every aspect of modern life" (NRC, 2012, p. 7). Further, to promote access to science and engineering, "students, over multiple years of school, [ought to] actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the [disciplinary] core ideas in these fields" (pp. 8-9). In this vision of science education, disciplinary core ideas are interwoven with science and engineering practices, as well as crosscutting concepts that ultimately unify all the science disciplines. Based on guiding principles of the need for better quality science education, the NRC (2012) framework "broadly outlines the knowledge and practices of the sciences and engineering that all students should learn by the end of high school" (p. 29), and this framework forms the basis of the current NGSS.

Three-Dimensional Science Learning

Indeed, this framework includes the following three dimensions: crosscutting concepts (CCCs), disciplinary core ideas (DCIs), and the science and engineering practices (SEPs). These three dimensions of science education constitute what is currently known as the NGSS. Together, these three dimensions of science aid students with not only learning about the content of the disciplines, but also about the nature of science (NOS). The National Research Council (2012) defines the crosscutting concepts

(CCCs) as those "concepts that bridge disciplinary boundaries, having explanatory value throughout much of science and engineering" (p. 83), and the disciplinary core ideas (DCIs) as the core knowledge of each of the science disciplines. Lastly, the Science and Engineering Practices (SEPs) are defined as those practices that help students understand how scientific knowledge develops, as well as the work of scientists (NRC, 2012). The CCCs, DCIs, and SEPs are presented as a cohesive strategy for science education that moves away from Bagley's (1939) traditional perspective of teaching and instead embraces the progressivist vision of teaching proposed by Dewey (1902/2011). As the dimension most indicative of the constructivist theory of learning, the SEPs, became the logical focus for this qualitative action research study, and I explain them further below.

The Science and Engineering Practices and the Nature of Science

What are the Science and Engineering Practices?

The National Research Council (2012) lists the SEPs as the following: 1) asking questions, 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations, 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information. Together, these eight practices are intended to "help students understand how scientific knowledge develops" and "can also pique students' curiosity, capture their interest, and motivate their continued study [in the sciences]" (p. 42). This becomes of paramount importance for minority students and other groups that are under-represented in STEM fields. These SEPs were developed to move students away from traditional, "cookbook" investigations in favor of inquiries that ensure science student learning "emphasizes practices and reflects a bit of the struggle [of

science]" (Duschl & Bybee, 2014, p. 2). Providing students with these opportunities to engage in the struggle of science aligns with the vision of the NGSS.

The Relationship Between the SEPs and the Nature of Science

Providing students with an opportunity to engage in the struggle of science also offers them an opportunity to appreciate the difference between being informed about science versus understanding science. The NGSS Lead States (2013), the 26 states involved in developing the NGSS, further assert that the nature of science (NOS) encompasses a set of eight scientific understandings, which are an important learning outcome in science education (NGSS Lead States, 2013). Of these eight understandings, four most closely align with the science and engineering practices (SEPs): 1) scientific investigations use a variety of methods, 2) scientific knowledge is based on empirical evidence, 3) scientific knowledge is open to revision in light of new evidence, 4) scientific models, laws, mechanism, and theories explain natural phenomena (NGSS Lead States, 2013). As this list indicates, the science and engineering practices outlined in the NGSS are designed to assist students with not only learning the *process* of science, but also the *nature* of science. With this in mind, some may assert that the "nature of science really is a fourth major aspect of NGSS" (McComas & Nouri, 2016, p. 560), beyond the CCCs, DCIs, and SEPs. This is further evident in the NGSS standards themselves, which explicitly address the NOS following the statement of each of the performance expectations (PEs) for K-12.

McComas and Nouri (2016) state that the term nature of science (NOS) is widely used in science education, broadly defined as "[providing] students some appreciation for and understanding of [scientific] knowledge generation and validation" (p. 556). In

effect, the NOS must accompany the science disciplinary content in a way that students are able to understand the struggle of science, as well as the efforts required to generate scientifically sound conceptual information (Capps & Crawford, 2013). McComas and Nouri (2016) further assert that it is only through the NOS that students will come to understand how science works, how scientific knowledge is created, and how scientists do what they do. These important functions of the NOS mirror the rationale for the NGSS as described in the Framework (NRC, 2012).

Nature of Science and Inquiry

Since the inception of the NGSS, "science teachers have asked, *why use the term practices? Why not continue using inquiry?*" (Bybee, 2011, p. 37). While the terms practices and inquiry may seem like distinct constructs, the NGSS encompass the notion that "scientific inquiry is one form of scientific practice" (Bybee, 2011, p. 38). Moreover, "practice is the most recent vocabulary choice for expressing an educational aim that students learn how to reason and act scientifically" (Ford, 2015, p. 1041). Essentially, the NGSS promote scientific practice through the use of inquiry. In other words, student participation in inquiry, if done according to the vision of the NGSS, ought to incorporate elements of the SEPs. The very essence of the NGSS is to promote student experiences with science in ways that closely mimic the work of actual scientists. In fact, when participating in inquiry activities in accordance with the SEPs, "learners begin to understand how scientists do their work" (Capps & Crawford, 2013, p. 499) and are provided "a context for reflection on [the] NOS" (p. 501). For example, scientists frequently ask questions, plan investigations, and formulate conclusions based on evidence collected during the investigation. In this regard, behaving like a scientist

involves the use of inquiry and sets the stage to better understand the nature of science (NOS).

Furthermore, Abd-el-Khalick and Lederman (2010) acknowledge that developing a deep understanding of the NOS requires “an appreciation of the central role of theory and inquiry in science” (p. 668). With this in mind, providing students with authentic scientific inquiry experiences also exposes them to the true NOS, particularly if those inquiry experiences approach inquiry in an unstructured way and rely not only on logic but also on “imagination and the invention of explanations” to develop scientific understandings (p. 668). In addition, Abd-el-Khalick and Lederman (2010) acknowledge that providing students with opportunities to engage in inquiry-oriented activities develops their explicit construct of the NOS, and that teachers who provide these engagement opportunities for their students develop a better understanding of the NOS themselves.

Structured Inquiry

Inquiry is a term that is used widely throughout the science community, but not all inquiry is presented to students in equal formats. As introduced in Chapter One, Zion and Mendelovici (2012) delineate a set of three distinct descriptions of inquiry: structured, guided, and open. In structured inquiry, the teacher poses a problem to students and provides students with a step-by-step list of guidelines to reach a predetermined outcome. The structured inquiry process is linear in nature and encourages students to arrive to appropriate expected conclusions based on the “correct” collection of evidence. By this description, structured inquiry “works well only for developing basic inquiry skills that are inadequate for appreciating the real nature of science” (p. 384).

Though the literature has shown the drawbacks of using structured inquiry in the context of authentic science learning, the familiarity of structured inquiry along with the desire to direct students to a pre-determined inquiry outcome caused me to prefer structured inquiry over other methods of inquiry in my science classroom. This preference, when it came into conflict with the NGSS, formed the underlying basis for this qualitative action research study.

Guided and Open Inquiry

Guided inquiry involves students' answering a teacher posited research question using a teacher developed procedure; however, students work collaboratively within the confines of this procedure to decide how to answer the question (Zion & Mendelovici, 2012). The students ultimately lead the inquiry process, are involved decision-makers from the data collection stage and beyond, and may come up with well-conceived, yet unforeseen conclusions. However, they do not have any role in the logical planning of the investigation, whereas open inquiry, "the most complex level of inquiry-based learning" (p. 384), involves students' formulating their own research question and planning their own investigation to answer it. Questions can be selected from a selection of teacher posited questions or can be generated because of students' curiosity. Asking questions, defining problems, and planning investigations "simulates and reflects the type of research and experimental work that is performed by scientists" (p. 384), all of which encompass the vision for science learning posited by the NGSS. For the purposes of this dissertation, the generic term inquiry will denote the open inquiry approach, as this approach is most closely aligned to the vision of the NGSS.

Open Inquiry Closely Aligns with the Vision of the NGSS

The alignment of the NGSS to the open inquiry approach is obvious because *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) clearly states that asking questions and defining problems, as well as planning and conducting investigations, are hallmarks of the science and engineering practices (SEPs), which are a critical component of the three dimensions of science learning outlined throughout the text (NRC, 2012). Furthermore, during open inquiry, students might also develop and use models to answer a research question, analyze and interpret collected data, construct explanations, and engage in argument from evidence based on the data collected during the open inquiry investigation.

Benefits of Inquiry

Open Inquiry Results in Greater Student Engagement

Many studies have shown that the impact of inquiry instruction is largely positive on student cognition and attitudes toward STEM disciplines. Jiang and McComas (2015) conducted a qualitative study "to examine the effects of levels of openness in inquiry teaching on student science achievement and their attitudes toward science" (p. 558), measuring levels of inquiry openness on a spectrum from 0, a classroom environment where no inquiry is taking place, to 4, a classroom wherein "students are more fully involved in conducting activities, drawing conclusions, designing investigations, and asking questions" (p. 559). To better understand the relationship between science achievement and inquiry openness, the authors studied Programme for International Student Assessment (PISA) data from 2006, when the PISA assessment heavily emphasized science literacy. The researchers employed causal inference to determine

student science achievement and attitudes toward science and inquiry as a result of the level of inquiry openness they experienced in their science education. Notably, they found that level 4 inquiry, or the most open forms of inquiry, resulted in the lowest achievement score data. Conversely, level 4 inquiry led to the highest levels of positive attitudes toward science and the highest levels of student support of inquiry methods in the classroom. Though these results are promising for promoting student engagement in the classroom, it is possible that the PISA is not the best assessment to measure students' cognitive understandings of science, as open inquiry approaches to science instruction require assessment tools that are not standardized in format.

Engaging in the SEPs Promotes Student Understanding of the Practices

A mixed-methods study conducted by Kuhn et al. (2017) aimed to determine if allowing students to actively engage in the science and engineering practices (SEPs) outlined in the NGSS promoted deep student understanding of the practices. Forty-eight student participants drawn from three tenth-grade biological sciences classes taught by the same teacher were selected for the study. One of the three classes was randomly chosen to serve in the intervention condition, while students drawn randomly from the other two classes served in a control condition. The control condition involved the teacher's presenting instruction on photosynthesis without the use of inquiry, in the context of the SEPs, while students in the intervention condition received instruction on photosynthesis with inquiry in the context of the SEPs at the forefront. The specific SEPs that were emphasized during the intervention instruction segment were analyzing and interpreting data; engaging in argument from evidence; and obtaining, evaluating, and communicating information. The researchers found that students who engaged in these

SEPs were significantly better able to develop scientific claims following the analysis of data, construct scientific arguments, and support those scientific arguments with evidence from the presented data. In this regard, students in the intervention group had a stronger epistemological understanding regarding science practice, compared to the students in the control group (Kuhn et al., 2015).

Constructivist Inquiry Experiences Result in Greater STEM Career Expectancy

In addition to the benefits of inquiry on students' cognitive and affective domains, participation in constructivist inquiry also promotes student interest in STEM-based career aspirations. Wild (2015) conducted a qualitative study to determine if chemistry students' perceptions of a constructivist learning environment ultimately led them to aspire toward careers in STEM occupations, particularly in the physical sciences and mathematics. Wild (2015) argues that women and underrepresented ethnic groups are lacking representation in STEM careers, particularly in physical sciences and mathematics, and thus science instruction must be curated in a way that promotes the pursuit of STEM careers by these groups. Survey data were collected from an unstated number of student participants to determine student perceptions of constructivist learning environments and their STEM career expectations. The results of the study indicated that students who perceived their science classes to be highly constructivist and inquiry-oriented reported an increased expectation of a STEM career. An additional notable result of this study was the lack of correlation between STEM career expectations for male and female students, when a positive constructivist perception existed. In other words, gender differences did not impact the expectation of STEM careers in constructivist learning environments. These findings indicate that inquiry-oriented, constructivist pedagogies

can promote equitable access to careers in STEM fields for women, in addition to under-represented ethnic groups.

Inquiry Promotes Equity in the Diverse Classroom

Aside from the long-term benefits of inquiry for under-represented ethnic groups, the implementation of inquiry, particularly in the context of the NGSS, also promotes culturally responsive teaching in the science disciplines. In other words, the use of inquiry and the SEPs in the science classroom advances both equitable science teaching and learning (NRC, 2012). Brown (2017) conducted a metasynthesis aimed at determining if inquiry-based instruction in the science classroom can complement culturally responsive science practices to advance science content knowledge and/or nature of science understanding of diverse students. Culturally responsive science practices are those practices that allow "students' cultural and linguistic backgrounds [to] be engaged as resources for science instruction" (Brown, 2017, p. 1146). By providing science classroom environments wherein inquiry opportunities, such as those outlined in the SEPs (NRC, 2012), are presented in combination with culturally responsive pedagogies, equitable science learning occurs. Brown (2017) synthesized 52 research articles to determine complementarity between culturally responsive science practices and the use of inquiry through the SEPs and found that "obtaining, evaluating and communicating information was the inquiry-based science SEP (NRC, 2012) that most often intersected with clear, observable culturally responsive pedagogy practices" (p. 1157). The use of this specific SEP provided "evidence of meaningful learning opportunities…where [culturally diverse] students were encouraged to pose questions, investigate answers to those questions, and develop scientific literacy through [inquiry]

activities" (p. 1157). Furthermore, Brown (2017) indicates that the SEP constructing explanations and designing solutions was also found to allow culturally diverse students to draw upon their own experiences and engage in meaningful learning tasks that were connected to their lives. It is also important to note Brown's (2017) findings in which the SEPs using mathematics and computational thinking, planning and conducting investigations and engaging in argument from evidence, "were least frequently encountered alongside culturally responsive practices" (p. 1164). These findings suggest that greater efforts are needed to integrate these particular SEPs into culturally responsive pedagogy in the science classroom and may be an area of future research.

Resistance to Inquiry Implementation

With all of the benefits of inquiry, one may wonder why inquiry teaching is not more widespread in science classrooms across the United States (Capps & Crawford, 2013; DiBiase & McDonald, 2015; Haag & Megowan, 2015; Smithenry, 2010). Teacher epistemological beliefs, teacher efficacy, attitudes toward student capabilities, and other classroom factors influence the likelihood of implementation of open inquiry in any individual science teacher's classroom.

The notion that teacher beliefs impact practice and practice impacts beliefs is not new, as "researchers and science teacher educators have relied on an assumption that there is a direct causal relationship between a science teacher's beliefs and their enacted pedagogy in classroom curricula" (Hutner & Markman, 2016, p. 676). With this in mind, a science teacher's epistemological beliefs "about the nature of knowledge and the nature of knowing" (Jackson & Talbert, 2012, p. 244) directly influence the teaching strategies

they employ. In other words, teachers' beliefs about how knowledge is acquired ultimately determine how they teach their students.

Teacher Learning Beliefs Impact Teaching Beliefs

Rosenfeld and Rosenfeld (2006) conducted a study to determine the reasons some teachers readily embrace reform-based teaching while others are highly resistant to it. They asked 11 middle school science teachers to participate in three four-hour workshops to better understand their individual learning differences (ILDs), or preferred approaches to acquiring knowledge. Following these workshops, the participant teachers completed learning style inventories and a survey regarding preferred learning environment. The survey responses were then analyzed to determine those teachers whose individual learning style was in alignment with constructivist teaching and those who aligned better with traditional pedagogies. Teachers who themselves held epistemological beliefs that learning science from an authority figure was appropriate were frustrated and uncomfortable with constructivist learning environments. Conversely, teachers who preferred to learn in environments where knowledge was applied embraced constructivist teaching and expressed joy for teaching using constructivist pedagogies. The results of this study show that individual epistemological beliefs often stem from teachers' own learning styles and can be a major barrier for epistemologically traditional teachers asked to adopt reform-based pedagogies.

Student Learning Beliefs Impact Teaching Beliefs

As Rosenfeld and Rosenfeld (2006) studied the link between ILDs and the implementation of constructivist pedagogy, Bennett and Park (2011) also investigated the underlying reasons why science teachers adopt traditional or constructivist teaching

pedagogies. To examine how teachers' epistemological beliefs impact their teaching practice, the researchers employed a case study approach. A single secondary biology teacher was selected for the study because he was an experienced teacher who identified with both constructivist and traditional methods of teaching. Data were collected through classroom observations and interviews over the course of 1.5 years. The researchers found that this teacher used either constructivist or traditional pedagogies in response to specific influencing factors. Though this teacher was often conflicted about which pedagogies to employ, he often resorted to traditional methods because his beliefs related to student learning were the most influential on his teaching style. In effect, in accordance with his epistemological beliefs, and in congruence with his beliefs about student abilities, this teacher tended to adopt a traditional approach to teaching.

Epistemological Beliefs are Influenced by Teacher Efficacy and Perceived Support

Lucero et al. (2013) argue that both teacher efficacy beliefs and context beliefs together inform science educator teaching practice, and specifically the level of inquiry in the classroom. The researchers conducted a qualitative study to determine the impact that efficacy and context beliefs had on teachers' likelihood of implementing structured or open inquiry in their classrooms. The authors clarify that efficacy beliefs are teachers' beliefs in their abilities to successfully implement inquiry in their classrooms, whereas context beliefs refer to teacher beliefs about how conducive the teaching environment and people surrounding that environment are for implementing inquiry pedagogies. The researchers selected 300 science teachers to complete a self-assessment survey designed to understand the extent teachers implemented either structured or open inquiry in their classes, their efficacy levels, and their levels of satisfaction with their teaching

environment as a support tool to enact higher levels of inquiry in their classrooms. The survey responses showed that those teachers with low-efficacy beliefs provided structured inquiry opportunities to their students as opposed to those with high-efficacy beliefs, who used progressively more open inquiry strategies. Additionally, teachers with high context beliefs used more open inquiry approaches as opposed to those with lower context beliefs, who preferred structured inquiry. The results of this study show that the enactment of open inquiry in the classroom is impacted by both teacher efficacy and context beliefs. These results indicate that while teachers' epistemological beliefs can be positively oriented to open inquiry approaches, with low efficacy or context beliefs, it is unlikely that open inquiry will be enacted in the classroom. Indeed, as an early career science teacher, I specifically struggled with low efficacy beliefs and thus avoided implementing open inquiry in my classroom.

Teacher Motivation and Readiness for Constructivist Teaching Impact Practice

As described in Chapter One, the adoption of the NGSS corresponds to an increased need to implement open inquiry methods in the science classroom. However, adopting increasingly open forms of inquiry requires a substantial shift in teaching practice for science teachers, often in direct conflict with their epistemological beliefs. Haag and Megowan (2015) conducted a mixed-methods study aimed at determining "the readiness and motivation of middle and high school in-service teachers to apply NGSS science and engineering practices in their classrooms" (p. 416). To determine the readiness of these teachers, the researchers attempted to "discern the characteristics of teachers who feel well prepared to implement NGSS practices" (p. 418) by collecting survey data from a total of 710 in-service middle and high school science teachers across

the United States. The survey consisted of Likert-scale questions wherein teachers were asked to rate their motivation and readiness to implement the NGSS SEPs. In addition, teachers were provided the opportunity to comment on their NGSS motivation and readiness in a comment box and were allowed to express any concerns in these areas. The quantitative results showed that high school science teachers feel more motivated and prepared to implement the SEPs of the NGSS than their middle school counterparts. However, the results of the open-ended response data revealed that the high school science teachers still felt “anxious about inadequate training, limited instructional time, and lack of resources” (p. 422). Moreover, the qualitative data revealed that “many teachers considered the [NGSS] to be too complex [and] in some cases exceeding the knowledge and training of the educators who would be expected to teach the content” (p. 422). My own early experiences trying to implement the NGSS mirror this finding as I felt overwhelmed with the complexity of ensuring that students were effectively demonstrating content knowledge, while also adhering to the essence of the NGSS in the context of constructivist pedagogy. The findings of this study also help teachers and administrators to “identify factors affecting implementation and teacher readiness, particularly in the area of science and engineering practices” (p. 424). In this regard, professional development strategies aimed to aid science teachers with the implementation of the SEPs can promote the use of the practices.

As described in Chapter One, my experiences in my teacher preparation program did not adequately prepare me for teaching in the constructivist science classroom, and I did not receive the professional development experiences that Haag and Megowan (2015) indicate are crucial for novice teachers to successfully implement the NGSS in their

classrooms. As a result, during the summer prior to my school's adoption of the NGSS, I independently researched the essence of the NGSS as well as the pedagogical strategies that could aid me with successful implementation of the NGSS. As my early experiences implementing the NGSS in my classroom resulted in significant frustration, I turned to action research as a self-motivated opportunity for professional development aimed at carefully considering the constructivist strategies to use in my classroom that might promote a transition in my epistemological beliefs.

Strategies to Enact the Science and Engineering Practices in the Classroom

The 5E Learning Sequence

Though the literature reveals many reasons science teachers are resistant to open inquiry implementation, a number of strategies are available to aid science educators with infusing the SEPs into their lessons. In *Translating the NGSS for Classroom Instruction*, Bybee (2013) asserts that science educators ought to think beyond simply planning lessons, to planning integrated sequences of instruction wherein all three dimensions of the NGSS are addressed, namely through the 5E model of instruction, which invites students to engage, explore, explain, elaborate, and evaluate a particular scientific phenomenon. Of these 5Es, the explore portion allows the greatest exposure to the SEPs, though Bybee (2013) argues that "the learning experiences [across all 5Es] should contribute to students' development of the scientific or engineering practices, crosscutting concepts, and disciplinary core ideas" (p. 56). The explore portion of the 5E sequence "should provide students with a common base of experiences within which they identify and begin developing science ideas, concepts, and practices" (p. 58). In effect, during the exploratory phase of the 5E sequence, students participate in open inquiry.

Performance Expectations can Guide Lesson Planning

Krajcik et al. (2014) also propose a multi-step process to guide teachers in developing a sequence of lessons to build student proficiency in the three-dimensions of the NGSS. They propose that teachers arrange the performance expectations (PEs) of the NGSS into coherent "bundles." Teachers ought to look at the three dimensions presented in each bundle and ask themselves "what understandings need to be developed? What content ideas will students need to know? What must students be able to do?" (p. 163). Once these questions have been answered teachers can "identify [the] science and engineering practices that support instruction of the [disciplinary] core ideas" and then "develop a coherent sequence of learning tasks that blend together various science and engineering practices with the core ideas and crosscutting concepts" (p. 163). Doing so provides teachers who are inexperienced with the NGSS a framework from which they can develop instructional sequences that align to the vision of the NGSS. Following this advice, this qualitative action research study used a distinct instructional sequence to collect data, which will be described in greater detail in Chapter Three.

Sequential Fluctuation Between Traditional and Constructivist Pedagogies

Smithenry (2010) presents a less abstract model of implementing inquiry in traditional chemistry classrooms. Through a case study, he observed the strategies that a high school chemistry teacher used to infuse inquiry into her curriculum, while still maintaining elements of traditional pedagogies. Though this research was published prior to the release of the NGSS, many of the components of inquiry that the participant teacher used in the classroom mimic the SEPs. Following observations, Smithenry (2010) proposed a 4-step model to integrate inquiry into a chemistry curriculum: 1) the teacher

uses traditional pedagogies to introduce the topic of interest, 2) the teacher transitions to inquiry by allowing students to explore the topic further in ways that promote an open-inquiry approach, 3) the students engage in the inquiry, and 4) the students transition out of the inquiry experience by reflecting on the experience in a traditional context. While this model does not adequately encompass the crosscutting concepts presented in the NGSS, it does address both the disciplinary core ideas (DCIs) and, more importantly, the SEPs in ways that may be more comfortable for teachers, like me, whose epistemological beliefs conflict with constructivist pedagogies. This sequential fluctuation between both traditional and constructivist pedagogies was the approach taken to implement the NGSS in my classroom during this qualitative action research study and will be described in depth in Chapter Three.

Argument-Driven Inquiry

Though the lesson planning strategies of Bybee (2013), Krajcik et al. (2014), and Smithenry (2010) provide a general overview of how science teachers can implement the three dimensions of the NGSS in their classrooms, they do not go into great specificity in any one area of the SEPs. In contrast, Sampson et al. (2015) attempt to provide a framework for science educators to incorporate open inquiry into their practice with their book *Argument-Driven Inquiry in Chemistry: Lab Investigations for Grades 9-12*. The argument-driven inquiry (ADI) approach involves eight steps for completing open inquiry tasks: 1) identification of the task, 2) designing a method and collecting data, 3) data analysis and development of a tentative argument, 4) argumentation session, 5) explicit and reflective discussion, 6) writing the investigation report, 7) double-blind group peer review, and finally 8) revision and submission of the investigation report.

Together, the authors argue, these eight steps provide students with open-inquiry experiences that allow them to engage with all three dimensions of the NGSS, and even the Common Core State Standards (CCSS). While the authors strongly suggest chemistry educators use all eight steps of the ADI approach, they acknowledge that teachers "must decide when and how to use a laboratory to best support student learning" (p. 20). In effect, teachers just beginning the process of transitioning from traditional to constructivist pedagogies may choose to use only a few steps of the ADI approach to get themselves, and students, comfortable with certain aspects of the NGSS. For example, a chemistry teacher who is most interested in exploring the implementation of the SEPs may choose to omit steps five through eight of the ADI model's eight-step method. As students gain proficiency in planning and conducting investigations, collecting and analyzing data, and constructing an argument from evidence, steps five through eight can gradually be included. The benefit of the ADI model is that it "provides science teachers with a way to transform classic or traditional lab activities into authentic and educative investigations that enable students to become more proficient in science" (Sampson et al., 2015, p. 19), particularly as they transition from traditional to constructivist pedagogies.

Claim, Evidence, Reasoning as Components of a Scientific Argument

The ADI model proposed by Sampson et al. (2015) emphasizes the importance of the science and engineering practice of engaging in argument from evidence, indicating that a good scientific argument is composed of three distinct parts: a claim, evidence to support the claim, and scientific reasoning or justification that supports the overall argument. The claim is a simple answer to the guiding question of the investigation, the evidence consists of the data (measurements or observations) collected during the

investigation that supports the claim, and the reasoning or justification is the underlying scientific principle that defends students' choice of evidence to support their claim. Though Sampson et al. (2015) advocate for an extensive argumentation session wherein various lab groups present their arguments, followed by an extensive written report, Bjorn (2018) asserts that extensive lab reports are not required to assess and promote science students' conceptual understanding. Rather a "mini-poster," or a one-page standard letter sheet of paper, is sufficient for students "to synthesize their laboratory findings by providing a Claim, Evidence, and Reasoning [CER] statement" (p. 23). In effect, Bjorn's (2018) suggestion eliminates the need for the extensive investigation report proposed by Sampson et al. (2015), but still promotes the SEP of engaging in argument from evidence. Streamlining the argument presentation in this way not only focuses students on developing skills related to constructing an effective argument, but also promotes the accessibility of the NGSS by English language learners (Bjorn, 2018), thereby enhancing equity in the science classroom. Further, both Bjorn (2018) and Sampson et al. (2015) reflect on the importance of students' communicating their arguments to the class as a whole, as a means to address the SEP of obtaining, evaluating, and communicating information. A reasonable strategy for science teachers wishing to incorporate the SEPs with greater frequency in their classrooms may be to employ a combination of both Sampson et al.'s (2015) and Bjorn's (2018) proposed strategies. Chapter Three will provide greater detail about the use of Sampson et al.'s (2015) ADI model and Bjorn's (2018) "mini-poster" strategy to engage students in the SEPs in my classroom.

The Road to Changing Epistemological Beliefs

Beliefs about teaching and learning have a profound effect on teachers' pedagogical decisions and actions in the classroom (Bennett & Park, 2011; Herrington et al., 2016; Hutner & Markman, 2016; Wall, 2018; Zambak et al., 2017). Particularly during times of curricular reform, cognitive dissonance arises wherein a teacher's deep-rooted epistemological beliefs conflict with beliefs about the benefits of the proposed curricular reform. While classroom implementation of the NGSS is possible with the tools proposed by Bybee (2013), Krajcik et al. (2015), Sampson et al. (2015), Bjorn (2018), and so on, additional interventions may aid teachers with adapting their epistemological beliefs so that they are in greater congruence with current reform practices.

Time and Experience Can Result in Epistemological Change

Wall (2018) asserts that, in fact, no intervention is needed to change a teacher's epistemological beliefs. Rather, epistemological beliefs develop and change over time with years of teaching experience, as evident through a longitudinal, mixed-methods study wherein six pre-service teachers participated in surveys and interviews over the course of nine years. Data were collected in two segments: first to determine participant beliefs at the onset of their teacher preparation program, and again six years after the completion of the teacher preparation program. The results of this longitudinal study found that the pre-service teachers often held egocentric epistemological beliefs, wherein they believed that students learned best using pedagogies that were most effective for them, when they were students themselves. In fact, these teachers held epistemological beliefs in alignment with traditional pedagogies during their teacher preparation program

and during the early years of their teaching experience. As these teachers experienced more learners and gained more classroom experience, their epistemological beliefs "[shifted] from employing egocentric rationales to utilizing a more student-centered approach" (p. 38). In effect, with greater classroom experience "egocentrism [diminishes] and awareness of student diversity [intensifies]" (p. 38), such that teachers with greater classroom experience recognize the need to employ pedagogies that will reach a wider cross-section of learners, with learning styles that differ from their own. The findings of this study suggest that teachers who are in the early years of their teaching experience at the time reform movements gain momentum may initially resist the change, but may recognize the change as beneficial, and develop epistemological beliefs that align with the proposed reform, with time and experience. Wall's (2018) assertion encouraged me as I began this qualitative action research study to examine how student experiences with NGSS-aligned tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning.

Professional Development Experiences Favor Epistemological Change

Rather than allowing time and experience alone to promote a change in epistemological beliefs, participation in professional development experiences might also hasten the shift. Zambak et al. (2017) employed a quasi-experimental design to determine if teacher participation in a professional development (PD) experience designed to improve inquiry-based instruction (IBI) might be beneficial for altering a teacher's epistemological beliefs, as a construct of their efficacy and context beliefs about classroom inquiry. Seventy middle school science teachers were recruited to participate in a PD program designed to improve the quality of their IBI. During the course of this

PD experience, participant beliefs and implementation of inquiry were measured at various points in time with a belief survey and classroom observations. Additionally, student achievement was measured using a computer adaptive test that assesses student academic progress. Student achievement data were necessary because the researchers intended to follow Guskey's (2002) model of teacher change, wherein "changes in teachers' instructional practices and student achievement *precede* [emphasis added] changes in [beliefs]" (Zambak et al., 2017, p. 109). The results of this study showed that the PD experience "was effective in enabling teachers to change their beliefs and their instructional practices" (p. 113). Echoing Guskey's (2002) model of change, teacher beliefs changed "as long as they saw evidence of growth in their student's achievement" (p. 113). The results of this study show that PD programs aimed at assisting teachers with implementing inquiry in their classroom may be effective at enacting teacher epistemological change according to Guskey's (2002) model. In other words, epistemological beliefs are likely to be changed when student achievement improves following inquiry experiences; however, inquiry experiences that promote improved student achievement may require PD experiences to successfully develop.

Research Experiences for Teachers Impact Epistemological Change

The purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. To pursue this purpose, I conducted qualitative action research in my own classroom, with my own students as participants, while monitoring my epistemological beliefs. As I actively examined my problem of practice the results of Herrington et al.'s (2016) study were a powerful

motivator for my own research. Herrington et al. (2016) conducted a qualitative study to examine the effect of a research experience for teachers (RET), as part of a PD experience, on teacher beliefs, attitudes, and values about inquiry-based science instruction. They argue, “PD programs that adopt RETs to transform K-12 science teachers’ understanding and practice of inquiry have the potential to be pivotal in achieving the NGSS vision” (p. 184). The authors distinguish between beliefs, attitudes, and values by stating that each is a disposition that occurs on a spectrum of increasing deep-rootedness. In other words, inquiry beliefs are individual judgments about what is good and bad about inquiry-based instruction, inquiry attitudes are those expressions “that indicate an enduring increase in preference to enact behaviors that reflect…beliefs about inquiry” (p. 186), and inquiry values are the internal drives for inquiry behaviors that become preferable to an individual. The RET, as part of the PD experience, matched teachers to mentors based on interests in inquiry-based instruction. During the RET, teachers were required to review literature, master laboratory techniques, and collect and analyze data in relation to the inquiry-based instruction implemented in their teaching practice. To determine if the RET resulted in changes in teacher beliefs, attitudes, and values about inquiry-based instruction, interviews were conducted with thirteen middle and high school science teachers both before the RET and again one year after the start of the RET. Interview data were transcribed, coded, and analyzed, and the researchers found that all of the thirteen teachers had some degree of a belief change after participating in the RET. Seven out of the thirteen teacher participants exhibited a change in attitude toward inquiry-based attitudes, and only two teachers experienced a value change as a result of the RET. Herrington et al. (2016) distinguish between changes in beliefs,

attitudes, and values in an important way: "teachers with a value change expressed their goals as educators in terms of a focus on their students', colleagues', and district's growth, while teachers with a belief or attitude change were still focused on helping their students *and* developing themselves as effective educators" (p. 200). These results are profound in that they indicate that RETs are beneficial at not only changing beliefs, but can also promote the highest level of epistemological change, a change in epistemological *values*.

Summary

The NGSS constitute a three-dimensional approach to science teaching, wherein disciplinary core ideas are presented alongside science and engineering practices and crosscutting practices to deliver a science curriculum that promotes the development of authentic science student learning (NRC, 2012). Though the goals and the vision of the NGSS are amenable to science educators, as the literature in this chapter attests, the actual implementation of the vision is a complex undertaking. Such an adjustment requires tremendous changes in beliefs and attitudes by all who are affected. Those affected by the NGSS acknowledge the inevitability of this change; however, many experience "a profound conservative impulse [governing their] psychology, making [them] naturally resistant to change and leaving [them] chronically ambivalent when confronted with innovation" (Evans, 1996, p. 21). Change, particularly in classroom contexts, can be difficult to realize, as it requires educators to embrace viewpoints, ideas, and theoretical perspectives that are often in conflict with their experiential backgrounds and resultant belief systems.

Teacher epistemological beliefs constitute a significant barrier to realizing the central goals and visions of the NGSS. Changing teacher epistemological beliefs occurs only with classroom experience, support, and continued professional development. While the literature supports the notion that changing teachers' epistemological beliefs is possible, it is a change that requires significant time and effort.

The present action research study revolves around my own epistemological beliefs and their dissonance in relation to the vision of the NGSS. The vision of the NGSS promotes science teaching wherein students are active constructers of their own science knowledge, while my epistemological beliefs strongly conflict with this vision. Thus, my study intentionally involved the implementation of the NGSS in my chemistry classroom in ways that can promote a shift in my epistemological beliefs in favor of the vision of the NGSS. A description of the implementation of the NGSS in my chemistry classroom, as informed by the literature above, will be discussed in greater detail in Chapter Three.

CHAPTER 3

METHODOLOGY

As the previous chapter illustrated, moving from traditional to reform-based pedagogies in the science classroom can be a task fraught with uncertainty and struggle. However, in states that have currently adopted the Next Generation Science Standards (NGSS), reform-based pedagogies are necessary to ensure students are meeting state-mandated science curriculum goals. The adoption of the NGSS at the state level also means that science educators no longer have the autonomy to continue implementing traditional pedagogies in the classroom, despite their personal epistemological beliefs. As a result, science teachers whose epistemological beliefs conflict with the constructivist pedagogies outlined in the NGSS often struggle to implement the NGSS in their own classrooms. Consequently, the purpose of this qualitative action research study is to examine how student experiences with NGSS-aligned tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning.

To pursue this purpose, I presented a series of inquiry activities to my college preparatory (CP) high school chemistry classes. The activities directly aligned with the NGSS and specifically addressed the Science and Engineering Practices (SEPs), providing students with opportunities to engage in learning tasks that embodied the essence of the NGSS. During these learning opportunities, I collected data to answer the following two research questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?
2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

The remainder of this chapter will provide a detailed description of the participants and the setting of the study. Additionally, the chapter will include a discussion of the rationale for the specific action research methodology, as well as a discussion of the data collection tools. Specifically, the chapter will describe the inquiry activities, interview protocols, student artifacts, observations, and teacher reflections that I used. Finally, the chapter will conclude with a rich description of the data analysis strategies chosen to answer the research questions.

Context, Participants, and Researcher Positionality

Context

This action research study was conducted in a college preparatory (CP) chemistry classroom at a highly diverse, urban high school that is a public charter school in a suburb of Los Angeles. According to the school site's 2017-18 School Accountability Report Card, the student population at this charter high school is about 40% Hispanic/Latino, about 25% white, and about 35% other minorities such as African American, Asian and Pacific Islander. Additionally, approximately 50% of the student population is socioeconomically disadvantaged. It is also important to note that prior to

conducting this qualitative action research study, the research protocol was submitted to both the University of South Carolina and school district and subsequently approved by both entities.

A typical college preparatory chemistry class contains 36 students, aged 15-17, from a variety of cultural, socioeconomic, and academic backgrounds. As noted in earlier chapters, this qualitative action research study was conducted during the Thermochemistry unit, which is typically presented during the second semester of the school year, because the disciplinary core ideas of the unit can be readily explored through the SEPs of the NGSS.

Because I used my own students as participants, and subsequently reflected on my own epistemological beliefs as my student participants interacted with the pedagogical strategies I implemented, a qualitative action research approach was most appropriate for my study. Since I executed the study "for the purpose of solving a problem or obtaining information to inform local practice" (Fraenkel et al., 2015, p. 587), it qualifies as action research. I anchored my action research in a qualitative methodology since qualitative research provides insight into classroom experiences and serves as a basis for bringing about a desired change in practice (Efron & Ravid, 2013).

Participants

As this qualitative action research study explores how student participation in NGSS-aligned learning tasks impacts my epistemological beliefs, student participants were essential to address the research questions so that student engagement and understanding might, as expected, influence my epistemological beliefs (Roehrig & Luft, 2004; Savasci & Berlin, 2012).

The target participant sample included 24 purposively sampled students from three (3) college preparatory chemistry classes. The rationale for this target participant sample is rooted in two reasons: first, since three (3) CP classes were used to recruit participants, eight (8) student participants from each class would account for approximately 25% of the class population. Second, semi-structured focus group interviews were used as a data collection instrument, and Fraenkel et al. (2015) assert that no more than eight (8) participants should participate in a focus group interview at one time. With this in mind, a purposive sample of approximately 24 students limits focus group interview sessions to no more than three (3). Though the target participant sample was 24 students, only 15 purposively sampled students ultimately opted to participate in this qualitative action research study. This discrepancy and the potential limitations of this discrepancy will be discussed in further detail in Chapter Five.

Participant Sampling Strategy

Purposive criterion sampling was used to select the participants for this qualitative action research study so the participant sample would be representative of the wide variety of students in my CP chemistry classes. The students were selected based on their identified cultural backgrounds, their age, their academic background, and their linguistic background, thereby ensuring maximum variation of the sample (Merriam & Tisdell, 2016). Furthermore, student participants were selected to equally represent both male and female students and thereby “ensure that diverse perspectives are represented” (Efron & Ravid, 2013, p. 62). Additional information on the participants will be provided in Chapter Four. It is also important to note that all participants have provided consent (see Appendix A), along with parent/guardian permission to participate.

Researcher Positionality

As a participant researcher, I must acknowledge my positionality to elaborate on who I am in relation to my participants and setting (Herr & Anderson, 2015). The purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. To conduct the research, I provided my students opportunities to engage with the SEPs, and then by way of observations, artifacts, and focus group interviews, analyzed student conceptual understanding and engagement. Student demonstrations of conceptual understanding and engagement were expected to influence my epistemological beliefs, and any impacts on my epistemological beliefs were documented in a personal reflection journal. Due to the overall structure of this qualitative action research study, I took the position of an insider action researcher (Herr & Anderson, 2015), which allowed me to pursue a professional self-transformation by transitioning from traditional to constructivist epistemological beliefs, particularly as I teach in a state that has formally adopted the NGSS. As an insider action researcher, I conducted this qualitative action research study in my own classroom setting, using my own students and myself as participants in the study. It is important, however, to explain that this qualitative action research study does not view the students as insiders, as the aim of the study was to promote a transformation of my own epistemological beliefs. Nevertheless, this study still benefitted the student participants, as the pedagogical implementations were in alignment with the current NGSS.

Biases Related to my Positionality

As an insider action researcher (Herr & Anderson, 2015), I must further address biases and power struggles associated with this position. An implicit aim of this qualitative action research study was to ultimately influence my epistemological beliefs in favor of constructivism, thereby alleviating my problem of practice. As a result, I ran the risk of "unconsciously distort[ing] the data in such a way as to make an [epistemological transition more likely]" (Fraenkel et al., 2015, p. 171). Additionally, the student participants from whom data were collected during the study were my own students, who likely viewed me as an authority figure in the classroom, thus, their interview responses may have reflected what participants assumed I wanted to hear, rather than their authentic feelings. My study design, described below, sought to mitigate these concerns by incorporating semi-structured interviews in a focus group format. Doing so encourages participants to provide authentic responses to interview questions, as they listen to and reflect on the responses of their peers.

Research Design

This qualitative action research study examined the impact of reform-based pedagogical implementation in the high school chemistry classroom on my epistemological beliefs. Klehr (2012) asserts that "qualitative methods [are] a more organic and complexly instructive way to …explore…questions about practice and pedagogy" (p. 122). Similarly, Efron and Ravid (2013) indicate that qualitative research focuses on "the meanings of …experiences" (p. 40) in the natural setting of all participants. As this qualitative action research study examined the relationship between students' interactions with constructivist pedagogies and the influence these interactions

have on my epistemological beliefs, I searched for meaning in student behaviors, responses, and artifacts, which underscores the central purpose of qualitative research (Creswell & Creswell, 2018).

Grounded Theory

This qualitative action research study focuses on the transition in my epistemological beliefs as a result of student experiences with NGSS-aligned learning tasks, and a grounded theory approach is valuable for describing this transition because "the purpose of grounded theory is to inductively generate theory that is grounded in, or emerges from, the data" (Bloomberg & Volpe, 2019, p. 55). Through the data collected in this qualitative action research study, I aimed to identify and pursue the transition in my epistemological beliefs as a result of student participation in NGSS-aligned learning tasks; because of this, anchoring my research in the tradition of grounded theory was the most appropriate approach.

This grounded theory action research study was further conceived in the constructivist-interpretivist research paradigm (Durdella, 2019). The constructivist-interpretivist paradigm in qualitative research assumes that meaning is constructed socially through interactions between all parties involved in the research and the multiple perspectives of these parties ultimately leads to the construction of meaning (Durdella, 2019). As the purpose of this qualitative action research study was to determine how student experiences with the NGSS ultimately influence my epistemological beliefs, I constructed meaning through the perspectives of my students' experiences, as well as my experiences engaging with student participants during the intervention. It is important to note that because an inductive approach to data analysis was preferred in this qualitative

action research study, a constant comparative approach to data analysis was compatible, as this approach to data analysis aids action researchers who seek to build a grounded theory (Merriam & Tisdell, 2016). The constant comparative method of data analysis assumes that data collection and analysis occur concurrently (Durdella, 2019) and a theory is suggested during each cycle of data collection and analysis; however, following simultaneous data collection and analysis, a theory was not suggested until all data were collected and analyzed from the instruments described above. Though preliminary theories were not explicitly stated following each cycle of data collection and analysis, emergent theories were noted, and used to guide subsequent cycles of data collection and analysis.

The decision to root this qualitative action research study in the tradition of grounded theory ultimately required decisions about "whom to talk with or observe, how to talk with or observe them, and how to make sense of what they say or do" (Durdella, 2019, p. 93). The investigation in this study centers on the implementation of the following specific SEPs: developing and using models, using mathematics and computational thinking, constructing explanations and designing solutions, and planning and carrying out investigations, to determine how student engagement with these SEPs influences my epistemological beliefs. CP chemistry students interacted with these SEPs through a series of inquiry-oriented activities, and their experiences and understandings were best understood by way of observations, focus group interviews, and student-generated artifacts. This investigation incorporated the "explore" component of Bybee's (2013) 5E model of NGSS implementation in the science classroom. Furthermore, the investigation took place over a series of class meetings and included three (3) discrete

opportunities for students to explore several of the disciplinary core ideas (DCIs) of the Thermochemistry unit. As Bybee (2013) asserts, “a useful perspective is to approach the translation [of the NGSS in the science classroom] as a sequence of lessons” (p. 6). Between each of these three (3) discrete opportunities for students to engage with the SEPs, a pause in data collection - “a clear point in fieldwork activities that promotes the use of data analysis into the data collection” (Durdella, 2019, p. 103) occurred to allow an opportunity for data analysis following each intervention segment. In other words, in accordance with the grounded theory tradition, data were collected, and then preliminary data analysis was conducted to shape what occurred during the next segment of data collection (Durdella, 2019). A diagram of the research design is seen in Figure 3.1

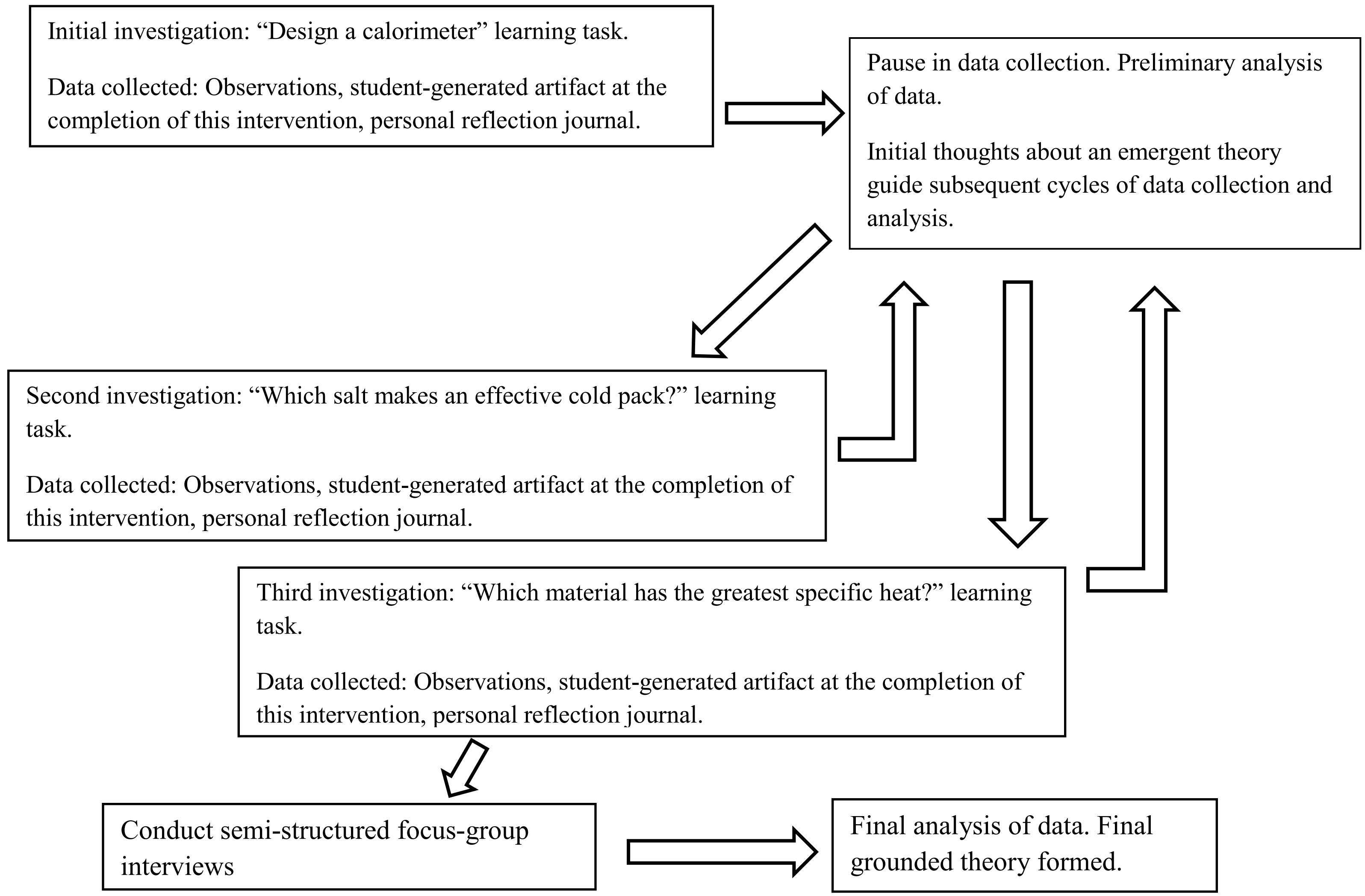

Figure 3.1 Overview of Grounded Theory Research Tradition

As can be seen in Figure 3.1, a constant, non-linear cycle of data collection and data analysis followed the constant comparative method used in grounded theory qualitative research studies (Durdella, 2019; Fraenkel et al., 2015; Merriam & Tisdell, 2016). Additionally, Figure 3.1 shows that semi-structured focus-group interviews were conducted after all three (3) interventions took place. As "semi-structured interviews are often best conducted toward the end of a study [in qualitative research]" (Fraenkel et al., 2015, p. 449), doing so provided me with an opportunity to elicit participant responses that further investigate data collected earlier in the study. Earlier data were used to ground the emerging theory in relation to my research questions.

Data Collection Instruments

To answer my research questions, I used a variety of data collection instruments. In alignment with qualitative grounded theory, the instruments included observations, semi-structured interviews, student-generated artifacts, and a personal reflection journal. Qualitative researchers typically use three main data collection instruments: "observing people as they go about their daily activities[;]…conducting in-depth interviews with people about their ideas, their opinions, and their experiences; and analyzing documents [such as artifacts]" (Fraenkel et al., 2015, p. 443). Additionally, a personal reflection journal enabled me to document my opinions about the use of traditional versus reform-based pedagogies in my classroom and track any changes in my epistemological beliefs as a result of student participation in NGSS-aligned learning tasks.

Observations

Observations were conducted during each of the three (3) investigation segments of this study, when student participants engaged in inquiry activities that emphasize the

SEPs of the NGSS. As a practitioner researcher, I could not entirely refrain from observing all of my students irrespective of their consent to participate in this qualitative action research study. However, while all of my students were carefully observed as they participated in the planned NGSS-aligned learning tasks, only those students who submitted consent forms were invited to participate in the semi-structured focus group interviews, and I only collected artifacts from those students. Choosing to observe all of my students as they participated in the planned NGSS-aligned learning tasks effectively removed the complications associated with participant attrition when conducting focus group interviews. Had participants removed themselves from the study prior to the focus group interview, I wanted to ensure that *all* interview participants had been carefully observed participating in the NGSS-aligned learning tasks.

As this is a qualitative action research study, observations are crucial since "the intimacy and closeness in social settings that you can experience through participant observation is nearly unmatched in the field of qualitative research" (Durdella, 2019, p. 223). Indeed, observing students as they socially constructed conceptual meaning and used their metacognitive skills to solve problems provided me with intimate insight regarding their learning and engagement. As a teacher studying my own students, I assumed the role of an overt participant observer (Fraenkel et al., 2015), and as such all of my students were aware they were being observed. As a practitioner researcher, I carefully balanced my role as a researcher and a teacher. In other words, my goal was to continue interacting with all of my students and offering teacher support while also simultaneously collecting observation data from all of my students.

To ensure that observations were conducted in a manner that directly targeted my research questions, I used a set of questions to guide my observations (Durdella, 2019).

- What is the setting in which students are interacting?
- How are students grouped and positioned in those groups?
- How are students interacting with each other?
- What are students saying to each other?
- How is student metacognition evident?
- How are students persevering with the task?
- Is there evidence of student engagement?

In the process of responding to the questions above I recorded descriptive and reflective (Durdella, 2019) field notes. Both of these types of field notes provided their own insight into the research problem, as "descriptive field notes detail the people, places, and events" that are evident in the research setting, while "reflective field notes…allow [a researcher to reflect on] new ideas, important insights, or emerging patterns from fieldwork" (Durdella, 2019, p. 223). Following the observation guide above allowed me to better understand how students were engaged, both behaviorally and cognitively, within the investigation. In other words, student engagement could be demonstrated by statements of enthusiasm, whether to themselves or with their peers, or even by body language that suggested total engagement with the activity. Conversely, observations could also provide evidence of students' lack of engagement with the intervention e.g. expressions of boredom or frustration in verbal or non-verbal communications with themselves or their peers.

Observations of students gave me insight related to research question one; how does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of college preparatory high school chemistry students? In addition, observations as a data collection tool allowed me as a practitioner researcher to make "more authentic claims about [my] own thinking and understanding" (Pinnegar & Hamilton, 2009, p. 112) in the context of my changing epistemological beliefs. In other words, as an active observer, I engaged in immersive understanding of the "nuance of action and the subtlety of word" (p. 117) of my student participants, both of which facilitated my understanding of their influence on my epistemological beliefs.

Personal Reflection Journal

A personal reflection journal was also used as a data collection instrument during this qualitative action research study to record "open-ended writing on [my] experiences, feelings, and reflections" (Coleman & Leider, 2014, p. 57) following each intervention. In addition to recording open-ended reflections of day-to-day experiences, I addressed two prompts daily during each of the intervention segments:

- What did I observe or experience today that reinforced my epistemological beliefs? In other words, what did I observe or experience that supports the use of traditional instruction to aid with student understanding and engagement?
- What did I observe or experience today that contradicted my epistemological beliefs? In other words, what did I observe or experience that negates the use of traditional instruction methods, and instead promotes the use of reform-based pedagogies?

By addressing these two specific prompts each day during the study, I was better able to focus my personal reflections on addressing the problem of practice and the research questions. Furthermore, addressing two specific prompts provided a better opportunity for me to track changes in my epistemological beliefs over the course of the study.

Student-Generated Artifacts

Prior to conducting the semi-structured focus group interviews, student-generated artifacts were collected following each NGSS-aligned learning task and analyzed for evidence of student understanding of the DCIs. The artifacts were in "mini-poster" format (see Appendix B), as Bjorn (2018) asserts that extensive written lab reports are not required to assess and promote science students' conceptual thinking or nature of science skills. Rather, a "mini-poster," or a one-page standard letter sheet of paper, is sufficient for students "to synthesize their laboratory findings by providing a Claim, Evidence, and Reasoning statement" (p. 23). Though this study employed a qualitative methodology, student-generated artifacts were analyzed according to both the manifest and latent content (Fraenkel et al., 2015). Schreier (2014) argues that the main difference between quantitative and qualitative content analysis is the use of *either* the manifest or latent meaning respectively, whereas both the manifest *and* latent meaning of the student-generated artifacts are notable for this qualitative study.

As previously mentioned, this qualitative action research study was conducted during the Thermochemistry unit, and the specific NGSS standards that are associated with this unit are HS-PS3-3 and HS-PS3-4 (NGSS Lead States, 2013). Standard HS-PS3-3 reads: "Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy" (NGSS Lead States, 2013, p. 255). The

NGSS Lead States (2013) clarify that the emphasis of this standard is on both the qualitative and quantitative evaluations of the device. With that said, students were required to both qualitatively and quantitatively analyze their device, and thus their artifacts were analyzed for both their manifest and latent content.

As shown in Figure 3.1, this action research study begins with an inquiry activity wherein students design their own calorimeter device. This inquiry activity aligns with NGSS standard HS-PS3-4, which reads: "Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined with a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics)" (NGSS Lead States, 2013, p. 255). Again, the NGSS Lead States (2013) clarify that the emphasis of this standard is on "analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually" (p. 255). As students were required to communicate mathematical thinking, as well as depth of conceptual understanding, the manifest and latent content of these artifacts were also considered. Student generated artifacts were analyzed specifically for mathematical logic and sound scientific reasoning to support this logic, according to a rubric.

Semi-Structured Focus Group Interviews

Detailed field notes from observations provided the context for semi-structured focus group interviews, which were used to collect data from student participants regarding their experiences with the intervention. The rationale for using interviews as a data collection tool is that "interviewing is an important way for a researcher to check the

accuracy of – to verify or refute – impressions gained through observation" (Fraenkel et al., 2015, p. 448). With that said, the semi-structured focus group interviews were conducted at the end of the study. Semi-structured interviews were preferred over structured interviews because "less-structured [interview] formats assume that individual respondents define the world in unique ways" (Merriam & Tisdell, 2016, p. 110). In other words, to better answer the study's research questions, I sought to learn about the perspectives of all participants in a way that promoted their ability to authentically share their own personal experience. Furthermore, a semi-structured interview "allows the researcher to respond to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topic" (Merriam & Tisdell, 2016, p. 111). Again, to gain greater clarity on the authentic thoughts, feelings, and experiences of participants, I strove to be flexible during the interview process and avoid the rigidity of structured interviews.

A focus group format was used to conduct semi-structured interviews for a variety of reasons. First, as the participants are high school students, a focus group eliminated the discomfort some teenaged participants may feel in a face-to-face, one-on-one interview environment. Second, as the intervention experience relied on student participation in a social context, it was sensible for student participants to reflect on their experiences in a social context as well. A focus group provides a "social context where the participants can hear the views of others and consider their own views accordingly" (Fraenkel et al., 2015, p. 455). All focus group interviews lasted approximately one hour, were conducted in my own classroom setting, and covered several core questions. Because the participant sample was 15 students, three focus groups were conducted to ensure that no more than

eight (8) students were grouped together for a single focus group interview and to account for my three CP Chemistry courses. Keeping students from the same class period grouped together during each of the interview sessions was also out of consideration for their comfort. During each of the focus group interviews, an audio recording device was used to capture exactly what was said. In addition to recording each of the focus group interviews, I also took detailed notes during each interview to help me "formulate new questions as the interview moves along" and "facilitate later analysis, including locating important quotations from the [recording] itself" (Fraenkel et al., 2015, p. 455).

Durdella (2019) suggests qualitative researchers "look for ways to convert, translate, or reinterpret their research questions into interview questions that they can use in an interview guide" (p. 219). With this in mind, I developed an initial set of interview questions including:

- How did the inquiry lessons differ from typical, traditional lessons?
- Do you prefer engaging in these types of activities or traditional lectures to learn the content? Why?
- How well do you think the activities performed in class helped you understand the content and skills associated with the unit?
- What could I have done prior to any of the activities that would have changed your opinion of them?
- Did you notice any behaviors or comments I made at any time during these activities that suggested I liked or disliked doing these activities in class? Explain.
- Is there anything else you would like to share about your participation in the inquiry lessons?

While these interview questions formed a framework or guide for the semi-structured interviews, they also allowed for opportunities for additional questions to be asked, depending on participant responses.

The Relationship Between Data Collection Instruments and the Research Questions

The purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. Data collected through the instruments described above enabled me to illustrate the conceptual understanding and engagement of my students, as well as my transitioning epistemological beliefs. Each of the instruments served a purpose to address the study's research questions. Data collected from observations, student-generated artifacts and semi-structured focus group interviews directly addressed research question one: how does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory high school chemistry students? Additionally, data collected from my daily teaching journal reflections addressed research question two: how does college preparatory high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs? As this qualitative action research study is anchored in the tradition of grounded theory, data from each of the instruments were analyzed concurrently with data collection. Before elaborating on the analysis process, a detailed description of the research procedure is presented in the next section.

Research Procedure

The Thermochemistry unit during which this qualitative action research study took place covered content related to calorimetry. The lesson sequence aligned with the 5E learning model (Bybee, 2013), wherein students engage, explore, explain, elaborate, and evaluate a particular scientific phenomenon during an instructional sequence. Of these 5Es, the explore portion of the instructional sequence allows the greatest exposure to the SEPs, though Bybee (2013) argues that "the learning experiences [across all 5Es] should contribute to students' development of the scientific or engineering practices, crosscutting concepts, and disciplinary core ideas" (p. 56). The explore portion "should provide students with a common base of experiences within which they identify and begin developing science ideas, concepts, and practices" (p. 58). During the exploratory phase of the 5E sequence, students participate in open inquiry experiences so my intervention aligns with this phase. The duration of the study spanned thirteen (13) class meetings, plus additional time to conduct semi-structured focus group interviews, and took place within the first six (6) weeks of the spring semester. The choice to limit this action research study to the above time frame was to ensure that I did not become overwhelmed by implementing too many instructional strategies that conflicted with my epistemological beliefs over a long period of time. Choosing to limit this action research study to a specified duration allowed me to focus my efforts on delivering instruction that was most closely aligned to the NGSS and understanding how student experiences with this instruction influenced their conceptual understanding and engagement, and in turn influenced my epistemological beliefs. To aid with delineating the research procedure in

a way that is easy for readers to follow, I will describe the procedure as a series of daily student activities and data collection procedures.

Day 1

This qualitative action research study began with an inquiry activity guided by the question, "*what makes a good calorimeter*?" (see Appendix C) This inquiry activity was developed and published by the Health and Science Pipeline Initiative (HASPI, 2018), whose central goal is to encourage diverse secondary science students to pursue careers in the medical fields. This activity encourages students to pursue degrees in medical engineering, and as such was sensible to include in the learning series because of its adherence to the SEPs outlined in the NGSS. In fact, not only does this activity align to NGSS standard HS-PS3-3, but it also promotes the use of the following SEPs: developing and using models, using mathematics and computational thinking, constructing explanations and designing solutions, and planning and carrying out investigations. This activity took place over two (2) class periods, and students had an additional one (1) class period to construct their scientific argument (i.e. their answer to the guiding question) in the form of a mini-poster. The activity was first introduced to students verbally, and students were informed that their calorimeters would ultimately be used to plan and carry out subsequent investigations in the Thermochemistry unit. While students engaged in the activity, I circulated throughout the room listening to group conversations, answering questions, and supervising the safety of students. I also recorded detailed field notes, particularly observations that were notable in relation to the research study, in alignment with the observation guide described earlier in this chapter.

To determine the ideal calorimeter design, class data were pooled from all collaborative groups and displayed on the white board at the front of the classroom. The pooled class data adhered to the following format:

Table 3.1. Learning Task 1 Pooled Class Data Table

Group number	Calorimeter Cup Material	Rate of temperature change (°C/min)

Pooling class data in this way was beneficial because this format provided an opportunity for students to engage in discussion, as well as for student groups who used the same design to compare their results. Following the completion of the day's activities, I recorded my reflections in my personal teaching journal and responded to the specific prompts introduced earlier in this chapter.

Day 2

On day two (2) of this qualitative action research study, students continued to refine their calorimeter designs. Students performed the same procedure as on day one (1); however, they had to refine their design to get an even lower rate of temperature change than the previous day. Students were aware that the lower the rate of temperature change, the better their calorimeter design, as a good calorimeter ought to be well-insulated to avoid large temperature fluctuations. Students were required to use the calorimeter cup material that was determined to be the best insulator (from the previous lesson); however, they were also required to add component materials to their calorimeter cup to improve its insulation.

As with the procedure on day one (1), I circulated throughout the classroom, addressing questions, observing student engagement, supervising student safety, and

recording detailed field notes, particularly in relation to the purpose of this action research study and in alignment with the observation guide. As student groups refined their calorimeter designs and used those calorimeters to perform the simple procedure, they calculated the rate of temperature change using the formula provided in the assignment. Student groups were then invited to complete a table similar to Table 3.1 and indicate the materials used in their design as well as the rate of temperature change their calorimeter achieved. Once again, pooling class data was beneficial, promoting the collaborative nature of science exploration and allowing student groups to easily compare calorimeter designs. Also, I again noted reflections in my personal teaching journal and responded to the same specific prompts.

Day 3

On day three (3) of this qualitative action research study, students analyzed their findings from the previous class meeting (day 2) and constructed an argument that addressed the guiding question of the investigation, "what makes a good calorimeter?" Students followed the mini-poster template in accordance with Bjorn's (2018) suggestions for a streamlined alternative to the lengthy traditional lab report. Students had already been exposed to the mini-poster template prior to this lesson and should have fully understood each of the components of a good scientific argument. Completing a mini-poster following in-class inquiry investigations provided students with an opportunity to engage in the following SEPs: analyzing and interpreting data, using mathematics and computational thinking, and perhaps most prominently, engaging in argument from evidence. The mini-poster template required students to make a claim that directly answered the guiding question of the investigation. Students could then support

their claim with sufficient evidence in the form of data or calculations and provide reasoning regarding why the evidence they chose adequately supported their claim. By following the claim, evidence, reasoning (CER) format for the mini-poster, students were directly engaging in argument from evidence, in accordance with all the components that make a good scientific argument (Sampson et al., 2015).

As students constructed their mini-posters, I circulated throughout the room, listening to conversations, observing students engaged in the task, answering questions, asking informal questions to better understand student engagement with the task, and recording detailed field notes, in alignment with my observation guide. Following the lesson, I reflected in my personal teaching journal and addressed the same specific. Students' mini-posters were collected as the first student-generated artifact. (see Appendix D).

Day 4

On day four (4) of the study, data were not collected from student participants. This "pause" in data collection directly aligns with the grounded theory tradition of qualitative research and allows for preliminary data analysis, particularly from transcribed field notes, to inform the next steps of data collection (Durdella, 2019). However, because the lesson for the day followed a more traditional agenda, I collected data from myself via my teaching journal since the prompts focus on my experiences that negate or reinforce traditional versus reform-based epistemological beliefs.

Days 5 and 6

Student groups used their calorimeter designs from the previous lessons to engage in a second inquiry activity with the guiding question is "which salt should be used to

make an effective cold pack?" (see Appendix E). This activity was modified from Sampson et al.'s (2015) text *Argument Driven Inquiry* (ADI).

As with task 1, I verbally introduced the inquiry activity, described the guiding question, and oriented students with the materials available for their use, and addressed any initial questions. Student groups then began planning their procedure to answer the guiding question. Unlike task 1, student groups were required to plan the investigation procedure, as well as the procedure by which data would be collected and analyzed to answer the activity's guiding question. Providing students with the opportunity to plan and conduct their own investigations aligns very strongly with the SEPs of the NGSS. Additionally, it is important to note that since student groups were planning and conducting their own investigations, I needed to check their procedures prior to their commencement of data collection to ensure the procedures were sound and aligned well to the guiding question. During this approval process, I reviewed students' preliminary procedures and provided guidance regarding any areas that required refinement or modification. Doing so reinforced my role as a "guide" in the constructivist classroom, rather than a source of knowledge and information for students (Kruckeberg, 2006).

As before, while students were engaged in the activity, I circulated throughout the room, listened to group conversations, answered questions, supervised the safety of students, and recorded detailed field notes in alignment with my observation guide. At the end of both day 5 and 6, I also continued to record reflections in my personal teaching journal along with responses to the same specific prompts.

Day 7

As with day three (3) of this qualitative action research study, students again used their analyzed data to answer the guiding question in a mini-poster format. As described earlier, the mini-posters followed the CER format and students were required to cite evidence in the form of collected and analyzed data to further support their scientific arguments. Of course, engaging in argument from evidence is in alignment with the SEPs of the NGSS, and following a mini-poster template provides a structured way for students to construct an argument in a cohesive and concise manner.

While students worked on their mini-poster artifacts, I circulated throughout the room, listening to conversations, observing students engaged in the task, answering questions, asking informal questions to better understand student engagement with the task, and recording detailed field notes in alignment with my observation guide. Following the lesson, I reflected in my personal teaching journal as before. Students' mini-posters were collected as the second student-generated artifact (see Appendix F).

Day 8

In accordance with the grounded theory tradition of qualitative action research, day eight (8) served as another "pause" in data collection to allow for preliminary data analysis, particularly from transcribed field notes, to inform the next steps of data collection (Durdella, 2019). As before, the lesson followed a more traditional agenda, to provide students with direct instruction regarding some of the important procedural norms for the upcoming inquiry investigation. It is important to note that specific procedures were not provided, but rather helpful hints to aid students with planning their own procedures in Task 3. Doing so once again reinforced my role as a "guide" in the

constructivist classroom, rather than a source of knowledge and information (Kruckeberg, 2006). As in the prior break in data collection from student participants, I continued to collect data from myself by answering the specific teaching journal prompts to focus on my experiences that negate or reinforce traditional versus reform-based epistemological beliefs in the context of specific classroom occurrences.

Days 9 through 13

Day nine (9) of this qualitative action research study marked the start of the final inquiry activity, Task 3, during which student groups answered the following guiding question: "which material has the greatest specific heat?" (see Appendix G). As with Task 2, this inquiry activity was modified from Sampson et al.'s (2015) text *Argument Driven Inquiry* (ADI).

As with Tasks 1 and 2, I began Task 3 by verbally reviewing the guiding question, discussing the materials available for use, and explaining how data would be pooled from all student groups. Due to the rigor of this inquiry activity, students engaged with the task for five (5) class periods, with the fifth class period devoted to the development of a mini-poster designed to answer the guiding question of the inquiry.

Following the initial verbal overview, student groups began planning their procedure. As in Task 2, once student groups were confident that they had constructed a feasible procedure, I reviewed their plans and provided guidance to revise or modify as needed to ensure their final procedures were scientifically sound before they began collecting data. Interaction with students at this stage of the inquiry provided me with an opportunity to monitor student learning progression and critical thinking development, i.e. observation data relevant to my qualitative action research study.

Student groups inevitably progressed through the inquiry activity at varying paces, while I, as before circulated throughout the room, listening to group conversations, answering questions, supervising the safety of students, and recording detailed field notes. Furthermore, at the end of each lesson during Task 3, I reflected in my personal teaching journal.

On the last day of the inquiry lesson sequence, students used their analyzed data to answer the guiding question in a mini-poster format, while I circulated throughout the room, continuing to observe, interact, and record field notes as before. Following the lesson, I once again reflected in my personal teaching journal. I also collected students' mini-posters as the third student-generated artifact (see Appendix H).

Day 14 and Beyond

Upon completion of all inquiry activities, I had collected a large amount of data. Though two distinct "pauses" in data collection (Day 4 and Day 8) facilitated preliminary analysis of the data, at this point in my study, I prepared to transition completely to data analysis by transcribing all observation notes and reviewing all student-generated artifacts in accordance with their respective rubrics. Electronic transcription of field notes aids and facilitates subsequent coding, and ensures participant confidentiality (Bloomberg & Volpe, 2019; Charmaz, 2014). Reflective entries in my personal teaching journal did not need to be transcribed, as all entries were completed electronically. As with my field notes, this facilitated the coding process, but more importantly, maintaining an electronic journal from the start ensured my entries would not be altered, thereby authentically capturing my initial thoughts. The final source of data came from the focus group interviews, which occurred following the completion of all inquiry tasks, but prior to

transcribing all notes. Students who participated in the focus group interviews obtained permission from their parent and/or guardian to participate.

Data Analysis

Because this qualitative action research study is rooted in the tradition of grounded theory, "the much preferred way to analyze data…is to do it simultaneously with data collection" (Merriam & Tisdell, 2016, p. 197), using a constant comparative process wherein data collected sequentially throughout the study are subsequently compared to data collected during earlier phases of the study. In this study, the first research question aimed to determine how my students' interactions with the SEPs of the NGSS impact their conceptual understanding and engagement with the DCIs. Data collected from observations, student-generated artifacts, and focus group interviews were analyzed in light of this question. My second research question aimed to determine how student conceptual understanding and engagement following interaction with the SEPs of the NGSS impact my epistemological beliefs. Data collected from observations, student-generated artifacts, focus group interviews, and my personal reflection journal were analyzed in light of this question. Thus, each data collection instrument served an important role in this study. To access the insights provided by my data, I engaged in transcription, coding, and thematic categorizing.

Transcription of Data

Transcription involves "transitioning from one form […] to another form that can be used for segmenting, coding, and so on" (Durdella, 2019, pp. 275-6). In this case, brief notes or memos made during observations or interviews were expanded and written in a detailed, textual format. Audio-recorded files obtained during focus group interviews

were also transcribed. These transcriptions were “denaturalized” (Durdella, 2019, p. 276) and performed by an outside service found at Rev.com. This tool was chosen for its prompt processing speed and for its positive endorsements from professional and academic organizations such as PBS and UCLA. Following receipt of transcripts from Rev, I did a second check of the accuracy of the transcripts by listening to the audio files, correcting any minor errors, such as names of participants.

Coding of Data

Coding provides qualitative researchers with the means for “interrogating, sorting, and synthesizing hundreds of pages of [transcribed] interviews, fieldnotes, documents, and other texts” (Charmaz, 2014, p. 113). In fact, in qualitative grounded theory studies, such as this one, “coding is the pivotal link between collecting data and developing an emergent theory to explain these data” (Charmaz, 2014, p. 113). Charmaz (2014) asserts that there are three distinct stages of coding: initial coding, focused coding, and theoretical coding. Initial coding can take one of two forms: word-by-word coding or line-by-line coding. Charmaz (2014) argues that line-by-line coding may be more suitable for grounded theorists, as this strategy works well with data generated from interviews, observations, and documents. Segmenting transcripts into line-by-line units allows the researcher to “engage in pattern detection and description work” (Durdella, 2019, p. 281). Line-by-line coding is an initial coding process in which preliminary categories, or codes, emerge in the data and these codes “form the basic building blocks of data transformation from participant interview responses, or field notes to arranged text in a theorized pattern” (Durdella, 2019, p. 279).

Following the initial coding stage, focused coding involves the researcher's "studying and assessing [their] initial codes" by "concentrating on what [the] initial codes say and the comparisons [made] between them" (Charmaz, 2014, p. 140). In the tradition of grounded theory, this comparison between codes is a hallmark of the constant comparative method of data analysis. In effect, grounded theorists assess initial codes and compare them with each other to determine which codes have the strongest analytic power (Charmaz, 2014). Once focused codes or categories emerge, theoretical coding requires researchers to determine how these focused codes may relate to each other in a way that might evolve into an emergent theory (Charmaz, 2014). Theoretical coding can also be thought of as thematizing (Durdella, 2019). Charmaz (2014) asserts that the primary function of theoretical coding is ultimately the development of emergent theories, which cannot surface without first clustering focused codes into themes. This thematic categorizing groups segments of focused data into broad patterns to provide theoretical insight into the phenomenon of study (Durdella, 2019). I will say more about my coding process in Chapter Four.

Preliminary Data Analysis

Though Charmaz (2014) describes data analysis as a series of coding stages, Durdella (2019) proposes the use of a three-phase data analysis model, which guided my approach: preliminary data analysis, thematic data analysis, and interpretation. The preliminary data analysis phase includes Charmaz's (2014) initial coding stage, in addition to the need for researchers to appropriately transcribe data and determine the best way to handle and store data within the confines of research ethics. As indicated earlier, my focus group interviews were transcribed via Rev.com in a denaturalized

format wherein grammatical issues are addressed and the written record is stripped of instances of "ums" and "ahhs" (Durdella, 2019). Additionally, the interview transcripts were formatted in a way that best promotes data analysis, e.g. by including line numbers. (Merriam & Tisdell, 2016). Similarly, I added line numbers to my observation notes and my personal reflection journal because line-by-line initial coding is more suitable for qualitative studies rooted in the tradition of grounded theory (Charmaz, 2014).

Thematic Data Analysis

The second phase of Durdella's (2019) three-phase data analysis model is the thematic data analysis phase, when qualitative researchers engage in what Charmaz (2014) terms "focused coding," by comparing and organizing initial codes such that themes in the data emerge. This comparison promotes the emergence of prominent themes or focused codes that can be used to develop initial theories before the next cycle of code comparison begins.

Data Interpretation

The final stage of data analysis in Durdella's (2019) three-phase analysis model is interpretation, during which researchers should think about how the theory proposed in the thematic analysis phase relates to existing literature to interpret their conclusions. In other words, how might the research findings be presented to readers in a way that anchors the problem to existing literature? While it is important to note that the purpose of action research is not to produce generalizable results that fill a gap in the literature (Efron & Ravid, 2013), action research as a methodology can further situate a problem in the literature to enact personal practitioner change. This is the approach I took with my study, as I will illustrate in Chapter Four.

Validity and Reliability

Action research studies rely on researchers' investigations of themselves in relation to their settings to investigate a problem of practice that is meaningful and relevant to a researcher's setting. In other words, action researchers embrace their position as "the researcher and the researched and as having a central role in the practice being studied" (Pinnegar & Hamilton, 2009, p. v). Since practitioner research requires the researcher to embrace practice as research and research as practice (Pinnegar & Hamilton, 2009), a unique set of challenges and dilemmas surrounding trustworthiness emerge, and must be addressed.

Practitioner researchers must pay close attention to the notion of honesty when communicating their research findings by "sharing intimate beliefs, values, experiences, and emotions" (Coleman & Leider, 2014, p. 59) in such a way that promotes intimacy and openness with the reader (Bullough & Pinnegar, 2001). Pinnegar and Hamilton (2009) further assert that to be honest requires a practitioner researcher to provide "examples, details, and illustrations that interrogate taken-for-granted assumptions…regardless of how such accounts may make them appear as human beings" (p. 161). By doing so, practitioner researchers can connect with the audience in such a way that others are able to envision their own experiences through the description of the practitioner researcher (Bullough & Pinnegar, 2001), thus contributing to the transferability of the study.

In addition to honesty, practitioner researchers must provide readers with thick descriptions of character, scene, situation and action (Bullough & Pinnegar, 2001; Pruitt, 2012). Thick descriptions of the practitioner researcher, the setting, the context, and the

behaviors of the researcher and participants further promote validity through transferability. While the purpose of action research is not to produce generalizable results (Efron & Ravid, 2013), action research can surface familiarity among practitioner researchers' problems of practice. In effect, thick descriptions in action research studies promote the transferability of findings to other practitioners' contexts and settings.

Attention to validity and reliability in relation to data collection and analysis is also imperative and can be achieved through such strategies as triangulating data and consulting with a critical friend (Coleman & Leider, 2014; Schuck, 2002). Triangulation of data involves the collection of data from multiple sources, such as the observations, interviews, artifacts, and personal reflections used in this study. Collecting data from multiple sources provides researchers an opportunity to cross-reference findings. For example, what a participant says in an interview can be checked against what that participant did during an observation (Merriam & Tisdell, 2016), which can be further referenced against the artifact that the participant generated. Additionally, collaborating with a critical friend promotes validity and reliability in action research by aiding with research design, assessing data interpretations, and offering an outsider's perspective on research findings (Coleman & Leider, 2014; Schuck, 2002). As a doctoral student, I had multiple opportunities to elicit help from critical friends over the course of this study.

Summary

A research design, including clearly defined along data collection and analysis methods, is imperative to ensure information is gathered in a systematic manner to address a study's research questions. This chapter described such a design for this qualitative action research study, elaborating on how it is rooted in the tradition of

grounded theory. Additionally, Chapter Three provided information related to the study's setting and participants, which further established the context of the problem and contributed to the study's validity and transferability. The result of this design will be reported in Chapter Four.

CHAPTER 4

ANALYSIS OF DATA

As described in the previous chapters, the purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. This study investigated a noteworthy problem of practice in my classroom wherein implementing the constructivist vision of the NGSS significantly conflicted with my epistemological beliefs that favor traditional pedagogies. As the NGSS is a state-mandated approach to the science education standards, I knew I had no choice but to implement the NGSS in my classroom, yet I struggled with how to do so in the context of my conflicting epistemological beliefs. With this in mind, I conducted an action research study to better understand how student participation in NGSS-aligned learning tasks could help me confidently transition toward constructivist pedagogies. As explained in Chapter Three, I selected a qualitative grounded theory methodology because "grounded theory methods consist of systematic, yet flexible guidelines for collecting and analyzing qualitative data to construct theories from the data themselves" (Charmaz, 2014, p. 1). Furthermore, the theoretical framework of this study is rooted in two intertwining theories: the theory of constructivism and the theoretical construct of beliefs, such that qualitative data from observations, daily reflections, student

artifacts, and interviews could be used to adequately uncover theories regarding the relationship between constructivist practice and participant beliefs. Data collected during this qualitative action research study were used to answer the following two research questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?
2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

The remainder of this chapter will focus on presenting the data collected from observations, student-generated artifacts, focus group interviews, and my teacher reflections, as well as my interpretations of the data, rooted in grounded theory.

Data Narratives and Interpretations

Data will be presented through detailed narratives, and these narratives will be connected and synthesized through comprehensive explanatory text. All data collected directly relate to the research questions, and each section below contains a description of my use of a data collection instrument, the analysis of the data collected from each instrument, and a discussion of my interpretations of the analyzed data. Presenting one data source at a time allows me to transparently describe the varying data analysis methods used for each data source. In other words, different coding techniques were required due to the different types of data rendered from each data collection instrument.

This chapter begins with the data related to observations, then personal reflection journals, followed by student artifacts, and finally focus group interviews. This particular sequence was chosen because observation data were the first data collected, and the entries in my daily reflection journal were made as a result of the data collected from those observations. Next, data from student-generated artifacts were analyzed because these artifacts were collected after students were observed participating in the NGSS-aligned learning activities. Finally, data from semi-structured focus group interviews were analyzed last primarily because focus group interviews were conducted at the end of the study when participants had the opportunity to engage in all of the NGSS-aligned learning tasks presented during this action research study. Figure 4.1 provides a general overview of the sequence of Chapter Four.

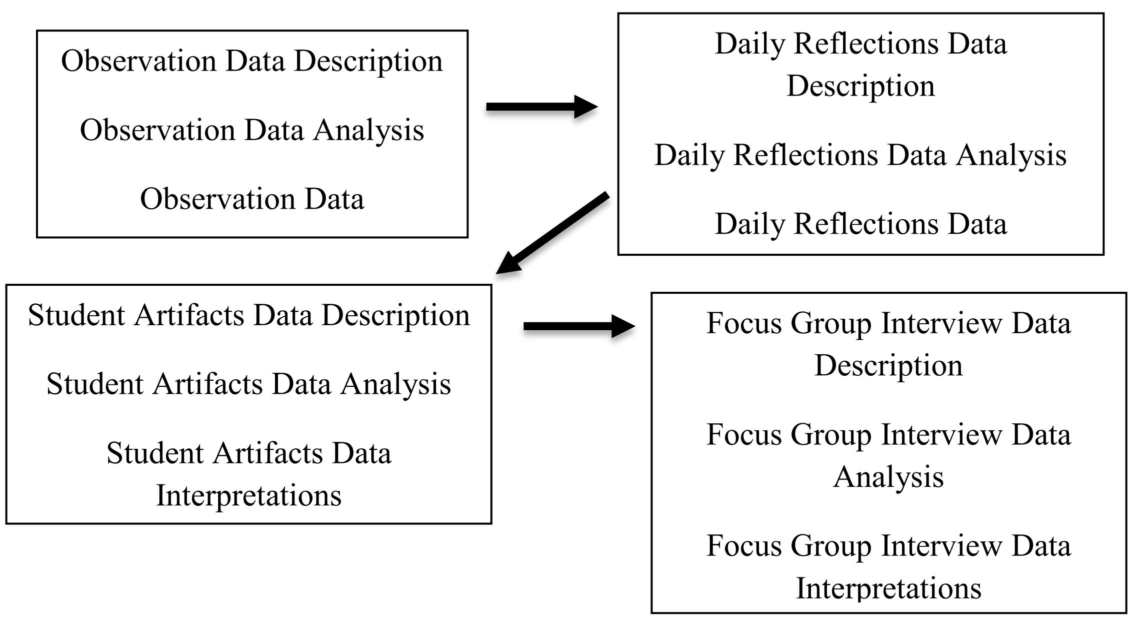

Figure 4.1 Sequence of Data Presentation for Chapter Four

Observation Data

As explained in Chapter Three, observation data were collected from each of three college preparatory sections of my high school chemistry class. Observing student participation in NGSS-aligned learning tasks provided me insight into how well students persevere, collaborate, and engage with constructivist learning tasks in the chemistry classroom. These insights aligned with research question one, enabling me to assess the conceptual understanding and engagement of my students in NGSS-aligned learning activities.

Observations were conducted in my own classroom setting, and with student participants oriented in the same groups throughout the entirety of this qualitative action research study. As a result, the detailed description of the setting and groups below also provides useful context for subsequent sections focused on my other data sources.

This qualitative action research study took place over a series of thirteen consecutive class meetings during the Thermochemistry unit of a college preparatory high school chemistry course. As described in Chapter One, a college preparatory high school chemistry course differs from an honors or advanced placement (AP) chemistry course in the level of academic rigor of the content. For example, students in honors and AP chemistry are required to apply more rigorous mathematical and theoretical principles, which are not typically presented to students in college preparatory chemistry classes. A description of the setting provides greater context of the environment in which my CP students participated in the NGSS-aligned learning tasks planned for this action research study.

The setting of this qualitative action research study was a designated high school chemistry classroom and is decorated with many examples of student-generated work, resulting in a colorful and inviting atmosphere. The classroom can accommodate a maximum of 36 students paired together at 18 lab-style tables. Students can also work in groups of four by simply pushing tables together and rearranging chairs so they are facing each other in a collaborative orientation. Such groups of four were the student lab groups that participated in the NGSS-aligned learning tasks presented during the course of this qualitative action research study.

My seating arrangements take into consideration the diversity of students and how that diversity will translate into a lab group of four students. For example, I strive for a variety of linguistic and academic backgrounds within each group to strengthen students' collective abilities when engaging in NGSS-aligned learning activities. As described in Chapter One, Vygotsky and Piaget argued that in the context of true constructivist learning, collaborative groups ought to be representative of the mixed abilities present in the learning environment (Eastwell, 2002; Slavin, 2012). As a result, each lab group in my study contained at least one student with a B average or above.

Observation Data Analysis

Due to the collaborative nature of NGSS-aligned learning tasks, students communicated verbally throughout each of the observations, and detailed field notes were recorded during these student interactions. To analyze these notes, I used descriptive coding, which "is one approach to documenting from rich field notes the tangible products that participants create, handle, work with, and experience" (Saldaña, 2016, p. 104), in a direct attempt to address my research questions. To engage in the descriptive

coding process, Saldaña (2016) recommends assigning a set of simple and descriptive nouns, which can then be organized and categorized narratively.

The descriptive codes used to analyze the field notes were *Teacher-Instruct, Teacher-Support, Student,* and *Peer-Support*. These descriptive codes were selected as they encompass varying degrees of adherence to both traditional and constructivist pedagogies, which then served to help me understand how adherence to each of these pedagogies influenced student conceptual understanding and engagement, and thus my epistemological beliefs. The descriptive code *Teacher-Instruct* was used to identify any instance in the field notes wherein I had to step in and explicitly instruct students regarding how to solve a particular problem. The descriptive code *Student* was used to identify instances wherein students individually arrived to a correct solution on their own. The terms *Peer-Support* and *Teacher-Support* were used to identify instances wherein students collaborated to solve a particular problem versus instances in which I had to support and guide students to arrive at the correct solution, without providing the explicit instruction indicated by the *Teacher-Instruct* code. All field notes collected during observations of all three class sections were coded according to these descriptive codes. Observation data were coded and analyzed holistically, rather than by class period, because data collected from observations during each of the three class periods did not yield significantly variable findings from class to class. In other words, the observation data collected across the three class periods was similar from class to class and thus an analysis of observation data from period to period would have yielded repetitive findings. The frequency of each descriptive code in the observation data is presented in Table 4.1 below.

Table 4.1 Field Note Descriptive Code Frequency

Descriptive Code	Frequency
Teacher-Instruct	17
Teacher-Support	32
Student	30
Peer-Support	53

The findings from the coded field notes show infrequent instances wherein I had to directly intervene over the course of the NGSS-aligned tasks, as evidenced by the frequency of the *Teacher-Instruct* descriptive code. To clarify, my direct intervention was required either because students indicated they required assistance or because my observations indicated students needed assistance to ensure their success with the NGSS-aligned learning tasks. As noted in Chapter Three, prior to the start of the NGSS-aligned learning tasks, I presented a traditional mini-lesson to my students to discuss the guiding question of the activity, describe the materials available for student use, and offer hints that might help student groups construct initial ideas about how to solve the guiding question. Many of the instances when explicit teacher guidance was required occurred despite this initial mini-lesson and may provide clues about the efficacy of traditional instruction for student understanding. For example, some students did not know how to record temperature data, some students were taking out the thermometer from the calorimeter between instances of data collection, and some students still struggled with correctly obtaining mass values from the balance scale. Instances where I had to provide explicit teacher guidance were epistemologically discouraging to me as they provided

evidence that traditional, direct instruction is not always the most effective method of student learning.

Additionally, some instances of my direct intervention resulting from my own observations were due to my desire to ensure student findings would ultimately result in appropriate scientific conclusions. For example, in the calorimeter design activity I had to explicitly guide students with regard to foam and its insulating superiority to other cup materials. Many student groups obtained data that did not adequately show that foam was the best insulator, and this of course made me uneasy. As a result, I felt I had to "give" students data that showed that foam was the best insulating material when designing a calorimeter, in part so their subsequent investigations could be conducted in a timely and effective manner. Often, teachers are resistant to implementing constructivist pedagogies in the classroom because of the amount of classroom time constructivist pedagogies require (DiBiase & McDonald, 2015). As this qualitative action research study examines the relationship between student constructivist experiences and my epistemological beliefs, I did not want negative attitudes I held against constructivist pedagogies from my early experiences trying to implement the NGSS in my class, namely the amount of class time constructivist pedagogies require, to hinder my determination to provide my students with an experience as closely aligned to constructivism as possible. In other words, allowing my students to proceed with the calorimeter design inquiry with the incorrect belief that foam is not a good insulating material would have required excessive time for students to conduct the investigation with a scientifically inferior insulator, and thus resulted in frustration with implementing constructivist pedagogies in my classroom.

Furthermore, as described in Chapter One, my previous experience implementing the NGSS in my classroom left me frustrated with the need to correct student misconceptions and misunderstandings. The thought of those feelings emerging again caused me to carefully weigh the benefits of intervening directly with students against the potential implications associated with allowing students to proceed with their investigations with misconstrued ideas about the insulating properties of foam. While the instances of direct teacher intervention were minimal, they were still significant, particularly in light of the rationale for their need.

Whereas *Teacher-Instruct* was relatively infrequent in the field notes, *Teacher-Support* was much more frequent. Despite similar labels, these codes actually differ in the capacity in which I supported students. Instances of *Teacher-Support* reflect the times when I intervened in a supportive capacity to guide students to continue thinking about problems they encountered during the learning tasks, and how to appropriately solve them. The *Teacher-Support* code was used to classify instances wherein students sought my assistance, or I intervened because of occurrences I observed, to offer support to students in a guided fashion. For example, I offered support to guide students with proper collection of temperature data, I encouraged student groups to continue collecting data even if they "felt" they were conducting the inquiry incorrectly, and I guided students with refining their procedures if they felt that their data collection methods could be improved. These instances of *Teacher-Support* differed from the observations coded *Teacher-Instruct* because my assistance was supportive, and thus I did not readily reveal answers to my students. Instead, I guided students by asking probing questions or providing clues about how they could solve any problems they encountered during

various stages of the investigations. As described above, at the start of each learning task, I provided a mini-lesson to students regarding the overall purpose of the activity and some purposeful clues regarding how to answer the guiding question of each investigation. This introductory lesson was meant to promote students' problem-solving capacity as well as promote metacognition in collaborative settings as students already had an understanding of the purpose of the investigation, were aware of some of the underlying principles that could be used to conduct the investigation, and thus would be better equipped to metacognitively assess their planned procedures, as well as the data collection and analysis methods they could use to answer the guiding question. Once students started the activities, I circulated the room and received numerous questions to clarify the introduction to the activity. Addressing student questions provided guidance throughout each learning task and gave me the opportunity to fulfill a more supportive role in the constructivist classroom, which is in direct contrast to the role of the teacher in a traditional classroom (Sarita, 2017). For example, students asked technical questions such as "*how many decimal places should temperature be rounded to?*," "*what does one gram of salt look like?*," and "*why do we record the mass of the salt alone, and not with the water?*," which provided me an opportunity to support students with their procedure development and data collection, without explicitly directing instruction.

Additionally, my role as a supportive figure in the classroom extended to mitigate student anxieties with the quality of the data collected. For example, once students began collecting data, multiple student groups asked questions such as "*why are our temperatures not changing much?*," "*why isn't anything happening with magnesium sulfate?*," and "*is the temperature not supposed to decrease?*" All of these questions

reflected students' anxiety, and perhaps their lack of confidence in their planned procedures, as students wished to ensure their data was "right." Supporting students by addressing these questions assured students their procedures and data were sound and satisfactory. As constructivist science learning requires students to construct their own knowledge and understanding by way of inquiry, supporting students through their inquiry experiences by providing reassurance allows them an improved ability to focus on how they can construct knowledge through their participation in inquiry experiences, instead of focusing on the soundness of their procedures or data, as in the instances warranting a *Teacher-Instruct* code.

Though descriptive codes for students' solving problems on their own and within collaborative capacities were separate and distinct when field notes were initially coded descriptively, those two codes can be combined when interpreting the observation data, as both codes refer to students' guiding their own learning, whether individually or collaboratively. The data show a large number of instances in which students were central to their own problem-solving abilities during the NGSS-aligned learning tasks. For example, throughout the course of the calorimeter design activity, such student comments as "*I don't see how putting foil underneath the cup would be insulating*" and "*we should provide the background for why we used foam*" show a notable degree of student-centered problem-solving and metacognition. Additionally, in the subsequent NGSS-aligned learning tasks, students made such comments as "*we don't want to use too much water to mix with our salt, since we don't want the water to overpower the salt,*" which also shows a high degree of student critical thinking when planning investigations.

Some additional quotations recorded during the observations of students show profound evidence of student metacognition and markedly influenced my epistemological beliefs in the early phases of this qualitative action research study. During the early stages of the cold pack activity, I had to explicitly guide students with respect to the amount of salt and water used to render adequate data that could be used to answer the guiding question of the learning task. Though I had to intervene explicitly, once students began collecting data, many groups collected data that was expected and that served to influence my epistemological beliefs in favor of constructivism. For example, student groups noted, "*it's definitely ammonium chloride that is the most effective for a cold pack*" and "*calcium chloride is getting really hot, so it cannot be that one,*" which reassured me that students were in fact arriving at the correct conclusions. Moreover, these observations reflected student application of previously learned principles related to the direction of heat flow to decide which salt would be most effective for a cold pack. Though I had to intervene and direct students with respect to the volume of water and mass of salt that would show obvious results, student procedures were constructed by students themselves and were created with minimal explicit guidance.

Similarly, students were overheard demonstrating deep cognitive understanding of the specific heat of a metal activity. Some notable quotations included, "*the water temperature will rise and the metal temperature will fall,*" and "*we should take the temperature of the water in the calorimeter until it stops changing.*" Once again, students were observed to be engaged in deciphering how to solve the problem on their own and demonstrated greater proficiency at doing so, particularly as this was the third NGSS-aligned learning task in the span of three weeks.

Observation Data Interpretations

The coded observation data show a frequency distribution wherein students were more likely to rely on themselves and their peers to solve problems related to the planning and investigation of the NGSS-aligned learning tasks, rather than simply seeking answers from me. This finding is significant because student construction of knowledge in social contexts is a major pedagogical goal of constructivist learning in the classroom. Students' constructing their own knowledge and understandings with only minimal supportive guidance from the teacher promotes student ownership of learning, provides students with an appreciation of multiple peer perspectives, and encourages students to become more aware of their own learning (Sarita, 2017).

Though the number of instances of the descriptive codes *Student* and *Peer-Support* heavily outweighed those of *Teacher-Instruct* and *Teacher-Support*, the instances of *Teacher-Instruct* and *Teacher-Support* provided insights into the pedagogical decisions I made to foster a constructivist classroom environment and the opportunities I recognized to behave in the role of a facilitator of student learning. Instances of teacher-provided support were natural throughout the course of the NGSS-aligned learning tasks, as expected in a constructivist learning environment. Conversely, as described above, the instances of my direct intervention and instruction resulted from a need to maintain fidelity to the NGSS-aligned learning tasks, and persevere with implementing constructivist pedagogies in my classroom. While many of my direct interventions communicated discrete, tangible knowledge related to scientific skills and processes, other interventions provided students with information that would keep them on track to meet the objectives of the NGSS-aligned learning task in a timely manner. The instances

of and reasons for teacher-led direct interventions had significant potential to shift my epistemological beliefs toward or away from constructivism. While the observations conducted throughout this qualitative action research study point to the receptiveness of constructivist learning by students, and a generally favorable experience toward constructivist teaching, it is important to note that true constructivism would have had students develop their own conclusions regarding the insulating properties of foam, as opposed to other cup materials. As discussed earlier, the rationale for my decision not to allow students to explore this phenomenon further was in accordance with the time constraints of the planned learning sequence. In effect, a decision to implement a traditional pedagogy in the midst of a constructivist lesson highlights how a confident epistemological transition from solely traditional pedagogies to constructivism cannot be rushed, but rather is a transitional process in which a mixture of pedagogies is used to realize one's own personal pedagogical goals. Though I provided some insight in this section into the pedagogical decisions made during the learning sequence, data from daily personal reflection journals provides additional insights into my thought processes during this qualitative action research study.

Data from Personal Reflection Journals

Following the observation of each period's participation in the NGSS-aligned learning tasks, I electronically recorded reflections in my daily personal reflection journal. As described in Chapter Three, my daily journal reflected on the following two prompts:

- What did I observe or experience today that reinforced my epistemological beliefs? In other words, what did I observe or experience that supports the use of traditional instruction to aid with student understanding and engagement?
- What did I observe or experience today that contradicted my epistemological beliefs? In other words, what did I observe or experience that negates the use of traditional instruction methods, and instead promotes the use of reform-based pedagogies?

Analysis of Data from Personal Reflection Journals

To analyze personal reflection entries, I used concept codes, which "tend to be applied to larger units or stanzas of data" (Saldaña, 2016, p. 120), such as daily journal entries. Using concept codes allowed me to assign a symbolic meaning to stanzas of text in a manner that captured the broad meaning of entries. Saldaña (2016) asserts that concept coding is an appropriate coding method for use in grounded theory methodologies. However, Bernard et al. (2017) hold an opposing view, arguing that content analysis of texts through application of concept codes is a deductive approach to qualitative analysis, whereas grounded theory requires an inductive approach. The two concept codes I used to analyze my personal reflection journals, "*traditional application*" and "*constructivist progress*," were indeed "derived from theory or from prior knowledge" (Bernard et al., 2017) and were selected to align with my research questions. The phrase *traditional application* referred to entries that described reflections of student understanding and engagement that were the direct product of traditional supports that were provided to students during the course of the NGSS-aligned learning tasks. Conversely, the phrase *constructivist progress* referred to entries that described

reflections of student understanding and engagement that were the result of student directed metacognitive or procedural processes. Coding my personal reflection journal entries in this way helped me answer the research questions as reflecting on observed student experiences that reinforced or negated my epistemological beliefs helped me better track any changes in my beliefs over the course of this qualitative action research study.

While this qualitative action research study uses a grounded theory methodology, and grounded theory methodology relies heavily on inductive methods of data analysis, Bernard et al. (2017) also acknowledge "real research is never purely inductive or purely deductive" (p. 220). In other words, as situating the problem of practice in the context of traditional versus constructivist pedagogies resulted in the acquisition of deeper theoretical understanding of these competing philosophies, inductive methods of literature analysis were used. These initial inductive methods aligned with the grounded theory approach of this action research study; however, as greater understanding of traditional versus constructivist teaching and learning was acquired, a deductive approach to analyzing portions of the collected data was also important when addressing my research questions.

As prompt one had me reflecting on the observations that reinforced my traditional epistemological beliefs, it is unsurprising that the majority of entries for prompt one were assigned the concept code *traditional application*. What is interesting, however, is that some entries for prompt one were coded as *constructivist progress* because they contained key terms that better reflected *constructivist progress* rather than *traditional application*. For example, one entry read, "*I noticed students were very*

engaged with the task," another entry stated, "*checking group procedures also allowed me to guide students,*" and finally, "*the guidance that I was providing to student groups led them to the correct procedure.*" The terms engaged, guide, and guidance better encompassed a constructivist pedagogy wherein the teacher guides students engaged with learning tasks, and thus were assigned *constructivist progress* codes.

Conversely, the majority of entries in response to prompt two were predictably coded as *constructivist progress*. As with prompt one above, some entries responding to prompt two received the *traditional application* code. For example, "*students asked repeated questions about how to calculate the change in temperature,*" "*students were not following their own procedures,*" and "*one student still struggled with variables*" were all reflections on moments when I had to intervene directly to help students persevere through the learning tasks and remain engaged with reform-based pedagogies. It is interesting to note that those entries coded as *traditional application* were all technical in nature and reflected the need for intervention related to specific scientific norms, skills, or processes that were required by students to continue engaging with the NGSS-aligned learning tasks.

Interpretation of Data from Personal Reflection Journals

The significance of the above findings is that instances in which traditional or constructivist pedagogies were reinforced did not occur in isolation from each other. In other words, times of traditional instruction were reinforced by providing students with guided support to engage them in the learning tasks. More importantly, however, the traditional aspects of the learning sequences served to aid students with participating in constructing their own understandings. These findings suggest that *constructivist*

progress, or positive influences on my constructivist epistemological beliefs, were made possible because of the use of *traditional application* and the guidance of students in the norms, skills, and processes to promote student engagement with the NGSS-aligned learning tasks. In other words, the findings from my daily personal reflection entries suggest an epistemological shift toward constructivism was possible because of the use of traditional pedagogies when appropriate.

Data from Student Artifacts

As explained in Chapter Three, student artifacts were collected at the culmination of each of the NGSS-aligned learning tasks as a means to measure student conceptual understanding of the unit's core objectives. These student artifacts were in the form of a mini-poster, wherein students were required to follow the mini-poster template (see appendix B) and answer the guiding question of each NGSS-aligned learning task in a claim, evidence, reasoning format. Mini-posters were collected from all focus group interview participants and subsequently analyzed. To begin the analysis of these artifacts, each mini-poster was scored according to its respective rubric (see appendices D, F, and G). After scoring, all student artifacts, from all three NGSS-aligned learning tasks were organized into three broad categories: basic submissions scored 0-5, proficient submissions scored 6-8, and advanced submissions scored 9-10 out of a possible ten points. Examples of student work belonging to each of the three broad categories can be found in appendices I, J, and K. The results of this categorization are presented in Table 4.2 below.

Table 4.2 Student Artifact Score Frequency

Scoring Category	Frequency
Basic	10
Proficient	9
Advanced	24

Grading student artifacts according to a rubric and using those grades to thematically analyze students' conceptual understanding was not done randomly. Chen and Bonner (2017) assert that "[implementing] learning activities that embed assessments so that both learning and assessments are contextual, meaningful to learners, and individualized to meet student needs" provides a platform to determine if student constructivist learning is indeed taking place (p. 20). In other words, allowing my students to participate in NGSS-aligned learning tasks, and simultaneously use the experiences in those tasks to develop scientific arguments in the form of a mini-poster, provides evidence of constructivist learning. As seen in Table 4.2 above, some students performed very well on this constructivist assessment, while some struggled.

Analysis of Data from Student Artifacts

Unlike data collected from observations and personal reflection journals, student artifacts were not analyzed via a coding approach, but rather were analyzed holistically against rubrics (see appendices D, F, and G) for evidence of student conceptual understanding, which is in alignment with my first research question. The findings of this holistic analysis are presented in Table 4.3 below.

Table 4.3 Frequency and Percentage of Satisfactory Claims, Evidence, and Reasoning

Scoring Category	Frequency	Frequency and percentage of correct or appropriate claims	Frequency and percentage of sufficient evidence	Frequency and percentage of appropriate reasoning
Basic	10	6 (60%)	1 (10%)	8 (80%)
Proficient	9	3 (33%)	8 (89%)	2 (22%)
Advanced	24	24 (100%)	24 (100%)	20 (83%)

Holistic analysis of student artifacts began with the artifacts that were in the basic category. Interestingly, of the ten artifacts in the basic category, eight of them provided adequate reasoning to support their claims. In other words, underlying scientific principles such as the purpose of a calorimeter, an explanation of the second law of Thermodynamics, or a working definition of specific heat capacity were present in 80% of artifacts in the basic category. What makes this finding anomalous is that students typically struggle most with the reasoning of a scientific argument, rather than the evidence (German, 2018), and this was not case for the artifacts in the basic category.

In spite of that success, and although 60% of the artifacts in the basic category made correct or appropriate claims, the remaining 40% either did not answer the guiding question for each NGSS-aligned learning task or did not appropriately match the evidence that was provided. Furthermore, out of the ten artifacts in the basic scoring category, nine of them were categorized as basic because of a lack of sufficient evidence. According to the rubrics for each of the mini-posters, evidence must be in the form of appropriate calculations and a brief explanation of how those calculations support the claim, yet 90% of the artifacts in the basic category did not provide the necessary

calculations or adequate evidence. The lone artifact that did provide appropriate evidence did not do so sufficiently, as only partial data was provided and that partial data did not effectively represent the data collected for the entirety of the specific NGSS-aligned learning task.

Unlike the artifacts in the basic category, those in the proficient category had a better presentation of evidence, with only one artifact missing appropriate evidence. All other artifacts in the proficient category either had complete evidence or were missing partial evidence that did not appropriately encompass the entirety of all of the NGSS-aligned learning tasks. Of the artifacts in the proficient category, four had correct or sufficient claims while six had incorrect or insufficient claims. As in the basic category, claims were either incorrectly matched to the evidence or did not appropriately answer the guiding question of the investigations. Since nine artifacts were in the proficient category, those six with unsatisfactory claims account for 67% of the proficient category. Curiously, however, artifacts in the proficient category showed a lack of appropriate reasoning, as seven of the artifacts in this category provided appropriate reasoning according to the underlying scientific principles required in the rubric. This finding differed compared to those artifacts in the basic category, which showed that more students provided appropriate reasoning with insufficient evidence.

Artifacts in the advanced category scored either 9 or 10 out of a possible ten points. Only four of the artifacts in the advanced category scored 9 points out of ten, and each of those four artifacts lost a single point because of weak reasoning, which is an area of struggle for many students (German, 2018). While those artifacts communicated appropriate reasoning, the reasoning either could have been more strongly used to

support the claim or only indirectly addressed underlying scientific principles without naming them explicitly. Those that scored full points showed strong adherence to the rubrics, with correct claims, logical evidence, and sound scientific reasoning.

Interpretations of Data from Student Artifacts

The thematic analysis of student artifacts reveals significant findings with regard to student participation in NGSS-aligned learning tasks. Analyzing student artifacts in the context of appropriateness of claims, evidence, and reasoning may provide insight into the conceptual understanding and engagement of students when participating in constructivist learning tasks. The NGSS-aligned learning tasks required students to plan and conduct their own investigations in order to collect and analyze data to support a proposed claim. Planning and conducting investigations as well as collecting and analyzing data are direct components of the Science and Engineering Practices (SEPs) of the NGSS and are also representative of the constructivist theory of learning.

On the other hand, scientific reasoning is rooted in the conceptual understanding of underlying scientific principles. Though students can theoretically discover these scientific principles themselves, the feasibility of this, coupled with the time constraints of the classroom, led me to directly instruct students about the underlying scientific principles involved in the NGSS-aligned learning tasks. Prior to the start of each of the NGSS-aligned learning tasks, I directly instructed students in such scientific principles as the function of a calorimeter, the second law of Thermodynamics, and the working definition of specific heat capacity. Unlike the direct instruction provided to aid students with developing the reasoning portion of their scientific arguments, students were expected to develop their own claims and evidence from the data collected and analyzed

through their planned investigations. The frequency of unsatisfactory evidence and unsatisfactory reasoning led me to wonder if some students still struggled with the constructivist nature of the learning tasks and instead preferred direct instruction to develop an appropriate scientific argument.

As mentioned earlier, artifacts were collected only from students who participated in subsequent focus group interviews. The rationale for this decision was to examine the generated artifacts and discover how their thoughts regarding traditional and constructivist pedagogies supported or negated their performance on the artifacts. A total of fifteen students ultimately participated in the focus group interviews, and thus artifacts were collected from these fifteen students. Artifacts were initially categorized into three distinct categories: basic, proficient, and advanced, to describe the relative performance of students on these artifacts. Work from two students out of the fifteen student participants belonged to the basic category for all three of the mini-posters collected after each NGSS-aligned learning task. Conversely, work from six students out of the fifteen student participants belonged to the advanced category for all three artifacts collected from each participant. Three students belonged to both the proficient and advanced categories for the three artifacts collected from each participant, and two students belonged to both the proficient and basic categories. Finally, two students had work that represented each of the three categories; basic, proficient, and advanced. Table 4.4 below summarizes these results.

Table 4.4 Frequency of Collective Scoring Categories

Collective Scoring Category	Number of Students
3 Basic	2
3 Advanced	6
2 Advanced, 1 Proficient	3
2 Proficient, 1 Basic	1
2 Basic, 1 Proficient	1
1 Basic, 1 Proficient, 1 Advanced	2

The two students whose work represented each of the three categories showed significant variation in work quality from task to task. With that in mind, it is not possible to infer what their work suggests about the use of traditional or constructivist pedagogies; however, their interview responses provide greater insight into their feelings, and those insights will be described in the next section of this chapter. For students belonging entirely to the advanced category, participation in NGSS-aligned learning tasks may have helped them develop conceptual understandings about the procedures, data, and analysis required to answer the guiding questions for each task. Conversely, the artifacts that belonged entirely to the basic category show that these students may have struggled with developing claims and evidence that reflected understanding of the NGSS-aligned learning task. However, as seen in Table 4.4 above, these students were able to provide reasoning that supported the claims they were making, and this reasoning may likely reflect a preference for traditional learning.

As seen in Table 4.4, the remaining five students belonged to a combination of scoring categories. Three of these five students belonged to a combination of categories that showed at least proficient demonstration of conceptual understanding, and thus it can be inferred that these students may have strong abilities with constructivist learning tasks. This inference is made because the artifacts from these students that belonged to the proficient category were lacking minor components, such as evidence from the entirety of the learning task or a stronger explanation of scientific reasoning. The two students who belonged to the combination of proficient and basic categories did not submit artifacts that demonstrated sufficient proficiency, as they were on the low end of the proficient range, scoring only six out of ten possible points. As the range for proficient was between 6-8, a score of six indicates that proficiency was just barely achieved. With this in mind, it is reasonable to infer that these two students may have struggled with the constructivist nature of the NGSS-aligned learning tasks and did not know how to collect and analyze data or root the problem in scientific principles in a way that adequately forms the basis of a valid scientific argument.

Summarizing the results of Table 4.4, it can be said that a total of nine students (six from the advanced category, and the three from the advanced/proficient category) may have demonstrated conceptual understanding of the scientific principles addressed by the NGSS-aligned learning tasks. Conversely, four students demonstrated that they may have struggled with conceptual understanding in the context of the constructivist learning tasks. The two students whose artifacts represented all three categories cannot be adequately categorized as demonstrating success or struggle in the NGSS-aligned learning tasks from artifacts alone.

As this qualitative action research study examines the impact of student participation in constructivist learning tasks on my epistemological beliefs, a relationship between student performance on the mini-poster and my epistemological beliefs arises. As my conclusions of student demonstration of learning were tied directly to the mini-poster task, it is logical that my beliefs of student learning in NGSS-learning tasks are rooted in their performance on the mini-posters. Boesdorfer et al. (2019) argue that teacher beliefs regarding teaching and student learning ought to be separate constructs when analyzing epistemological shifts. In other words, separating these two constructs may result in an increased likelihood in epistemological change, as teacher beliefs about student learning are more likely to influence beliefs about teaching, and thus, changes in teacher actions in the classroom emerge. In fact, the use of the mini-poster as evidence of student learning coincides with Boesdorfer et al.'s (2019) argument that such tools, which allow students to use prior knowledge to answer questions or meet challenges, provide teachers with evidence of student learning, and thus can impact their epistemological beliefs. Furthermore, Boesdorfer et al. (2019) argue that teachers' beliefs are often more strongly influenced by the tools that they perceive as useful for student learning, as opposed to those strategies that enhance their own teaching. With this in mind, student demonstration of learning emerges at the forefront of epistemological change.

As nine of the students in Table 4.4 demonstrated successful learning during the NGSS-aligned learning task, it is reasonable to conclude that a shift in my epistemological beliefs is developing. A complete shift has not yet occurred, as there are still four students who have not demonstrated sufficient student learning as a result of the NGSS-aligned learning tasks. It is difficult to concretely determine if students'

demonstration of understanding on the mini-poster task indeed translates to a preference or aversion for constructivist pedagogies, particularly in the context of participant sample size. Fortunately, the focus group interviews I conducted enabled me to better understand the struggles that those four students demonstrated, as well as the feelings and attitudes of those who demonstrated conceptual understanding.

Data from Focus Group Interviews

Focus group interviews were conducted three separate times, and each focus group interview included no more than eight students. As noted in Chapter Three, I chose to conduct focus group interviews rather than 1-on-1 interviews to promote participants' maximum comfort and also to foster a dialogue as participants heard each other's responses to the interview questions. I recorded the interviews using an audio device and followed the general framework of questions described in Chapter Three although participant responses often led to the generation of additional questions. Prior to the start of each focus group, I emphasized to participants that the interview was meant to follow an informal conversational style. In addition, student participants were seated in a circular arrangement so that all participants could make eye contact with those speaking at any given time, and refreshments were provided to ensure the environment was as comfortable as possible for my student participants.

Analysis of Data from Focus Group Interviews

As noted in Chapter Three, I used a transcription tool called Rev, which can be found at www.rev.com, although I independently verified the accuracy of each transcript. Interview transcripts were then analyzed according to a three-step process that included initial in-vivo and process coding simultaneously, followed by focused coding (Charmaz,

2014; Saldaña, 2016). The interview transcripts included all of the instances wherein I was speaking, labelled as "researcher," though these sections were not coded, as "the interviewer's questions, prompts, and comments are not coded" (Saldaña, 2016, p. 17). For participant comments, in-vivo coding was the initial method of choice because descriptive coding, as used for observation field notes, would not generate sufficient "meanings about the participants and their perspectives" (Saldaña, 2016, p. 76). In other words, descriptive coding relies on using nouns as codes, and it is verbs and gerunds that assign deeper meaning to the emotions, thoughts, and values of participants' feelings about the interview topic (Saldaña, 2016). In-vivo coding "draws from the participants' own language" (Saldaña, 2016, p. 97), allowing the researcher to identify notable words and phrases. In this way, the researcher identifies what is significant to the participant, which aids the researcher with crystallizing and condensing meanings from participant experiences (Charmaz, 2014). Some examples of initial in-vivo codes that emerged from the interview transcripts included such phrases as "*further our thinking*," "*notes help us understand*," and "*I was overly frustrated*."

In-vivo coding of interview transcripts yielded an enormous volume of codes, as almost every participant response contained a notable in-vivo code. Due to this, a subsequent coding mechanism was required to further consolidate and categorize the initial in-vivo codes. A second coding system was used, known as process coding, which "uses gerunds [words ending in -ing] exclusively for codes" (Saldaña, 2016, p. 97). This coding strategy accompanies in-vivo coding, as an initial coding method, to develop emerging meanings in interview data. Additionally, using a process coding approach "condenses a larger number of …codes into a more manageable lump for analysis"

(Saldaña, 2016, p. 229). Table 4.5 shows an example of how a number of initial in-vivo codes were ultimately categorized and assigned the process code of *understanding*. The in-vivo codes in Table 4.5 are actual quotations of student responses from the interview transcripts. Each of those quotations stood out to me as important, and thus received its own in-vivo code. With the resulting list, in-vivo codes were then recategorized using gerunds, and Table 4.5 shows how the in-vivo codes received the process code of *understanding*.

Table 4.5 Recategorized In-Vivo Codes with the Process Code of *Understanding*.

Process Code: Understanding				
UNDERSTAND HOW IT'S BEING USED	HELPS YOU UNDERSTAND	PUTS THE INFORMATION IN YOUR HEAD	THINK FOR OURSELVES	LET'S US FIGURE IT OUT
SOLIDIFIES WHAT WE ARE LEARNING	UNDERSTAND WHAT I'M DOING	I REALLY UNDERSTAND	WOW WE ACTUALLY UNDERSTAND	CHALLENGE OUR BRAINS
LET STUFF INTO YOUR HEAD	CHALLENGE OURSELVES	WE HAVE TO THINK WITH OUR BRAINS	FURTHER OUR THINKING	I DO REALLY GOOD WITH CREATING PROCEDURES
EXPANDS OUR MINDSET	WE'RE THE ONES CREATING THE STEPS	THINK MORE DEEPER	WE CAN GET IT DONE	

Similar process codes were generated for the rest of the in-vivo codes generated from the interview transcripts. The additional process codes that emerged from the in-vivo codes were *constructing meaning, collaborating, struggling, supporting, assessing,* and *isolating*.

The initial in-vivo coding and subsequent process coding provided a segue to the second cycle coding method of focused coding, marked by a transition stage of transforming the process codes into themes. Using Saldaña's (2016) strategy of defining process codes by adding the verbs "is" and "means" in relation to the in-vivo codes, I, for

example, defined *understanding* as "the process by which students are able to think deeply and challenge themselves to figure out how to solve a problem." The other process codes, transformed into themes in a similar manner, appear in Table 4.6 below.

Table 4.6. Process Codes and their Resultant Themes

Process Code	Resultant Theme
Understanding	Understanding is the process by which students are able to think deeply and challenge themselves to figure out how to solve a problem.
Constructing Meaning	Constructing meaning is the process by which students apply concepts through activities to help with understanding.
Collaborating	Collaborating means communicating with peers to solve problems or alleviate confusion.
Struggling	Struggling is when students feel stressed, confused, or frustrated by how to solve problems.
Supporting	Supporting means students feel that the teacher or tools used by the teacher help them understand and construct meanings during hands-on tasks.
Assessing	Assessing is the process of assigning grades to students following completion of a learning task.
Isolating	Isolating means students feel they cannot rely on their group members to help them solve problems.

Assigning themes to process codes in this manner provides further insight into how in-vivo codes were organized and the rationale I used for assigning specific in-vivo codes to process code categories. Furthermore, assigning thematic definitions to each of the process codes aided me with identifying additional insights into the interview data and the deep thoughts of student participants.

Following the transition stage of "thematizing" the process codes, the final cycle of coding involved a focused coding approach. As "focused coding follows in-vivo [coding]" (Saldaña, 2016, p. 240), it was natural to use focused coding as a means to

examine the process codes from initial in-vivo coding for the "most frequent or significant codes to develop the most salient categories" (p. 240).

As described earlier, the process codes that emerged from transcribed in-vivo codes were *understanding, constructing meaning, collaborating, struggling, supporting, assessing,* and *isolating*. These seven process codes were then arranged from categories to subcategories to further organize them into a coherent organization pattern. Figure 4.2 below shows how the seven process codes were organized into a more focused pattern.

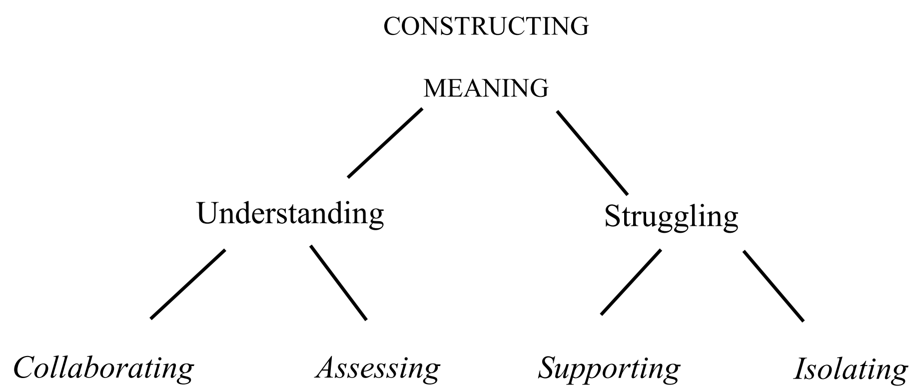

Figure 4.2 Categories and Subcategories of Process Codes

The rationale for the categorization of process codes as seen in Figure 4.2 is described in the following analytic memo:

After reviewing the process code categories, I feel that ISOLATING should be subsumed under STRUGGLING. This is because many student participants indicated that a part of the reason for their struggle with the NGSS-aligned learning tasks was that certain group members did not contribute to the collaboration, and thus students were left with no choice but to struggle with the problems on their own. However, SUPPORTING should also be subsumed under STRUGGLING because often the struggle of the NGSS-aligned learning tasks directly resulted in students' seeking support either from their productive group members or from me. Additionally, I placed the process code of CONSTRUCTING

MEANING as an overarching category of its own because ultimately the purpose of the NGSS-aligned learning tasks was to see how well students constructed their own conceptual meanings. From participant responses, it was clear to me that students' constructing their own meanings led to a sense of UNDERSTANDING, but not without struggle. Furthermore, COLLABORATING was subsumed under UNDERSTANDING because it was through collaboration that many students felt conceptual understanding was developed. Finally, ASSESSING was subsumed under UNDERSTANDING because many student participants indicated that their desire to demonstrate understanding and construct meaning was because they knew that at the end of any given NGSS-aligned learning task, they would be assessed by way of the mini-poster.

Interpretations from Focus Group Interviews

The above analytic memo not only uncovers the rationale behind the categorization pattern of Figure 4.2, but also sets the stage for an emerging theory. Saldaña (2016) asserts that analytic memos that describe the interrelatedness of categories build a foundation for theory development.

As supported by the literature presented in Chapter Two, constructing meaning was the core of the constructivist learning experiences provided to my students, and it appears it occurred when students felt they were developing conceptual understandings, but not always without struggle. As many students noted in the focus group interviews, struggle was an important component of the constructivist learning process and gave rise to student efforts to collaborate with their peers or seek my support to mitigate that struggle. For example, some students remarked that participating in the NGSS-aligned learning tasks was "*overly frustrating*," and some indicated that they felt they were

"*doing things wrong*." Though these comments reflected the struggle that students experienced, they followed up these comments with a desire to "*help each other understand*," by "*communicating with other people in [their] groups*." Struggle is an important component of the constructivist learning process in the science classroom, as having students engage in the SEPs of the NGSS "emphasizes practices and reflects a bit of the struggle [of science]" (Duschl & Bybee, 2014, p. 2). With this in mind, student struggle is not to be interpreted as something negative and to be avoided, but rather as a motivator for students to continue persevering with constructivist learning tasks. Additionally, this struggle may provide additional insight that those students who demonstrated basic understanding on the mini-poster task may in fact still be struggling with constructivist learning, rather than a concrete indication that those students prefer traditional pedagogies.

Aside from students' engaging with their peers or me to seek support with constructing meaning, many interviewed students indicated that the traditional lesson prior to the start of the NGSS-aligned learning task was also an important source of support. Student participants indicated that they would frequently "*refer back to notes*" and "*think of [my] lessons*" prior to the start of the learning tasks, and credited these supports for their ability to persist with the tasks and develop conceptual understandings in constructivist settings. This finding is notable because, as many student participants indicated, the sequencing of lessons from traditional to constructivist was an important component for the successful implementation of constructivist pedagogies. Additionally, it is important to note that some students struggled, not because of their lack of understanding, but rather because of their inability to effectively collaborate with their

peers. For example, some students indicated that they would "*just start*" the activities without the input of their group members because they felt that "*some people might not even work*" to aid with the problem-solving required to successfully engage with the tasks. Additionally, some students felt that they "*had no assistance*" from their group members so they felt that they "*had to do [it] by [themselves]*." This finding suggests that these students did not feel willing to help those peers who demonstrated lesser understandings. True collaboration occurred between students who had comparable levels of motivation and understanding to solve the problems together.

Discussion of Findings

As noted at the outset of this chapter, data collected during this qualitative action research study were used to answer the following two research questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?
2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

Extending the interpretations presented in the sections above, this section looks across the various data sources to present the findings in a summarized manner for each research question.

Findings Related to Research Question One

In response to research question one, the implementation of the NGSS-aligned learning tasks in my classroom had a significant impact on the conceptual understanding and engagement of my college preparatory high school chemistry students. The observations conducted throughout the learning sequence showed a great deal of student engagement and metacognitive abilities during the NGSS-aligned learning tasks. As discussed earlier, students predominantly engaged in the learning tasks by collaborating with their peers or by using critical thinking skills to further their own individual understandings of the conceptual ideas of the learning task. Since most students persisted with the learning tasks by collaborating or using critical thinking skills, many of them showed a high level of engagement in learning tasks that were rooted in constructivism. As constructivism at its core is a pedagogy wherein conceptual meanings are created in social contexts, students demonstrated their ability to engage wholly in the constructivist nature of the learning tasks.

Data from my daily personal reflection journals also showed that students were engaged in the learning tasks; however, this engagement persisted when students received assistance in traditional formats. For example, multiple times throughout the learning sequence, I had to provide students either with direct technical support to facilitate their data collection, or I had to provide them with direct conceptual support in order for them to continue with the learning task in a manner that directly targeted the guiding question of each learning task.

Student artifacts showed generally strong conceptual understandings for the majority of students, while some students generally struggled to demonstrate conceptual

understandings in the form of a concise scientific argument. For students with strong artifacts participation in NGSS-aligned learning tasks helped them develop conceptual understandings about the procedures, data, and analysis required to answer the guiding questions for each task. Conversely, the students with weaker artifacts may have struggled with developing scientific arguments that reflected understanding of the NGSS-aligned learning tasks. Though the majority of students demonstrated generally strong conceptual understandings, some students' conceptual understanding was not deepened enough with the NGSS-aligned learning tasks, and developing remedial pedagogical strategies may be an area for future research.

Finally, semi-structured focus group interviews revealed that many students felt that their participation in the NGSS-aligned learning tasks was highly engaging and fun as they indicated the tasks provided them an opportunity to "*do stuff with [their] hands,*" and they were able to "*apply what [they] were learning*"; however, developing deep conceptual understandings did not occur without some degree of struggle. Often, this struggle led students to collaborate with their peers as a means to gain different perspectives to solve problems, or they sought my guided help as a facilitator. Additionally, the fifteen students who participated in the focus group interviews unanimously indicated that providing them with direct instruction prior to the presentation of constructivist learning tasks facilitated their persistence with constructivist learning. In other words, students felt that having a repository of traditional information from which to draw aided their ability to effectively engage with the constructivist learning tasks and further develop deep conceptual understandings of the NGSS-aligned learning tasks.

Findings Related to Research Question Two

A major focus of this qualitative action research study was how student participation in NGSS-aligned learning tasks impacted my epistemological beliefs. As mentioned throughout this manuscript, my deeply held epistemological beliefs were in favor of traditional pedagogies because of earlier experiences that did not leave me feeling confident regarding the reliability of constructivist pedagogies for promoting student conceptual understanding. With this in mind, the data collected throughout this qualitative action research study served to influence my epistemological beliefs in various ways.

Observation data revealed that student participation in NGSS-aligned learning tasks required my continued support of student learning in varying capacities. The majority of the time, the assistance that I provided to students was as a facilitator of student learning, which is expected in constructivist learning environments. Providing guided support in this manner was sufficient for the majority of instances in which students sought my support; however, some instances required me to intervene in a more direct, traditional manner wherein as the instructor I provided direct information to my students to aid with their understandings. Though the majority of the time I observed students using student-centered approaches coupled with my facilitated guidance to develop conceptual understandings, the few instances when I provided direct guided instruction led me to believe that an epistemological shift completely in favor of exclusively constructivist pedagogies was not entirely possible for me. My decision to use traditional instruction to aid students arose from my underlying resistance to have students continue to construct meanings about phenomena due to classroom time

constraints. Nevertheless, the observation findings show that direct teacher intervention was not required excessively and that the majority of the time my attitudes favored the use of constructivist pedagogies as I noticed through observations that the need to directly instruct students as they participated in NGSS-aligned learning tasks was not as frequent as I had anticipated at the start of this action research study.

Daily personal reflections also revealed that my providing traditional support to my students during the NGSS-aligned learning tasks aided students' constructing their own understandings. In other words, any positive influences on my constructivist epistemological beliefs were made possible because my traditional interventions promoted student engagement with the NGSS-aligned learning tasks. The findings from the daily personal reflections suggest that an epistemological shift toward constructivism was possible for me because of the use of traditional pedagogies when appropriate.

Student artifacts revealed that the majority of student participants were able to demonstrate conceptual understandings related to the NGSS-aligned learning tasks. As student demonstration of learning emerges at the forefront of epistemological change, it is reasonable to conclude that a shift in my epistemological beliefs is developing as a result of the performance of the majority of my students. Ideally, all students would have demonstrated at least proficient demonstration of conceptual understandings, and because this was not the case, a complete epistemological shift has not yet occurred. Though a complete shift has not yet occurred, based on the performance of my students on the mini-posters throughout the learning sequence, an epistemological shift in favor of constructivism has begun.

Finally, data from focus group interviews suggest students particularly enjoy the opportunity to engage in NGSS-aligned learning tasks. Additionally, student participants repeatedly emphasized that a core component of the NGSS-aligned learning tasks involved their struggles to solve the problems without the explicit guidance of the teacher. In effect, the notion of struggle coincided with the ability for students to develop understandings and construct meanings from those understandings. As discussed in Chapter One, a notable reason for my aversion to the constructivist pedagogies of the NGSS was because I believed student struggle was a direct reflection of my ineffectiveness as a teacher. As noted from participant responses to interview prompts, struggle became a motivating force for many students to persist with the learning tasks. Furthermore, many participants indicated that the direct instruction provided to students to help guide them to solve the problems associated with a given NGSS-aligned learning task further assisted them with developing understandings and constructing meanings. The notion of struggle being an expected part of the constructivist learning process and the notion of direct instruction to help guide students have both resulted in an epistemological shift in favor of constructivist learning processes.

Though the findings from the data show that a complete epistemological shift has not entirely occurred, it is important to note that my epistemological beliefs prior to the start of this qualitative action research study were deeply in favor of traditional pedagogies. Following this qualitative action research study, I can confidently conclude that my epistemological beliefs are no longer exclusively in favor of traditional pedagogies. My experience implementing NGSS-aligned learning tasks in my classroom has revealed that students are indeed capable of developing their own understandings and

constructing their own meanings in social contexts, with my guided support. Additionally, this experience has revealed that student struggle does not necessarily reflect on teacher effectiveness, but rather is something to expect and accept, particularly in constructivist science classrooms. The broader implications of what has been discovered during this qualitative action research study will be discussed in the next chapter.

CHAPTER 5

IMPLICATIONS

As described in the previous chapters, the purpose of this qualitative action research study was to examine how student experiences with NGSS-aligned learning tasks ultimately impact my epistemological beliefs, in the context of traditional versus reform-based science learning. This purpose aligns with my problem of practice as described in Chapter One. The problem of practice related to my epistemological beliefs that were deeply in favor of traditional pedagogies; however, I knew that as a science teacher in the state of California, I had no choice but to adopt the NGSS and implement constructivist, reform-based learning opportunities in my classroom. Earlier experiences trying to implement the NGSS in my classroom were accompanied by struggle and a sense of frustration surrounding student learning. As the NGSS is a state-mandated reform movement in California, I was left with little autonomy to solely use traditional pedagogies in my classroom, so I turned to qualitative action research to carefully explore how to implement the NGSS in my classroom despite my deeply-rooted epistemological beliefs favoring traditional instruction. To pursue the study's purpose, I posed the following questions:

1) How does the implementation of the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact the conceptual understanding and engagement of my college preparatory (CP) high school chemistry students?

2) How does college preparatory (CP) high school chemistry student participation in the science and engineering practices (SEPs), as outlined in the Next Generation Science Standards (NGSS), impact my epistemological beliefs?

Derived from the study design in Chapter Three, the primary findings of this qualitative action research study, as explained in Chapter Four, reveal that the implementation of constructivist pedagogies, as supported through the use of the NGSS, cannot occur without some level of traditional guidance and instruction. Additionally, student participants demonstrated high levels of engagement when participating in constructivist learning tasks, however, developing deep conceptual understandings of the content did not occur without some degree of struggle. The construct of struggle is an important facet of this action research study as my early experiences implementing the NGSS occurred with significant personal struggle, and students demonstrated struggle when engaged in constructivist learning tasks. An important finding centering on the construct of struggle is the notion that student struggle is not necessarily reflective of teacher effectiveness as students still demonstrated conceptual understandings despite their struggles. Though a complete epistemological shift exclusively in favor of constructivist pedagogies did not occur, it is important to note that my epistemological beliefs are no longer solely in favor of traditional pedagogies. Instead, through this qualitative action research study, my epistemological beliefs have moved in a favorable direction toward constructivist pedagogies as a means to engage students and promote their conceptual access to the disciplinary content of my CP Chemistry course.

The remainder of this chapter will reflect on the major findings of this qualitative action research study by rooting these findings in the problem of practice and the review

of literature described in Chapter Two. Additionally, the major findings will be discussed in relation to their implications for my practice as a science educator and other science educators wishing to enact epistemological change in their own classrooms. Moreover, a discussion of the specific unanticipated methodological constraints and challenges will be presented, with specific reference to the planned methodological choices described in Chapter Three. This chapter will also provide a discussion of how the findings of this action research study will be used to inform the next steps of my professional practice and how the findings ultimately influence the decisions I will make in the pursuit of additional research opportunities. Finally, Chapter Five will conclude with a reflection on the use and benefit of action research to investigate problems of practice.

Reflection on Findings

As previously described, the major findings associated with this action research study included the notion that a complete epistemological shift in favor of constructivist pedagogies may not be possible without the use of traditional pedagogies to support the transition. Additionally, teachers must embrace the probability of student struggle during constructivist learning tasks and that this struggle is not something to fear, as it is an expected part of the student learning process in constructivist classrooms. The implications associated with these findings suggest that teachers wishing to transition to constructivist pedagogies must embrace student struggle as a natural part of the student learning process and that a shift to constructivism does not mean entirely relinquishing the use of traditional pedagogies.

How the Findings Inform my Understanding of the Problem of Practice

This qualitative action research study investigated a noteworthy problem of practice in my classroom wherein implementing the constructivist vision of the NGSS significantly conflicted with my epistemological beliefs that favor traditional pedagogies. The way I framed my problem of practice assumed that epistemological change must be realized in its entirety and must involve a complete shift in favor of constructivist pedagogies to fully align with the vision of the NGSS. Framing the problem this way reflected what the literature implied regarding epistemological beliefs as a dichotomous construct wherein one's beliefs are either rooted in traditional or constructivist pedagogies. The key findings of this study suggest that epistemological change in favor of constructivist pedagogies can still be realized with the concurrent use of traditional pedagogies, and need not be a complete shift to qualify as epistemological change. Additionally, as suggested in Chapter One, the avoidance of student struggle was an underlying reason for my deep-rooted epistemological beliefs in favor of traditional methods of instruction. The finding that student struggle is to be expected in constructivist classrooms indicates that overcoming deep-rooted epistemological beliefs in favor of traditional pedagogies meant accepting student struggle as a natural part of the student learning process.

Epistemological Change as a Gradual and Dynamic Process

The finding that epistemological change from traditional to constructivist pedagogies does not occur without the combined use of both pedagogies fits indirectly into the context of the literature discussed in Chapter Two. Though the literature described in Chapter Two defines the relationship between teacher beliefs and enacted

classroom practice, this relationship is defined in dichotomous terms of favoring either a constructivist or traditional approach to instruction and does not delineate epistemological change in the context of a combined approach to pedagogical decision-making.

Abidelli-Sahin and Bailey (2017) argue that epistemological change ought not be described in the context of epistemological beliefs but rather in terms of an epistemological worldview. The distinction between the two terms is that epistemological beliefs refer to "beliefs about the nature of knowledge and knowledge acquisition" (p. 27) whereas an epistemological worldview refers to "the collective set of epistemological beliefs that comprise a holistic belief system" (p. 27). This distinction is important in the context of the primary finding of this qualitative action research study as an epistemological transition should not be deemed unsuccessful if one's epistemological beliefs do not completely belong to either the traditional or constructivist category. Additionally, Abidelli-Sahin and Bailey (2017) assert that in terms of epistemological worldviews, individual worldviews occur on a continuum from "realist to relativist" (p. 295), wherein "a realist would endorse beliefs related to traditional teaching practices…[and] a relativist worldview would endorse beliefs aligned with constructivist practices" (p. 295).

In effect, as Abidelli-Sahin and Bailey (2017) assert that epistemological worldviews occur on a continuum, it is not unusual for one's epistemological worldview to progress along the continuum from realist to increasingly relativist with experience and time. In fact, Abidelli-Sahin and Bailey's (2017) assertion that experience and time promote epistemological change echoes Wall's (2018) claim that epistemological beliefs

develop and change over time with years of teaching experience. This affirms my finding that my epistemological beliefs did indeed shift from traditional to constructivist pedagogies with experience in my classroom, but only somewhat. In effect, in accordance with Abidelli-Sahin and Bailey's (2017) notion of an epistemological worldview continuum, a marked personal epistemological shift did occur.

Though my personal epistemological beliefs did move toward the use of greater constructivist pedagogies, Duffy et al. (2017) assert that the repeated use of constructivist pedagogy should facilitate the development of greater constructivist beliefs, thereby further proceeding along the worldview spectrum that Abidelli-Sahin and Bailey (2017) describe. Duffy et al. (2017) indicate that ideally teachers' application of constructivist pedagogies would stem from explicit instruction during pre-service teaching courses; however, in-service teachers who did not have this exposure in their teacher preparation programs must take the initiative to deconstruct how to apply constructivist pedagogies in their own classrooms. Though Duffy et al. (2017) speculate that greater constructivist teaching practices yield epistemological beliefs in favor of constructivism, the reality is that deeply-rooted beliefs are difficult to change and while epistemological changes in beliefs may occur, they are often not sweeping or exclusive to one theory of learning. In other words, like Abidelli-Sahin and Bailey's (2017) assertion that epistemological beliefs are better considered as a holistic worldview, Duffy et al. (2017) indicate that epistemological change need not be wholly realized to be considered change and can develop over time with experience.

Finally, Watkins et al. (2017) also acknowledge that epistemological change is a dynamic process that occurs progressively with experience and time. In addition to the

dynamics of epistemological change, Watkins et al. (2017) assert that epistemological beliefs are the product of multiple sources of epistemologies rather than a single, unitary construct. In other words, epistemological beliefs are complex and unique to each individual, stem from the wide array of teaching and learning experiences that teachers gain over the course of their lifetimes, and as a result are difficult to categorize in a single epistemological viewpoint. Watkins et al. (2017) prefer the term epistemological progress over epistemological change and specifically study epistemological progress in the science classroom. The findings of their study reveal that epistemological progress is influenced by what is happening in the science classroom at any given time. In other words, specific situations and occurrences in the classroom markedly influence epistemological progress, and in this regard epistemological beliefs may oscillate between one view to the next. The findings of this study might explain why my epistemological progress could only be made possible with the use of traditional pedagogies to support the process, as various situations during the course of the study led me to make pedagogical decisions in favor of traditional or constructivist approaches of instruction. Watkins et al. (2017) acknowledge that while the findings of their study shed light on the complexity of epistemological beliefs and the influence of these beliefs on moment-to-moment decisions in the classroom, further research is needed to track epistemological progress over longer periods of time to gain insight into how repeated occurrences or situations influence epistemological beliefs over time.

Student Struggle is a Necessary Component of Epistemological Change

The second finding of this qualitative action research study, that struggle is an important component of the student learning process in a constructivist classroom and is

not something that ought to be avoided, was not directly addressed by the literature discussed in Chapter Two. Fouché (2013) asserts that student struggle in constructivist learning environments is a necessary experience and that students who are deprived of the opportunity to struggle during constructivist learning tasks are unable to "replace their alternate or naïve misconceptions with more accurate mental models" (p. 46). The very basis of the constructivist classroom is to allow students the opportunity to construct their own understandings of disciplinary content knowledge. Denying students the opportunity to construct their own understandings, while making mistakes along the way, undermines the essence of constructivism and does not allow students the chance to demonstrate authentic learning. Without this opportunity for students to construct their own understandings, epistemological change at any level cannot be realized. Instead, Fouché (2013) argues that struggle ought to be viewed as an experience of "productive failure" rather than an inability for students to demonstrate conceptual understanding.

Russo et al. (2020) further support Fouché's (2013) ideas that student struggle is a necessary component of the student learning process in the constructivist classroom. However, Russo et al. (2020) assert that how a teacher perceives student struggle may shed light on their magnitude of teaching enjoyment. In other words, "teachers who enjoy teaching…will also hold positive attitudes toward student struggle" (Russo et al., 2020, p. 3). The authors further suggest that those teachers who experience anxiety as a result of student struggle may do so because these teachers perceive student struggle as a direct threat to their own control of teaching, which echoes my own early attempts to implement constructivist pedagogies in my own classroom. As Russo et al. (2020) describe, my early struggles to adopt the constructivist nature of the NGSS stemmed from

a sense of a loss of control when faced with student struggle. In contrast with my earlier experiences with student struggle, this qualitative action research study allowed me to more readily accept student struggle as an important component of the student learning process during NGSS-aligned learning tasks. This finding is supported by Russo et al.'s (2020) assertion that "teaching approaches that value persistence in the face of challenge require substantive knowledge of content…as well as a high degree of teacher self-confidence to facilitate student learning" (p. 7). This assertion is notable in light of my own experience, as my initial attempt to implement the NGSS in my classroom occurred at the start of my second year of teaching. As a relatively inexperienced teacher, I did not have the self-confidence nor the substantive pedagogical content knowledge required to persist with constructivist teaching during times of student struggle. This qualitative action research study was conducted during the second semester of my sixth year in the secondary chemistry classroom. Between my second year of teaching and my sixth year of teaching, I gained practical experiences in the classroom that strengthened my self-confidence as a teacher as well as my pedagogical content knowledge, and it is likely that this combination permitted me to view student struggle as an acceptable by-product of student learning in the constructivist classroom.

Finally, Duffy et al. (2017) frame the essential difference between traditional and constructivist epistemological beliefs as being rooted in the amount of effort the teacher perceives as necessary for student learning. Teachers whose epistemological beliefs are rooted in traditional pedagogies often believe student learning should be an effortless process wherein the teacher directly transmits knowledge to students, while those with epistemological beliefs in favor of constructivism view student learning as a gradual and

effortful process. This simplification sheds light on my initial struggles with implementing constructivist teaching processes in my classroom. A major reason for the struggle associated with my early experiences implementing constructivist pedagogies was rooted in the idea that I did not feel comfortable with student struggle. In other words, I did not recognize that student struggle is a necessary part of the student learning process in constructivist classrooms, and instead I understood student struggle to reflect an inadequacy in my teaching. In effect, my traditional epistemological beliefs were further reinforced by the emergence of student struggle, which I perceived to be an unexpected part of the student learning process. Duffy et al.'s (2017) clear delineation of the difference between traditional and constructivist pedagogies in the context of student struggle further reinforces the notion that student struggle is an expected part of the student learning process in the constructivist classroom.

Impact of Findings on my Practice

The major findings associated with this qualitative action research study promote the continued implementation of the NGSS in my classroom. My earlier experiences implementing the NGSS in my classroom failed because I felt that the authentic use of the NGSS meant completely relinquishing the use of traditional pedagogies in any capacity and that student struggle was an indication that authentic student learning was not taking place. The findings of this qualitative action research study reveal that I can continue exploring the implementation of the NGSS in my classroom while still using traditional pedagogies as a means to support student constructivist learning. Additionally, I can continue developing NGSS-aligned learning tasks with the expectation that students will struggle, knowing this struggle is a normal by-product of the constructivist learning

process. These implications for my practice reveal that conducting this qualitative action research study led to a confident transition toward constructivist pedagogies, as I have developed a better understanding of the true meaning of constructivist student learning in the context of the NGSS.

Transferability of the Key Findings

Transferability in qualitative research is defined as how well the description of the research, context, participants, and participant-researcher relationship enables the reader of the study to determine if the study, and the findings associated with it, are useful in other situations (Fraenkel et al., 2015). Unlike generalizable studies, the reader of action research studies makes the connection to their unique context through the researcher's assertions of applicability of the study to other contexts (Fraenkel et al., 2015), thus promoting transferability of the findings. It is important to note that the purpose of action research is not to produce generalizable results, but rather to explore a unique problem of practice to improve one's practice, yet an action research inquiry can aid readers with similar problems of practice to transfer the results of the study to their own contexts.

With the above definitions in mind, the findings of this qualitative action research study may be transferable to other practitioners wishing to enact a change in their own epistemological beliefs in favor of constructivist pedagogies, particularly those practitioners whose epistemological beliefs conflict with the essence of the constructivist nature of the NGSS. While the focus of this qualitative action research study was how the use of NGSS-aligned learning tasks in the secondary chemistry classroom impacts my epistemological beliefs, the findings of this study are also transferable to educators in other science disciplines such as biology, physics, or earth science.

The NGSS encompass all of these fields, and thus those educators teaching in states that have formally adopted the NGSS might gain benefit from my experience implementing the NGSS in my classroom and the findings associated with my implementation.

In addition to the major findings of this qualitative action research study being transferable to other science education contexts, the findings are also transferable to science teacher educators. Post-secondary instructors who teach future science educators may transfer the findings of this qualitative action research study to guide their development of science education methods courses. As described in Chapter One, courses in my science teacher preparation program did not adequately prepare me to appreciate the constructivist theory of learning in the science classroom. Instead, science learning was situated in the science standards that preceded the NGSS, and thus teaching science *content* rather than the *process* of science formed the basis of my pre-service teaching and early in-service teaching experiences. The findings of this qualitative action research study may inspire post-secondary instructors to develop courses that not only expose pre-service teachers to the constructivist theory of learning but also allow them to practice using constructivist methods. Allowing pre-service science teachers the opportunity to use constructivist methods also has the added benefit of helping them acknowledge what Rosenfeld and Rosenfeld (2006) refer to as their Individual Learning Differences (ILDs), and explore how their ILDs might be influenced if they are provided a structured and scaffolded opportunity to engage with constructivist learning. Post-secondary instructors wishing to aid their science education students with developing deep understandings of the value of constructivism and the need for greater implementation of constructivist pedagogies in an era of reform-based science education

might find value in the major findings of this action research study. This value is rooted in the recognition that pre-service science teachers trained for the 21st-century science classroom will need to embrace the constructivist theory of student learning as a vital part of science teaching.

Validity and Reliability of the Key Findings

Validity in research is defined as "the appropriateness, correctness, meaningfulness, and usefulness of the specific inferences researchers make based on the data they collect" (Fraenkel et al., 2015, p. 149). As indicated earlier, external validity, or the generalizability of the research results is not an intended outcome of action research and thus not a consideration in this action research study. On the other hand, internal validity, or the unambiguity of the relationship between the data collected and the conclusions reported, is often subject to threat in action research studies (Fraenkel et al., 2015). Though I carefully sought to avoid threats to internal validity during this action research study, some threats were unavoidable. For example, as will be discussed in the next section, low participation may have affected the outcome of the study, and thus the conclusions regarding the major findings.

Reliability refers to the consistency of the data obtained from one administration of an instrument to another (Fraenkel et al., 2015). The data collection instruments used to collect data for this qualitative action research study included observations, a personal reflection journal, student artifacts, and focus group interviews. As this studied employed a qualitative methodology, it is natural for the data collection instruments to result in varying data; however, the instruments did not uncover data that was significantly different in the context of the major themes of this study. As a result, the major findings

of this study reflect a collection of reliably consistent thematic data. A deeper discussion of the methodology of this qualitative action research study follows in the next section.

Reflection on Methodology

As described in Chapter Three, this action research study was rooted in a grounded theory tradition of qualitative research. Furthermore, this qualitative action research study was conceived in the constructivist-interpretivist research paradigm, which assumes that meaning is constructed socially through interactions between all parties involved in the research and derived from their multiple perspectives (Durdella, 2019).

This study qualified as a qualitative action research study for a variety of reasons. First, this study effectively met a variety of goals of action research including the generation of new knowledge with the intention of improving my practice as a science educator (Efron & Ravid, 2013). This study design provided me with the opportunity to investigate my practice more closely and identify areas of practice that I deemed worthy of improvement for both my students and myself. Furthermore, this action research study was rooted in the grounded theory tradition of qualitative research, the goal of which is to "explain the relationships between factors that shape outcomes" (Durdella, 2019, p. 96). The aim of this study was to explain the relationships between student participation in NGSS-aligned learning tasks and my epistemological beliefs. Moreover, in addition to qualitative data collection instruments such as observations and student artifacts, participant interviews were a major source of data that ultimately guided the construction of a theory relating student participation in NGSS-aligned learning tasks and my epistemological beliefs.

Grounded Theory

Though this action research study met many of the goals of the grounded theory tradition of qualitative research, some aspects of the grounded theory tradition were not theoretically applied in this action research study. For example, the focused and theoretical coding consistent with grounded theory assumes that codes are applied inductively as understandings emerge from the close study of texts; instead, codes were applied deductively to the texts as derived from theory or prior knowledge. (Bernard et al., 2017). The choice to use a deductive coding process does not negate the use of grounded theory in this action research study, though it does not follow the theoretical roots of what constitutes grounded theory. As Bernard et al. (2017) assert, "real research is never purely inductive or purely deductive" (p. 220), and my decision to use deductive codes grounded my emergent theory in prior knowledge and theories that already describe the significant differences between traditional and constructivist pedagogies. Furthermore, the decision to apply deductive codes does not undermine the ultimate goals of grounded theory as "grounded theory methods can complement other approaches to qualitative data analysis" (Charmaz, 2014, p. 16).

The theoretical application of grounded theory also assumes a theoretical sampling approach when choosing study participants. Theoretical sampling requires the grounded theory researcher to choose specific participants to study "based on the content of the developing theory" (Bernard et al., 2017, p. 224) through each stage of the data collection and subsequent analysis consistent with grounded theory. In this qualitative action research study, purposive sampling was conducted primarily to ensure a representative cross-section of students who participated in the planned NGSS-aligned

learning tasks associated with this study. The difference between the purposive sampling technique used in this study and theoretical sampling is that the purposive sample was chosen at the end of the data collection segment of this qualitative action research study. Theoretical sampling assumes that participant selection may change at various stages of the study as theories emerge during the course of data collection. Though the sampling technique did not align with the theoretical basis of the grounded theory paradigm, Charmaz (2014) emphasizes that grounded theorists approach their research with a set of flexible guidelines in mind, rather than a methodological set of rules and requirements.

Low Participation

As noted earlier, low participation poses a threat to the internal validity of this qualitative action research study. Participant sample selection and size constituted the largest deviation from the elements of the research design discussed in Chapter Three, wherein I explained why I sought approximately 24 students from three (3) college preparatory chemistry classes. This rationale was twofold: first, since three (3) CP classes were used to recruit participants, eight (8) student participants from each class accounted for approximately 25% of the class population. Second, semi-structured focus group interviews were used as a data collection instrument, and Fraenkel et al. (2015) assert that no more than eight (8) participants should participate in a focus group interview at one time. Moreover, I desired a sample that represented a wide range of academic and cultural backgrounds to allow for the greatest variation in student reflections on their experiences with the NGSS-aligned learning tasks.

Indeed, I purposively selected a total of 32 students to participate in the focus group interviews, to maximize the probability that the desired 24 students agreed to

participate, and ultimately only 15 student participants agreed to participate in the focus group interviews. Adhering to researcher ethics, I did not offer the selected participants any incentives in the form of renumeration or enrichment grades, but did indicate that refreshments would be provided for those students participating in the focus group interviews. Though my focus group interview data still yielded significant information greater variation of participant responses may have been extracted had more students participated, especially because participant variation was not as heterogenous as I had initially planned.

Despite the cultural diversity of my student participants, academic backgrounds were not as widely represented. For example, in my initial purposive selection of participants, I wanted 1/3 of participants to be students with either IEPs or 504 plans, yet out of the 15 students who ultimately agreed to participate, only 20% met these criteria. Additional information regarding the challenges or experiences of students with IEPs or 504s may have provided more insight into their attitudes toward the NGSS-aligned learning tasks.

Though the variability in academic backgrounds was not as representative as I would have preferred, it was still evident among my participants. Ultimately, Fraenkel et al. (2015) suggest that the best way to mitigate the problem of low participation is to simply “do one’s best” (p. 169), which I believe I have done, particularly as it is unethical for me as an action researcher to command my students to participate in the focus group interviews.

Participant Attitudes

Observation data were also a major source of qualitative data throughout this qualitative action research study. My students were aware of the study and were aware that I was collecting observation data for later analysis, which may have threatened the internal validity of this study through the "Hawthorne effect" (Fraenkel et al., 2015, p. 175), wherein participants may perform better and in more positive ways when they are aware that they are being observed. For example, during one particular observation, when I was listening to a group's conversation, one student remarked that I should put his comments in my field notes. This signaled that the student was aware they were being observed, felt they were making unusually positive contributions, and wanted to be represented in my study.

Fraenkel et al. (2015) recommend circumventing such attitude threats to internal validity by not announcing that an experiment is being conducted. As discussed in Chapter Three, I opted not to obtain parent/guardian approval for students to participate in the observation portion of the study, as it would have been logistically difficult to observe only those students selected to participate in the subsequent focus group interview. Thus, I could have elected not to inform students that I was collecting observation data, except for those students selected for the subsequent focus group interview and students who were invited but declined to participate.

Though Fraenkel et al.'s (2015) description of the Hawthorne effect may be more applicable to traditional research studies, it is difficult to determine if this threat to internal validity is as serious in action research studies. As this qualitative action research study required me to observe the engagement and conceptual understanding of my

students as they participated in NGSS-aligned learning tasks, observations of engagement may be more subject to the Hawthorne effect than observations of conceptual understanding. In other words, while instances of student engagement may be influenced by students' knowledge of my observations, it is unlikely that their conceptual understanding would be influenced by my observations. With this in mind, disclosing to my students that I was conducting action research to better understand my teaching, I sent the message that I care deeply about how my pedagogical decisions affect them. As a result, it is possible that my students felt that pleasing me during observations was in fact a desirable outcome of this action research study.

Implementation Plan

The findings of this qualitative action research study reveal that epistemological beliefs exist on a spectrum, such that any directional movement along the continuum of this spectrum indicates a change in epistemological beliefs, and that student struggle is a natural and expected part of the learning process. This newfound knowledge better positions me for continued research in the areas of teacher beliefs, NGSS implementation, and student attitudes toward NGSS-aligned learning tasks. Reflecting on these areas of continued research resulted in the emergence of several research questions that I would like to explore moving forward. These areas of research, as well as the context in which these research problems will be explored is discussed in further detail in this section.

The first major finding of this qualitative action research study shows that a change in epistemological beliefs does not need to manifest in an exclusive preference for one pedagogy over another. In other words, I found that my epistemological beliefs did in

fact change from strictly traditional pedagogies to more constructivist teaching strategies; however, the change in favor of constructivist pedagogies was not realized without the use of traditional methods of instruction. This finding sets the stage for further areas of research regarding teacher epistemological beliefs in the era of the NGSS. My research interest encompasses the epistemological beliefs of pre-service science teachers, and specifically why pre-service science teachers pursue careers in science education if their epistemological beliefs are rooted mainly in traditional instruction. Understanding how pre-service science teachers with traditional epistemological beliefs plan to navigate the field of science education in the era of the NGSS is of particular interest to me since I was once a pre-service, and early in-service, teacher whose epistemological beliefs fundamentally conflicted with the vision of the NGSS.

Though this area of continued research does not fully qualify as action research, I plan to continue implementing qualitative research strategies to gain further insight. A qualitative methodology would be most appropriate for learning about the feelings and experiences of pre-service science educators to gain a better understanding of their motivation for pursuing careers in science education. Furthermore, as one of the key findings of this qualitative action research study revealed that epistemological beliefs tend to exist on a continuum, it would be interesting to discover where pre-service science teachers who primarily identify as traditionalists position their epistemological beliefs along this continuum.

The second major finding associated with this qualitative action research study revealed that student struggle is a natural and expected byproduct of student learning in constructivist classrooms. Student struggle is not something for teachers to fear, but

rather a necessary component for science students to truly understand the authentic experience of participating in science. With this in mind, another potential area of continued research is how pre-service and in-service science teachers perceive student struggle and how this perception changes depending on where on the continuum teachers' epistemological beliefs lie. Furthermore, how do perceptions of student struggle change depending on classroom experiences? This is an area of continued interest because my early experiences with the NGSS led me to fear student struggle, and it is likely that my fear of student struggle was due to my strong traditional epistemological beliefs coupled with my inexperience in the science classroom. Conversely, this research topic can be examined from the reverse perspective wherein the influence of perceptions of struggle ultimately impact teachers' epistemological beliefs. Again, though this research may not qualify as a traditional form of action research, a qualitative research methodology could generate insight into this topic, as interview data with participants would provide rich data regarding the thoughts, feelings, and perceptions of both pre-service and in-service science teachers.

Finally, this qualitative action research study has inspired an interest in how the NGSS promotes culturally responsive pedagogy in the science classroom. America's current science student demographic reflects a majority of minority students. With this changing demographic, the importance of providing science students with classroom experiences that embrace diversity is greater than ever. The literature is rife with research showing that females and ethnic minorities are underrepresented in the STEM fields (Baker, 2013; Ong et al., 2018). Providing diverse students with experiences that spark an interest in STEM careers is imperative, and careful lesson planning in the context of the

NGSS can help to promote greater cultural responsiveness, and thus improved STEM career expectations for diverse students. Ensuring that the science curriculum in the context of the NGSS promotes cultural responsiveness provides a platform of social justice for minority science students.

With this goal in mind, an action research opportunity arises wherein I can research how diverse students perceive NGSS-aligned learning tasks. Though I purposively sampled students to represent a wide range of cultural backgrounds for this qualitative action research study, the interview protocol used did not explicitly address how culture impacts diverse students' experiences with the NGSS. The NGSS often touts that the standards promote equity in the science classroom (NGSS Lead States, 2013), and indeed the literature shows that the SEPs of the NGSS rely on the experiential backgrounds of diverse learners to solve scientific problems, thus promoting equity in the science classroom. However, existing literature does not clearly delineate how students perceive the NGSS to meet their diverse learning needs, as well as how well the NGSS encompasses a culturally responsive approach to science teaching. In other words, do students perceive the NGSS to be as culturally responsive as the literature suggests?

Answering the above research question would encompass a traditional approach to qualitative action research, as further understanding of student attitudes and perceptions regarding the cultural responsiveness of the NGSS would rely heavily on interview data. Furthermore, the findings from this study could help me design future lessons anchored in the NGSS that are more culturally responsive, should interview responses indicate student perceptions that do not reflect favorably on the way the NGSS is presented in my classroom.

In addition to pursuing additional research opportunities, the proficiency I gained by implementing the NGSS throughout this action research study enables me to continue using the NGSS as a vehicle to promote social justice in the science classroom. Providing students with opportunities to explore phenomena rooted in social injustices contributes to the contextualization of science in real-world contexts, which in itself promotes cultural responsiveness. For example, the NGSS can be used to explore phenomena such as air pollution and its disproportionate impact on minority populations, or the social injustices of the Flint water crisis to aid students with understanding how authentic science can be used to overcome social injustices. Addressing social justice through the use of the NGSS aligns strongly to the vision of the NGSS as a means to deliver science instruction to diverse students in contexts that are meaningful.

Conclusion

The phrase action research embodies two important constructs: action and research. The term action implies that "*action* is central to the research enterprise" (Herr & Anderson, 2015, p. 3), as the researcher takes an intimate role in close proximity to the research. In effect, an emic perspective is imperative in action research as the researcher comes directly from within the culture in which the research is being conducted.

As an action researcher I had the opportunity to examine a problem of practice that was meaningful to me. My action research approach yielded several advantages over traditional approaches when pursuing this study's specific research questions. The most significant advantage is that the findings can improve my practice as an educator. In effect, "action research allows teachers to connect education theory and research to their classroom practice and helps them to become more reflective and analytical in their

teaching practice" (Johnson, 2012, p. 234). With this in mind, action research presented a strong opportunity for reflection on my teaching, as well as my deep-rooted epistemological beliefs as an educator. The major findings of this qualitative action research study revealed new information regarding my teaching practice and also shed light on the origins of my epistemological beliefs and how changing beliefs is a gradual, yet feasible, process. Additionally, the results of this qualitative action research study revealed that student struggle is not a construct that ought to be feared, but rather one that ought to be embraced as a clear indication of the student learning process in constructivist classrooms.

Without conducting this qualitative action research study, I would have undoubtedly still feared student struggle and perceived it as a sign of inadequate student learning. Markedly, the acceptance of student struggle facilitated the transition of my epistemological beliefs from solely traditional pedagogies to constructivist ones. Additionally, conducting this qualitative action research study ultimately poses a significant benefit for my future students as my epistemological beliefs, and thus my attitudes toward constructivist learning in the context of the NGSS, have changed. In this regard, conducting action research presented a significant opportunity for my growth and development as a practitioner.

Though cliché, the reality is that knowledge is power. Conducting this qualitative action research study allowed me to construct my own body of knowledge in the specific area of epistemological beliefs thereby empowering me to better understand my practice. Though abundant literature related to the topic of epistemological beliefs exists, the reality is that the literature could not adequately capture the unique challenges and

circumstances of my own changing epistemological beliefs. In effect, I no longer have to rely on what the "research" says about the topic of changing epistemological beliefs, as I have now generated my own understandings of the topic in my own specific context. Furthermore, "observation, reflection, and analysis of [my] own teaching practice [through action research is an] effective way to approach [my] professional development" (Johnson, 2012, p. 227). Indeed, conducting this qualitative action research study not only led to enacted change in my personal epistemological beliefs, but also professional change as a science educator. This professional change is necessary as the educational landscape continues to evolve as a result of changing student demographics and societal needs. As the educational landscape continues to change, educators must also lead through change, and educator change is ultimately facilitated through the use of an important tool in the arsenal of all practitioners seeking insight into their own educational settings: action research.

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APPENDIX A

PARENT/GUARDIAN CONSENT LETTER

Dear parents and guardians,

My name is Nancy Nasr, and I am your student's CP Chemistry teacher. In addition to being a teacher, I am also a doctoral student, through the University of South Carolina's online program in Curriculum and Instruction. During the spring semester, I will be conducting an action research self-study related to the impact of inquiry-based teaching on student engagement and achievement and their resultant influence on my beliefs as a teacher. As a self-study, my research is primarily focused on me and my professional development, but I am inviting your student to take part in this research study, because he/she is currently enrolled in my CP Chemistry class, and it is in my CP Chemistry class that the study will take place during the first half of the spring semester, during regular and after school hours.

If you agree to let your student participate in this research study, the following may occur:

- Your student may be observed participating in inquiry-based learning during regular classroom hours
- Your student's work may be collected, kept and analyzed for evidence of conceptual understanding.
- Your student may be asked to participate in a 60-minute focus group interview after school, related to their experience with inquiry-based learning.

Your student's identity will be protected, as I will not use real names, or other identifiers, when analyzing and reporting the data. Observation and interview data will be retained electronically, and only I will have access to the raw data. At any time, your student may choose not to answer any interview question, and may terminate the interview completely, without penalty.

Participation in this research study is voluntary and you are free to decline to have your student participate. Should you provide consent for your student to participate, you may withdraw your student's participation at any time, without penalty. It is also important to note that if you provide consent for your student to participate in this research study, your student may choose not to participate, without penalty.

If you have any questions or concerns regarding this action research study, or your student's involvement in this study, please do not hesitate to contact me via email at nnasr@ghctk12.com

Thank you,

Nancy Nasr

✂---

Student's Name ___________________________________ Class Period ____________

I DO / DO NOT give consent for my student to participate in this research study.

Parent/Guardian Name (print) ____________________________

Parent/Guardian signature ______________________________ Date

Student signature __________________________________ Date

APPENDIX B

MINI-POSTER TEMPLATE

Name:____
Per:________

Claim, Evidence, Reasoning Mini-Poster Template

Research question: What were you investigating?

Claim: A simple statement that clearly answers the question based on the data you collected.

Evidence: Here you will include data tables, drawings of observations, bar graphs/line graphs if applicable. This is the evidence that you are using to prove to the reader that your claim is correct.

"As seen in the data table…"

"As observed during the experiment…"

Reasoning: What principle/theory/law supports that the evidence you chose correctly supports your claim.

"Based on the evidence, we can conclude (restate your claim), because…"

APPENDIX C

NGSS-ALIGNED LEARNING TASK 1

Lab Guiding Question: What Makes a Good Calorimeter?

Modified from HASPI (2018)

Introduction: In this lab you will be asked to use engineering to design a calorimeter. A calorimeter is a device used to measure the energy flow into or out of a system. This works because the energy flows between the system you are studying and a set amount of water. Knowing the specific heat of water allows us to identify the amount of energy the water lost or gained in the process. This energy can be quantified based on temperature changes and mass of substances present. Because these experiments require the measurement of kinetic energy, a good calorimeter is one that can keep all energy in. A well-insulated device is essential.

In this lab activity you will be assigned a cup and your task will be to find the change in temperature over time for that cup. You and your group will then have a chance to look over the class data to analyze which cup is best when designing a calorimeter.

To determine the change in temperature over time for the cup assigned to you, you will need to use the following formula:

Rate of change:

$$\frac{\text{Change in temperature}}{\text{Change in time}} = \frac{\text{temperature at 5 minutes} - \text{temperature at 1 minute}}{\text{5 minutes} - \text{1 minute}}$$

Materials:

- Various cups with a variety of insulation
- 50mL graduated cylinder
- Thermometer
- Hot or boiling water
- Timer

Procedure:

1. Create a data table to collect data
2. Measure out 50mL of hot or boiling water and add it to your calorimeter.
3. Record the temperature every minute, for a total of 5 minutes
4. Find the change in temperature per minute, by using the formula provided above
5. Record the change in temperature on the board to pool class data

Day 1 questions:

1. Which container had the highest rate of temperature change? The lowest? Which material would be best to design a calorimeter? Why? (Hint: think about the purpose of a calorimeter)

Lab: What makes a good calorimeter? Day 2

Modified from HASPI (2018)

Introduction: In today's activity you will continue designing and constructing your calorimeter. Although an unlimited budget could create a wonderful calorimeter, in this lab each item you use will have a "cost" and you must keep the overall cost under $1. Once again, class data will be pooled to determine which design elements would be most suitable for a final calorimeter design. Your final calorimeter design will be used for subsequent lab activities in the unit.

Materials:

- The cup material that had the lowest rate of temperature change, from Day 1
- 50 mL graduated cylinder
- Thermometer
- Hot or boiling water
- Timer

Optional materials and their "cost":

- Elastic band 5¢
- Scotch tape 1¢ per inch
- Tissues 10¢ each
- Foil lid 10¢
- Ziploc baggie 15¢
- Cotton balls 2¢ each

In the space below, list all of your calorimeter materials and their cost, making sure the total cost is $1 or below.

Procedure:

1. Build your calorimeter with all the materials you chose.
2. Create a data table to collect data
3. Measure out 50mL of hot or boiling water and add it to your calorimeter.
4. Record the temperature every minute, for a total of 5 minutes
5. Find the change in temperature per minute, by using the formula provided above.
6. Record the change in temperature on the board to pool class data

Day 2 questions:

1. What was the rate of temperature change for the calorimeter you tested?

2. Looking at the pooled class data, what materials might you add or remove to your final calorimeter? Why?

Following the 2-day lab activity, you will answer the guiding question in a claim, evidence, reasoning format. You will utilize the CER format to generate a mini-poster. Remember, your claim is the answer to the guiding question; your evidence references data you collected during the experiment; and the reasoning is the underlying scientific principle that supports the evidence you chose to support your claim.

APPENDIX D

LEARNING TASK 1 STUDENT ARTIFACT RUBRIC

What makes a good calorimeter? LAB mini-poster rubric		
Criteria	Description	Maximum points
Claim	Simple answer that addresses the guiding question. (List all materials, particularly foam cup)	1
Evidence in the form of data tables or graphs	Day 1 class data table and rate of change calculation must be present. (2 points) Day 2 data table and rate of change calculation must be present. (3 points)	5
Reasoning supports both the claim and evidence provided	Justification should reference the overall purpose of a calorimeter (i.e. what is a calorimeter used for?)	2
Scientific conventions used	***Units*** used throughout in all calculations. Data tables clearly labelled.	1
Overall presentation	Template is used, neat and tidy, colored.	1

APPENDIX E

NGSS-ALIGNED LEARNING TASK 2

Lab: Which salt will produce an effective cold pack?

Modified from *Argument-Driven Inquiry in Chemistry* (Sampson et al., 2015)

Introduction: An instant cold pack is a first aid device that is used to treat injuries. Most commercial instant cold packs contain two plastic bags. One bag contains an ionic compound, and the other bag contains water. When the instant cold pack is squeezed hard enough, the bag containing the water breaks and the ionic compound and water mix. The dissolution of the ionic compound in the water results in an enthalpy change and a decrease in the overall temperature of the cold pack. In this investigation, you will explore the enthalpy changes that are associated with common salts and then apply what you have learned about these enthalpy changes to design an effective instant cold pack.

The enthalpy change associated with the dissolution process is called the *heat of solution* (ΔHsoln). At constant pressure, the ΔHsoln is equal in magnitude to heat (*q*) lost to or gained from the surroundings. In the case of a salt dissolving in water, the overall enthalpy change is the net result of two key processes. First, an input of energy is required to break the attractive forces that hold the ions in the salt together and to disrupt the intermolecular forces that hold the water molecules in the solvent together. The system *gains* energy during this process. Second, energy is released from the system as attractive forces form between the dissociated ions and the molecules of water. The system *loses* energy during this process. The ΔHsoln can therefore be either endothermic or exothermic depending on the net energy change in the system. The ΔHsoln is exothermic when the system releases more energy into the surroundings than it absorbs and endothermic when the system absorbs more energy than it releases.

A chemist can determine the molar ΔHsoln for a specific salt by mixing a sample of it with water inside a *calorimeter*. A calorimeter is an insulated container that is designed to prevent or at least reduce heat loss to the atmosphere. Once the salt and water are mixed, the chemist can record the temperature change that occurs inside the calorimeter as a result of the dissolution process. The magnitude of the heat energy change is then calculated using the following equation:

$$q = m \times c \times \Delta T$$

where q = heat energy change (in joules), m = ***total*** mass of the solution (water plus salt), c = the specific heat of the solution (4.18 J/g•°C), and ΔT = the observed temperature

change ($T_f - T_i$). The chemist can then calculate the molar ΔHsoln for the salt by dividing q by the number of moles (you will need to convert from grams to moles) of the salt (n) mixed with the water. The units for ΔHsoln will be J/mol.

The **guiding question** of this investigation is "which salt should be used to design an effective ice pack?"

Materials: You may use any of the following materials for your investigation

- No more than 5g of each of the following
  - Ammonium chloride (NH_4Cl)
  - Magnesium sulfate ($MgSO_4$)
  - Sodium thiosulfate (Na_2S_2O3)
- Distilled water
- Graduated cylinder
- Spatula
- Your calorimeter
- Thermometer
- Balance scale

Helpful hints: To answer the guiding question you will need to think about what data to collect and how to analyze it. To determine what data to collect, think about the following questions:

- What type of measurements or observations will you need to make during your investigation?
- Is it important to know the change in temperature of the solution or just its final temperature?
- How does the amount of salt or the amount of water influence your potential results?
- What will serve as your independent and dependent variables?
- How often will you collect data and when will you do it?
- How will you make sure that your data are of high quality?
- How will you keep track of the data you collect and how will you organize it?

To determine how to analyze your data, think about the following questions:

- How will you calculate the heat energy change associated with the formation of a solution?
- How will you calculate the molar ΔHsoln for each compound?
- What type of graph could you create to help make sense of your data?

Report: Following your data collection and analysis, your research team must present your findings and conclusions in the form of a mini-poster. Your mini-poster will be completed on a standard 8.5" x 11" sheet of printer paper. Your mini-poster will include

a clear claim; evidence in the form of data tables, graphs, diagrams etc.; and reasoning that supports the evidence you chose to support your claim. Remember, your mini-posters should be creative, colorful, and tidy.

APPENDIX F

LEARNING TASK 2 STUDENT ARTIFACT RUBRIC

Which salt? LAB mini-poster rubric		
Criteria	Description	Maximum points
Claim	Simple answer that addresses the guiding question. (Ammonium chloride)	2
Evidence in the form of data tables or graphs	Clear data table showing initial and final temperatures of all salts tested. 1 point for EACH calculation of ΔHsoln for all salts tested. ALL work must be present for 1 point.	4
Reasoning supports both the claim and evidence provided	Must correctly discuss the 2^{nd} law of Thermodynamics when salt and water combine.	2
Scientific conventions used	***Units*** used throughout. All data tables clearly labeled.	1
Overall presentation	Template is used, neat and tidy, colored.	1

APPENDIX G

NGSS-ALIGNED LEARNING TASK 3

Lab: Which metal has the greatest specific heat?

Modified from *Argument-Driven Inquiry in Chemistry* (Sampson et al., 2015)

Introduction: Scientists are able to identify unknown substances based on their chemical and physical properties. A substance is a type of matter with a specific composition and specific properties. One physical property of a substance is the amount of energy it will absorb per unit of mass. This property is called specific heat (s). Specific heat is the amount of energy, measured in joules, that is needed to raise the temperature of 1 gram of the substance by 1 degree Celsius. Scientists often need to know the specific heat of different substances when they attempt to track how energy moves into, out of, and within a system.

Chemists use a technique called calorimetry to determine the specific heat of a substance. Calorimetry, or the measurement of heat transfer, is based on the law of conservation of energy. This law states that energy is not created nor destroyed; it is only converted from one form to another. This fundamental law serves as the foundation for all the research that is done in the field of thermodynamics, which is the study of heat, temperature, and heat transfer.

Heat, or thermal energy, can be transferred through a substance and between two different objects that are in direct contact. Scientists call this process conduction. The transfer of heat energy through the process of conduction can be explained by thinking of the heat from a source causing the atoms of a substance to vibrate faster, which means they have greater kinetic energy. These atoms then cause the atoms next to them to vibrate faster by bumping into them, which means that the kinetic energy of the neighboring atoms increases as well. Over time, kinetic energy is transferred from one atom to the next. As more atoms in the substance gain kinetic energy over time, the temperature of the substance increases. This process is also how heat energy is able to transfer between two different objects that are in contact with each other.

The amount of heat (q) transferred to an object depends on three factors. The first is the mass (m) of the object. The second factor is the specific heat (c) value of object. This is important because an object will consist of a specific type of substance, and each type of substance has a unique specific heat value. The third factor is the resulting temperature change (ΔT). The mathematical relationship between these three factors and the amount of heat transferred to an object is

$$q = m \times c \times \Delta T$$

The materials that people use to build a new structure or to manufacture commercial goods have a wide range of specific heat values. Take concrete and wood as an example. Both of these materials can be used to build benches in parks or at bus stops for people to use. Wood, however, has a much higher specific heat than concrete. It therefore takes more heat energy to increase the temperature of a 10 kg piece of wood than it does to increase the temperature of a 10 kg piece of concrete. The piece of concrete, as a result, will get hotter faster than the piece of wood when it is exposed to the same amount of heat energy. This issue could be a potential problem in cities that tend to be hot and sunny most of the year. Engineers and manufacturers therefore need to know how to look up or determine the specific heat value of a potential building or manufacturing material before they decide to use it. In this investigation, you will have an opportunity to learn how to determine the specific heat value of a material using the process of calorimetry.

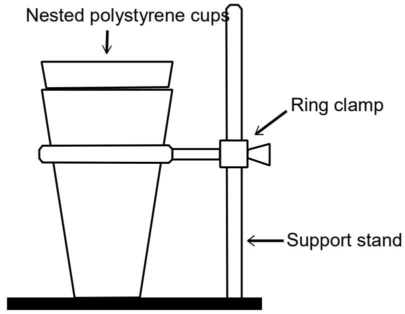
The **guiding question** of this investigation is "which metal has the greatest specific heat capacity?"

Materials: You may use any of the following materials for your investigation

- Metal samples (lead, iron, copper, aluminum, zinc)
- Distilled water
- Graduated cylinder
- Beakers
- Your calorimeter
- Thermometer
- Balance scale
- Hot plate
- Stirring rod
- Tongs

Helpful hints: To calculate the specific heat of a material, you will need to determine how much energy the material is able to transfer to a sample of water using a calorimeter. A calorimeter is used to prevent heat loss to the surroundings (see Figure L15.2).

FIGURE L15.2
A basic calorimeter



The heat gained by the water in a calorimeter is therefore equal in magnitude (but opposite in sign) to the heat lost by the material (Remember gaining heat is positive; losing heat is negative):

$$Q\ water = -Q\ metal$$

The amount of heat gained by the water is calculated using the mass of water used, the specific heat of water (4.18 J/g•°C), and the difference between the final and initial temperature of the water in the calorimeter. The amount of water used for calorimetry varies, but most people use between 10 and 50 ml because water has such a high specific heat. The equation for calculating the amount of heat gained by the water is

$$q\text{water} = m\text{water} \times c\text{water} \times \Delta T\text{water}$$

The amount of heat lost by a metal once it is added to the water is calculated using the mass of the metal, the specific heat of that metal, and the difference between the metal's final temperature and its initial temperature. The final temperature of the material is assumed to be the same as the final temperature of the water in the cup. The initial temperature of the material will be 100°C. To ensure that the initial temperature of the material will be 100°C before you add it to the water in the calorimeter, you can place the material in a boiling-water bath for 10–15 minutes. The equation for calculating the amount of heat lost by a metal is

$$-q metal = m\text{metal} \times c\text{metal} \times \Delta T metal$$

Now that you understand the basics of calorimetry, you must determine what data you need to collect, how you will collect it, and how you will analyze it in order to answer the guiding question.

To determine *what data you will need to collect,* think about the following questions:

- How will you know how much thermal energy has been transferred from a material to the water in a calorimeter?

- What information do you need to calculate the specific heat of material once you know how much thermal energy has been transferred from a material to the water in a calorimeter?

To determine *how you will collect your data,* think about the following questions:

- What equipment will you need to collect the data you need?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of the data you collect?
- How will you organize your data?

To determine *how you will analyze your data,* think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Report: Following your data collection and analysis, your research team must present your findings and conclusions in the form of a mini-poster. Your mini-poster will be completed on a standard 8.5” x 11” sheet of printer paper. Your mini-poster will include a clear claim; evidence in the form of data tables, graphs, diagrams etc.; and reasoning that supports the evidence you chose to support your claim. Remember, your mini-posters should be creative, colorful, and tidy!

APPENDIX H

LEARNING TASK 3 STUDENT ARTIFACT RUBRIC

Which has the greatest specific heat? LAB mini-poster rubric		
Criteria	Description	Maximum points
Claim	Simple answer that addresses the guiding question.	1
Evidence in the form of data tables or graphs	1 point for EACH calculation. Answers should be 0.XX ALL work must be presented to receive 1 point per calculation.	5
Reasoning supports both the claim and evidence provided	Justification refers to the definition of specific heat capacity.	2
Scientific conventions used	***Units*** used throughout in all calculations.	1
Overall presentation	Template is used, neat and tidy, colored.	1

APPENDIX I

ADVANCED STUDENT ARTIFACT

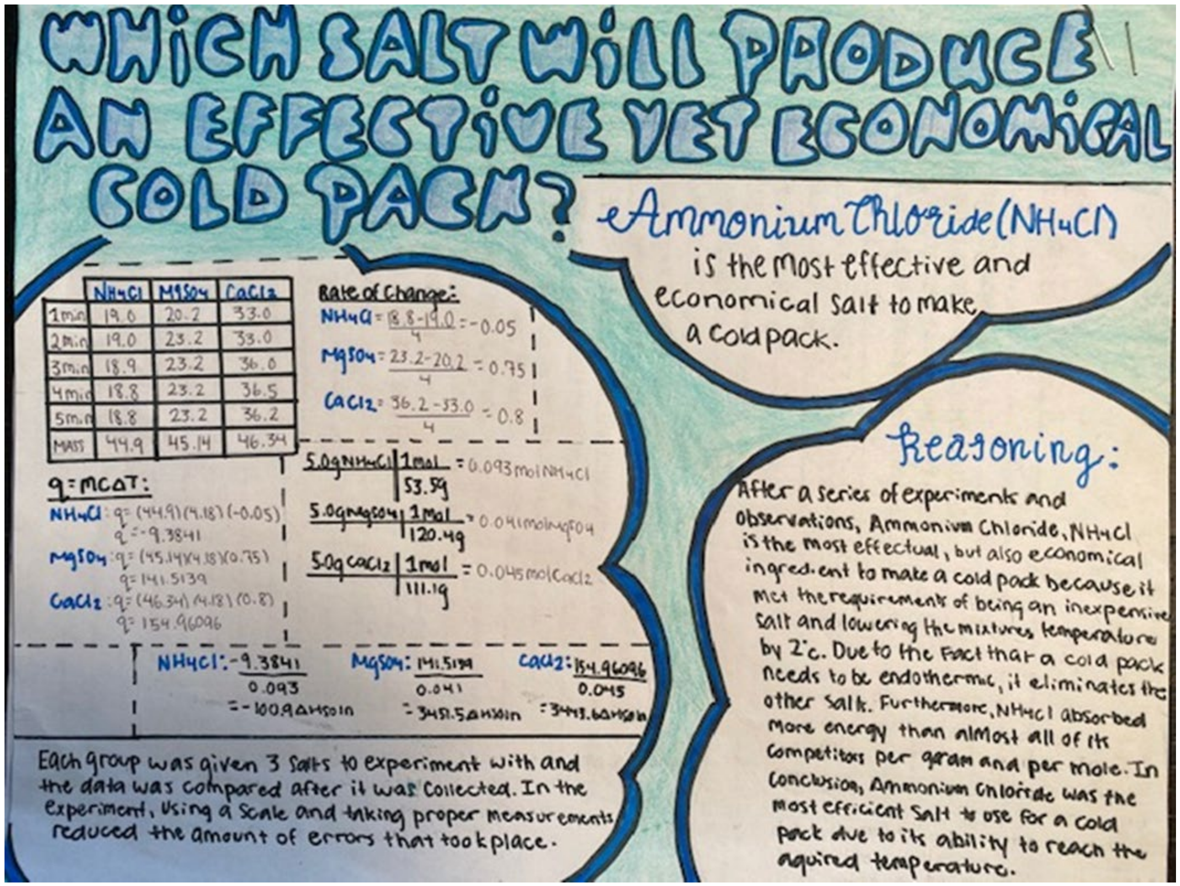


Figure I.1 Advanced Student Artifact

APPENDIX J

PROFICIENT STUDENT ARTIFACT

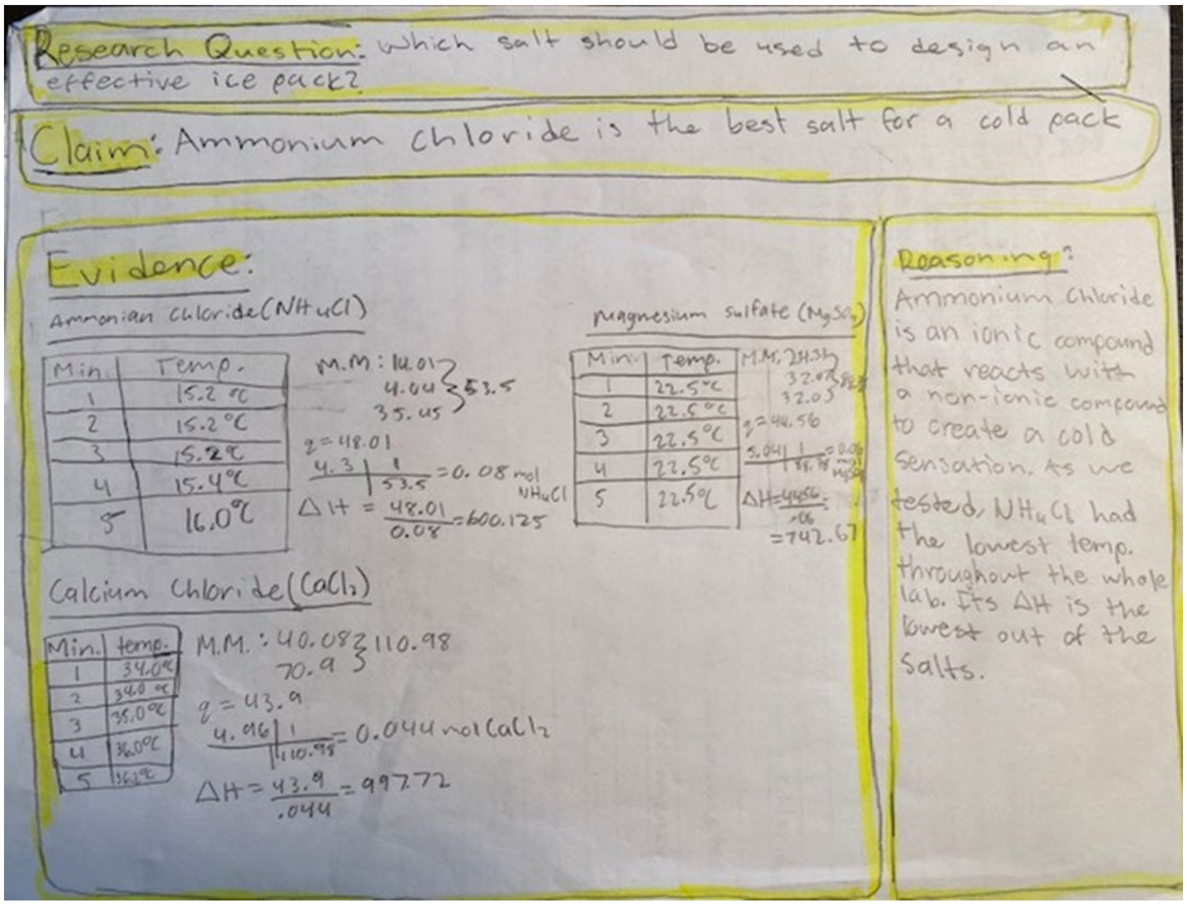


Figure J.1 Proficient Student Artifact

APPENDIX K

BASIC STUDENT ARTIFACT

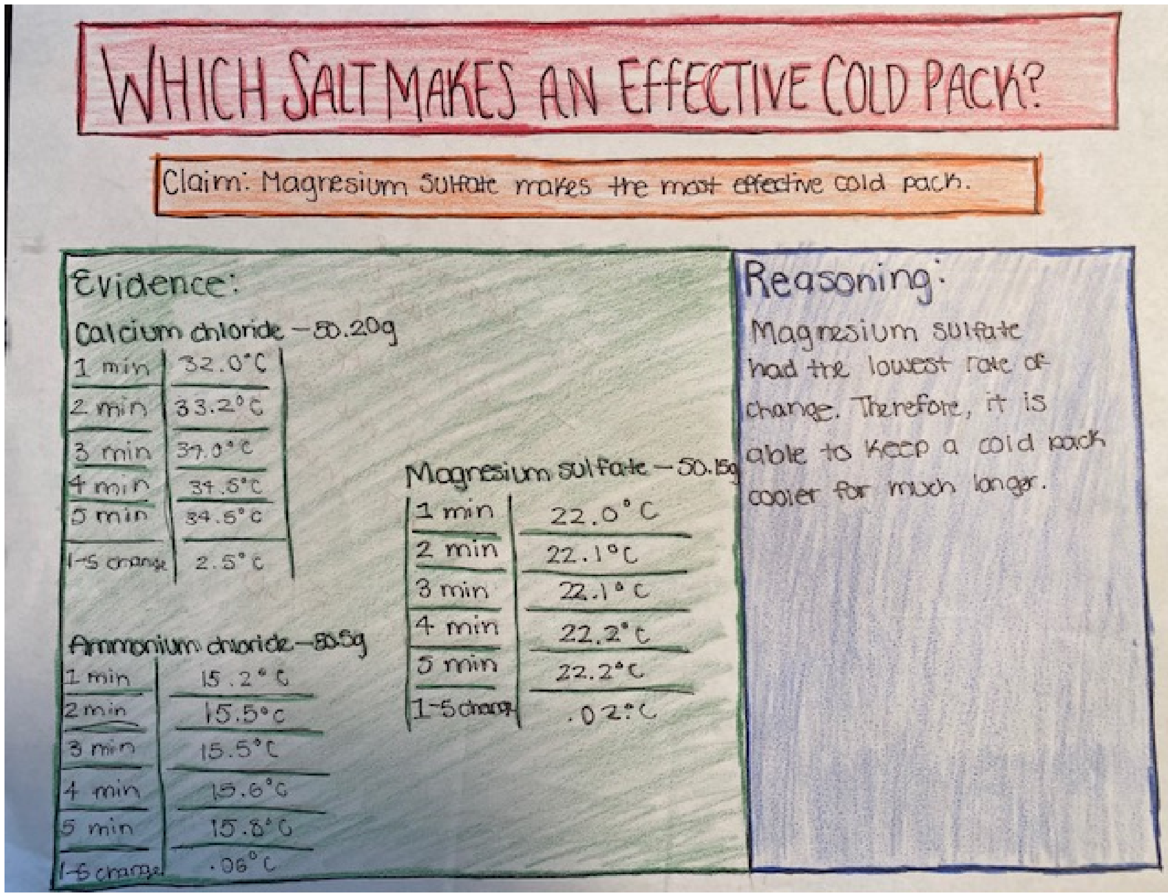


Figure K.1 Basic Student Artifact